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UREĐIVAČKA POLITIKA

Časopis Energija znanstveni je i stručni časopis s dugom tradicijom više od 50 godina. Pokriva područje elektroprivredne djelatnosti i energetike. Časopis Energija objavljuje izvorne znanstvene i stručne članke širokoga područja interesa, od specifičnih tehničkih problema do globalnih analiza procesa u području energetike.

U vrlo širokom spektru tema vezanih za funkcioniranje elektroprivredne djelatnosti i općenito energetike u tržišnim uvjetima i općoj globalizaciji, časopis ima poseban interes za specifične okolnosti ostvarivanja tih procesa u Hrvatskoj i njezinu regionalnom okruženju. Funkcioniranje i razvoj elektroenergetskih sustava u središnjoj i jugoistočnoj Europi, a posljedično i u Hrvatskoj, opterećeno je mnogobrojnim tehničko-tehnološkim, ekonomskim, pravnim i organizacijskim problemima. Namjera je časopisa da postane znanstvena i stručna tribina na kojoj će se kritički i konstruktivno elaborirati navedena problematika i ponuditi rješenja.

Časopis je posebno zainteresiran za sljedeću tematiku: opća energetika, tehnologije za proizvodnju električne energije, obnovljivi izvori i zaštita okoliša; korištenje i razvoj energetske opreme i sustava; funkcioniranje elektroenergetskoga sustava u tržišnim uvjetima poslovanja; izgradnja elektroenergetskih objekata i postrojenja; informacijski sustavi i telekomunikacije; restrukturiranje i privatizacija, reinženjering poslovnih procesa; trgovanje i opskrba električnom energijom, odnosi s kupcima; upravljanje znanjem i obrazovanje; europska i regionalna regulativa, inicijative i suradnja.

Stranice časopisa podjednako su otvorene iskusnim i mladim autorima, te autorima iz Hrvatske i inozemstva. Takva zastupljenost autora osigurava znanje i mudrost, inventivnost i hrabrost, te pluralizam ideja koje će čitatelji časopisa, vjerujemo, cijeniti i znati dobro iskoristiti u svojem profesionalnom radu.

EDITORIAL POLICY

The journal Energija is a scientific and professional journal with more than a 50-year tradition. Covering the areas of the electricity industry and energy sector, the journal Energija publishes original scientific and professional articles with a wide area of interests, from specific technical problems to global analyses of processes in the energy sector.

Among the very broad range of topics relating to the functioning of the electricity industry and the energy sector in general in a competitive and globalizing environment, the Journal has special interest in the specific circumstances in which these processes unfold in Croatia and the region. The functioning and development of electricity systems in Central and South Eastern Europe, consequently in Croatia too, is burdened with numerous engineering, economic, legal and organizational problems. The intention of the Journal is to become a scientific and professional forum where these problems will be critically and constructively elaborated and where solutions will be offered.

The Journal is especially interested in the following topics: energy sector in general, electricity production technologies, renewable sources and environmental protection; use and development of energy equipment and systems; functioning of the electricity system in competitive market conditions; construction of electric power facilities and plants; information systems and telecommunications; restructuring and privatization, re-engineering of business processes; electricity trade and supply, customer relations; knowledge management and training; European and regional legislation, initiatives and cooperation.

The pages of the Journal are equally open to experienced and young authors, from Croatia and abroad. Such representation of authors provides knowledge and wisdom, inventiveness and courage as well as pluralism of ideas which we believe the readers of the Journal will appreciate and know how to put to good use in their professional work.

UVOD
INTRODUCTION

Dragi čitatelji,
ovim brojem zaključujemo 55. godinu izlaženja časopisa Energija i prvu godinu izdavanja Energije kao međunarednog znanstvenog i stručnog časopisa. U proteklih godinu dana objavljeno je 27 članaka na ukupno 666 stranica hrvatskog i engleskog teksta i grafičkih priloga. Članke potpisuje 63 autora, 50 iz Hrvatske i 13 iz inozemstva. Objavljeni članci odražavaju zacrtanu uređivačku politiku časopisa Energija, no uvjeren sam da su moguća daljnja poboljšanja, posebno u smislu šireg zahvata regionalne energetske problematike.

U Energiji broj 6/2006. objavljujemo pet članaka:

- Pristup naknadi za priključak na prijenosnu i distribucijsku mrežu,
- Biodizel kao alternativno motorno gorivo,
- Prvih pola stoljeća komercijalnih nuklearnih elektrana,
- Optimalna RC zaštita tiristora,
- Optički naponski pretvarači.

U prvom članku elaborirana je veoma važna tema povezana s funkcioniranjem elektroenergetskog tržišta i javnih djelatnosti prijenosa i distribucije električne energije. Pitanje mogućnosti i uvjeta priključka na prijenosnu ili distribucijsku mrežu, odnosno povećanja priključne snage, temeljno je statusno pitanje za energetske subjekte koji koriste te sustave kao i za održivost rada takvih sustava. U članku se prikazuju osnovne značajke i postavke pristupa naknadi za priključak kupaca i proizvođača električne energije na prijenosnu i distribucijsku mrežu. Svi navedeni aspekti ilustriraju se dostupnim svjetskim rješenjima i rezultatima analogne metodološke obrade koja je primijenjena na umrežene energetske toplinske i plinske sustave.

Proizvodnja biogoriva, a posebno biodizela, dobiva sve više na značenju povezano s problematikom zaštite okoliša i diversifikacijom, odnosno sigurnosti energetske opskrbe. Gotovo sve zemlje Europske unije uspostavile su vlastitu proizvodnju biodizela. Drugi članak u ovom broju časopisa Energija analizira najvažnija svojstva biodizelskog

Dear Readers,
With this issue, we mark 55 years of the publication of Energija and the first year of the publication of Energija as an international scientific and professional journal. During the past year, we have published 27 articles, a total of 666 pages of Croatian and English texts with graphic supplements. The articles are signed by 63 authors, of whom 50 are from Croatia and 13 are from other countries. The published articles express the outlined editorial policy of the journal Energija but I am convinced that further improvements are possible, particularly in the sense of covering broader regional energy problems.

In Issue No. 6/2006 of Energija, we have published the following five articles:

- An Approach to Transmission and Distribution Network Connection Charges,
- Biodiesel as Alternative Engine Fuel,
- The First Half Century of Commercial Nuclear Power Plants,
- Optimal RC Protection of Thyristors, and
- Optical Voltage Transducers.

In the first article, there is an elaboration of a very important topic in connection with the function of the electricity market regarding the transmission and distribution of electricity. The question of the possibilities and conditions for connection to the transmission and distribution network, i.e. increasing the power rating, is a fundamental status question for energy subjects who use these systems as well as for the sustainability of such systems. In this article, the basic characteristics and precepts are presented regarding compensation for connecting the customer and the electricity producer to the transmission and distribution network. All these aspects are illustrated with available solutions that are in use in other parts of the world and the results of analogous methodological processing, which are applied to networked thermal energy and gas piping systems.

The production of biofuels, especially biodiesel, is gaining increasing significance in connection with environmental protection and diversification, as well as the reliability of the energy supply. Nearly all the goriva, njegovu primjenjivost kao alternativnog motornog goriva, kao i razinu smanjivanja utjecaja na okoliš u usporedbi s mineralnim dizel gorivom. Članak se bavi i procjenom mogućnosti proizvodnje biodizela u Hrvatskoj povezano s mogućnošću proizvodnje uljane repice koja je sirovinska osnova za tu proizvodnju.

Treći članak donosi opsežni pregled povijesnog razvoja i aktualnog stanja nuklearne energetike, strukturirano po glavnim temama koje su važne za promišljanje moguće buduće uloge nuklearnih elektrana u međunarodnoj i nacionalnoj energetici. Nuklearna energetika u svijetu imala je tri desetljeća sjajan uspjeh nakon kojeg je uslijedio dramatični pad povezan s havarijom u Černobilu. Aktualno stanje svjetske energetike nema pravog odgovora na očekivani raskorak između dinamično rastuće potražnje i ograničenih mogućnosti proizvodnje energije iz fosilnih goriva i obnovljivih izvora. U takvim okolnostima autori članka se zalažu za trezveno promišljanje o mogućoj ulozi nuklearnih elektrana u budućnosti, posebno zbog njihovog značajnog tehnološkog napretka.

Tiristori se vrlo široko primjenjuju u energetici i industriji, a najnovija vrlo zastupljena primjena je kod vjetroelektrana. Vrlo su osjetljivi na brzinu porasta anodnog napona, prenapona oporavka i brzinu porasta struje. Četvrti objavljeni članak bavi se temom izbora optimalne RC zaštite, nadograđujući dosadašnje pristupe u zaštiti tiristora. Analiza je provedena u normiranom obliku, što joj daje obilježje općenitosti.

Peti objavljeni članak bavi se načelima rada optičkih mjernih pretvarača za mjerenje visokog napona. Visoki napon se može mjeriti korištenjem Pockelsovog elektrooptičkog učinka. U članku su opisani, uz navođenje pripadnih matematičkih izraza, uzdužni i poprečni učinak s obzirom na smjer svjetlosnog snopa i električnog polja. Zaključno je opisana i primjena optičkog naponskog pretvarača kod visokonaponskog oklopljenog sklopnog postojenja.

U ovom broju časopisa Energija članke potpisuje četrnaest autora s fakulteta, iz elektroprivrede i gospodarstva te iz energetske regulatorne agencije. Vjerujem da će obrađene teme biti od interesa za čitatelje časopisa Energija.

Glavni urednik
Nikola Bruketa dipl.ing.

countries of the European Union have established their own biodiesel production. The second article in this issue of the journal Energija analyzes the most important properties of biodiesel fuel, its applicability as an alternative motor fuel, and its lower environmental impact in comparison to mineral diesel fuel. The article also discusses the possibility of the manufacture of biodiesel in Croatia, in connection with the possible production of rapeseed oil, which is the basic raw material for this fuel.

The third article provides an extensive look at the historical development and current situation of nuclear energy, structured according to the main topics of significance when considering the potential future role of nuclear power plants in the energy supply, both national and international. Nuclear energy enjoyed three decades of brilliant worldwide success, followed by a dramatic decline after the disaster in Chernobyl. The actual state of the world energy supply does not provide a satisfactory response to the anticipated discrepancy between the dynamically growing demand and the limited options for the production of energy from fossil fuels and renewable sources. Under such circumstances, the authors of this article support the dispassionate consideration of the potential role of nuclear power plants in the future, particularly owing to the significant technological advances that have been achieved.

Thyristors have very wide applications in energy and industry, and most recently have been widely used in wind turbines. They are highly sensitive to the rate of rise of anode voltage, the rate of rise of current, and recovery overvoltage. The topic of the fourth article in this issue is the selection of the optimal RC snubber circuit for thyristor protection. The analysis was conducted in standardized form.

The fifth article in this issue is about the basic operating principles of optical transducers for the measurement of high voltage. High voltage can be measured using the Pockels electro-optical effect. In addition to citing the applicable mathematical expressions, the article describes the longitudinal and perpendicular effects, taking the directions of the light beam and electrical field into account. In conclusion, there is a description of the application of optical voltage transducers in high voltage metal-enclosed switchgear.

In this issue of Energije, the articles are signed by 14 authors from universities, the electricity industry, business and energy regulatory agency. I believe that the topics covered will be of interest to the readers of the journal Energija.

Nikola Bruketa, dipl.ing.
Editor-in-Chief

PRISTUP NAKNADI ZA PRIKLJUČAK NA PRIJENOSNU I DISTRIBUCIJSKU MREŽU
AN APPROACH TO TRANSMISSION AND DISTRIBUTION NETWORK CONNECTION CHARGES

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U članku se izlažu rezultati obrade i analize osnovnih značajki i postavki pristupa naknadi za priključak kupca i proizvođača električne energije na elektroenergetsku prijenosnu i distribucijsku mrežu. Iskazuju se obuhvati i značenja osnovnih ili modificiranih varijanti pristupa naknadi za priključak u širem kontekstu elektroenergetskog sustava i tržišta električne energije. Svi navedeni aspekti ilustriraju se na dostupnim svjetskim rješenjima i iskustvima, te na rezultatima analogne metodološke obrade koja je primijenjena na umrežene cjevovodne energetske toplinske i plinske sustave. Namjera autora je ukazati na bitne značajke i postavke različitih pristupa naknadama za priključak, važnost razvidnosti odnosa naknada za priključak i naknada za korištenje mreže, te posljedice različitih pristupa za korisnike mreže, posebno proizvodne objekte obnovljivih izvora energije.

The article sets out the results of elaboration and analysis of the basic features and premises for an approach to charges for connecting consumer and generator of electricity to the transmission and distribution network. The scope and significances of basic and modified versions of approaches to connection charge in the general context of electrical energy system and the electrical energy market are shown.   All the aspects are illustrated from available world experience and practice as well as according to results of analogous methodological treatment applied to networked thermal energy and gas piping systems. It is the intention of the authors to draw attention to the essential features and assumptions of the different approaches to connection charges, the importance of transparency in the relations between connection charges and network use charges, and the consequences of different approaches to network users, particularly of renewable energy source generating plants.

Ključne riječi: duboki pristup naknadi za priključak, naknada za korištenje mreže, naknada za priključak, naknada za stvaranje tehničkih i energetskih uvjeta u mreži, plitki pristup naknadi za priključak

Key words: connection charge, creation of technical and energy conditions in the network charge, deep connection charge principle, network use charge, shallow connection charge principle

1 UVOD

Priključak na prijenosnu i distribucijsku mrežu predstavlja specifični segment općeg prava i uvjeta pristupa kupca i proizvođača električne energije elektroenergetskoj mreži. S druge strane, okvir priključka neposredno je i mjera poticajnosti okružja za priključak novih proizvodnih postrojenja obnovljivih izvora energije i kogeneracija.

Namjera autora je ukazati na bitne značajke i postavke različitih pristupa naknadama za priključak, važnost razvidnosti odnosa naknada za priključak i naknada za korištenje mreže, te posljedice različitih pristupa za korisnike mreže, posebno proizvodne objekte obnovljivih izvora energije. Pristup naknadi za priključak izraz je i odgovarajuće cjenovne politike općenito, tako da nije moguće izbjeći razmatranje utjecaja pristupa naknadi za priključak na naknadu za korištenje prijenosne i distribucijske mreže, ali i na tržište električne energije općenito.

2 PRISTUPI PRIKLJUČKU I NAKNADI ZA PRIKLJUČAK

2.1 Osnovni modeli pristupa priključku i naknadi za priključak

S obzirom na obuhvat elemenata i troškova koji nastaju izgradnjom priključka, dogradnje i pojačanja dijelova mreže, instalacija i opreme po dubini mreže, bilo da ih koristi samo jedan korisnik ili više korisnika mreže, dakako u konačnici i s obzirom na modele alokacije ili pridjeljivanja troškova koji nastaju u svezi sa svakim od navedenih elementa, razlikuju se tri osnovna modela pristupa naknadi za priključak [1] i [2], i to:

- model plitkog pristupa (engl. shallow connection charge principle),
- model dubokog pristupa (engl. deep connection charge principle), te
- mješoviti ili hibridni model (engl. shallowish connection charge principle).

Plitki pristup naknadi za priključak u pravilu rezultira niskim iznosima naknada za priključak proizvođača i kupca električne energije u momentu priključenja, pa je za njih načelno i poticajan. Nasuprot tome, duboki pristup u pravilu rezultira visokim iznosima naknada za priključak, te je time za proizvođača i kupca električne energije manje poticajan [3]. Temeljna razlika između dva navedena pristupa je u obuhvatu troškova tzv. posljednje petlje i dodatnih troškova dogradnje i pojačanja po dubini prijenosne, odnosno distribucijske mreže (slika 1

1 INTRODUCTION

A connection to the transmission and distribution network is a particular segment of the general law and conditions for consumer and generator of electricity to access the electricity network. On the other hand, the framework for connection is indirectly a measure of the environmental incentive for the connection of new renewable sources and cogeneration generating plants.

It is the intention of the authors to draw attention to the essential features and assumptions of the different approaches to connection charges, the importance of transparency in the relations between connection charges and network use charges, and the consequences of different approaches to network users, particularly of renewable energy source generating plants. An approach to a connection charge is also an expression of an appropriate price policy in general, and so it is not possible to avoid consideration of the impact of the approach to connection charge on network use charge, and on the market for electrical energy in general.

2 APPROACHES TO CONNECTION AND CONNECTION CHARGE

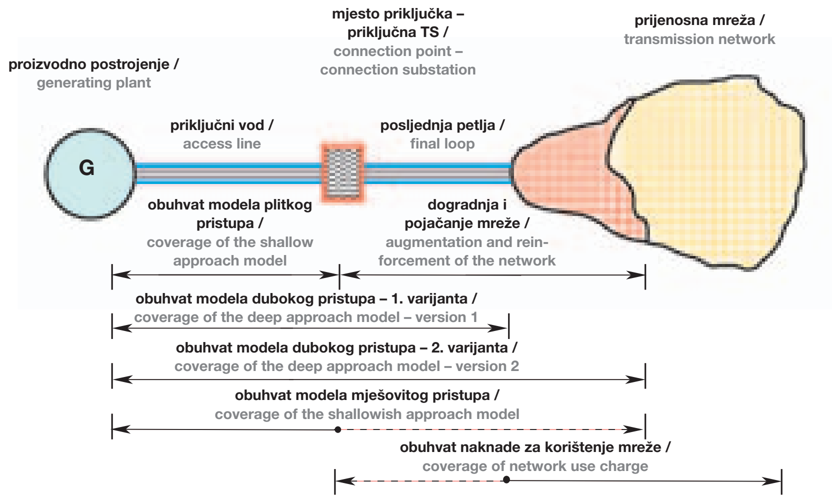
2.1 Basic models of approaches to connection and connection charge

With respect to the scope of elements and costs that are incurred with the development of connection, the augmentation and reinforcement of parts of the network, installations and equipment of deep assets, whether used only by one customer or by several customers of the network, of course, ultimately, and with respect to the allocation models or to sharing the costs that are incurred in connection with each of these elements, three basic models of approach to connection charge can be distinguished [1] and [2], as follows:

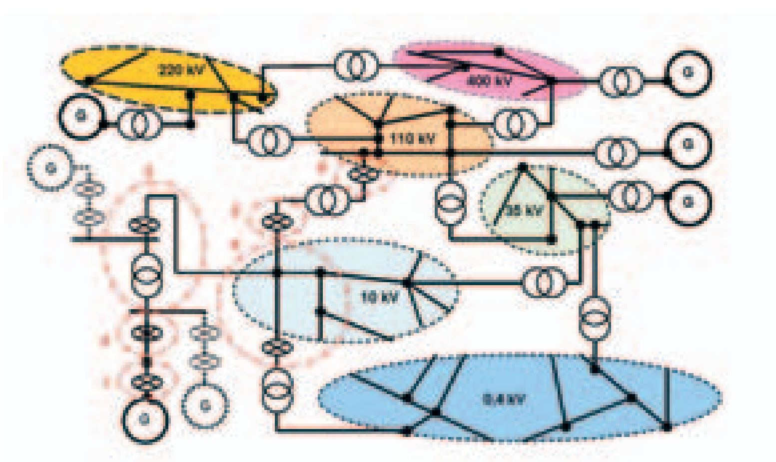
- the shallow connection charge principle,
- the deep connection charge principle,
- the shallowish connection charge principle.

The shallow connection charge principle as a rule results in low amounts of connection charges for generator of and customer for electrical energy at the moment of connection, and is in principle incentivising for them. As against this, the deep principle as a whole results in high amounts for connection charges, and is less incentivising for generator and customer [3]. The basic difference between the two principles quoted is in the scope or coverage of the costs of the so-called final loop and of additional costs of augmenting and i 2). Najopćenitije razgraničenje između ova dva principa je da se plitki pristup načelno odnosi na imovinu i troškove imovine koju koristi samo jedan kupac ili proizvođač (pozicija 1 i/ili 2, na slici 2), a duboki pristup dodatno i na imovinu i troškove imovine koja je zajednička za više korisnika mreže, ili koja je zajednička svim korisnicima mreže, kako je to slučaj s mrežama viših naponskih razina (engl. upstream network). Na slici 2 to su pozicije 3, 4, 5 i 6.

reinforcement of deep assets in the transmission or distribution network (Figures 1 and 2). The most general distinction between the two principles is that the shallow approach in principle relates to the assets and the costs of the assets used only by one customer or generator (position 1 and/or 2 in Figure 2), and the deep principle applies additionally to the assets and asset costs common to several users of the network, or common to all users of the network, as is the case with higher voltage level networks. In Figure 2, these are positions 3, 4, 5 and 6.



Slika 1
Opća shema elemenata priključka i obuhvata modela pristupa naknadi za priključak
Figure 1
General diagram of connection elements and coverage of the connection charge principle models



Slika 2
Obuhvat modela pristupa naknadi za priključenje
Figure 2
Coverage of connection charge principle models

Investicije u dogradnju i pojačanje po dubini mreže najčešće se odnose samo na stvaranje uvjeta za novi priključak ili povećanje postojećeg priključnog kapaciteta. Dakle, obuhvat te treće komponente načelno se proteže na prvu višu naponsku razinu, ali općenito ne i preko toga. Upravo ta treća komponenta može izazvati puno dvojbi i najsloženija je za utvrditi. Ona je složena

Investment into augmentation and reinforcement of deep network assets most frequently refers only to the creation of the conditions for a new connection or for increasing the existing connection capacity. Thus the scope of this third component in principle extends as far as the first higher voltage level network, but in general not beyond that. It is this third component that can cause i po tome što zahtijeva vrlo jasno razgraničenje naknada za priključak i naknada za korištenje mreža. Budući da se kod plitkog pristupa ta treća komponenta ne uključuje u troškove priključka, može se utvrditi da se ista socijalizira, tj. kroz naknade za korištenje mreže prenosi na sve korisnike mreže. Opravdanje za socijalizaciju dijela troškova za priključak lako je naći u potrebi poticanja realizacije strateških ciljeva i planova razvoja elektroenergetskog sektora ili u potrebi za socijalizacijom opće gospodarske i društvene koristi, npr. povećanog korištenja obnovljivih izvora energije, posebno vjetropotencijala [4].

2.2 Model plitkog pristupa naknadi za priključak

Kod plitkog pristupa naknada za priključak sadrži troškove izgradnje (polaganja) priključka, a može sadržavati i dio troškova tzv. posljednje petlje u mreži, naročito mrežni prekidač, bilo da tu posljednju petlju koristi samo jedan kupac ili proizvođač, bilo da ju koristi više kupaca ili proizvođača. U svakom slučaju obuhvat troškova priključka na mrežu koje plaća kupac ili proizvođač proteže se do odgovarajuće najbliže točke u mreži na kojoj se može osigurati odgovarajući traženi priključni kapacitet. Unutar obuhvata plitkog pristupa svakako nisu dijelovi mreže viših naponskih razina.

Plitki pristup je najjednostavniji za realizaciju u matematičkom i proceduralnom, dakle metodološkom smislu. Regulatornom tijelu i operatoru sustava taj pristup donosi dodatne složene zahtjeve u pogledu tretmana troškova dogradnje i pojačanja po dubini mreže. Vezano uz mrežu moguće su i situacije značajnog otklona od ranije utvrđenih optimalnih planova razvoja. Navedeni problemi u svezi s plitkim pristupom opravdavaju pristupe u kojima će se u naknade za priključak ugraditi i odgovarajući lokacijski i investicijski signali kroz ulazne i izlazne naknade ili naknade za korištenje mreže. Naravno, nije za očekivati da bi se realni troškovi mogli zanemariti ili u svakoj situaciji prenijeti u naknade za korištenje mreže. Sve to otežava primjenu plitkog pristupa i ujedno je njegov veliki nedostatak. Često se taj nedostatak pokušava ispraviti na različite načine, ali do sada niti jedan nije bilo dovoljno efikasan ili za različite svrhe prihvatljiv i održiv.

the most quandaries and that is the most difficult to determine. It is complex also because it requires a very clear demarcation of connection charges and network use charges. Since in the case of the shallow principle this third component is not included in the connection costs, it can be concluded accordingly that it is socialised, i.e., through network use charges it is shifted to all users of the network. Justification of socialisation of some of the connection costs is easy to find in the need to incentivise the effectuation of strategic objectives and development plans in the electrical energy sector or in the need for the socialisation of the general economic and social benefit, e.g. increased use of renewable sources of energy, particularly wind potentials [4].

2.2 Model of the shallow connection charge priciple

In the case of the shallow principle the connection charge includes the costs of developing (laying down) the connection, and can contain part of the costs of the so-called final loop in the network, particularly the network switchgear, whether this final loop is used by only one consumer or one generator, or whether it is used by several consumers or generators. In any event the scope of the costs of a connection to the network that are paid by a consumer or generator extend to the nearest appropriate point in the network that can provide the appropriate sought connection capacity. Certainly, higher voltage level parts of the network are not included within the scope of the shallow principle.

The shallow principle is the easiest to effectuate in a mathematical and procedural, hence methodological, sense. This principle sets the regulatory body and the operator additional complex demands with respect to treatment of the costs of augmentation and reinforcement of deep assets. It is possible that, connected with the network, there might be situations sharply diverging from earlier determined optimum plans of development. These problems in connection with the shallow principle justify principles in which appropriate location and investment signals are incorporated into the connection charges through entry and exit charges and network use charges. Naturally, it cannot be expected that realistic costs can be neglected and in every situation transferred into the network use charges. All of this defacilitates application of the shallow principle and constitutes its great drawback. Attempts are often made to correct this drawback in various ways, but to date none has been sufficiently effective or acceptable and sustainable for different purposes.

2.3 Model dubokog pristupa naknadi za priključak

Kod dubokog pristupa naknadi za priključak, unutar obuhvata su ne samo priključni vod do odgovarajuće točke u mreži, nego i udaljeni dijelovi mreže, odnosno dijelovi mreže viših naponskih razina. Dakle, u naknadu za priključak ulaze troškovi izgradnje samog priključka, troškovi izgradnje tzv. posljednje petlje mreže, te troškovi dogradnje i pojačanja vodova, instalacija i opreme po dubini mreže.

Politika dubokog pristupa načelno znači da se svi troškovi u svezi s priključkom plaćaju jednokratno u punom iznosu, što znači da se ukupni troškovi projekta povećavaju za puni iznos investicija u priključak. U nekim slučajevima, npr. kada se radi o proizvodnom objektu, te dodatne investicije mogu bitno utjecati na opravdanost i financijsku održivost projekta. Međutim, što se veći dio troškova pokrije kroz investicije za priključak, manji su rizici za operatora prijenosnog i operatora distribucijskog sustava, i manje su naknade za korištenje mreže za sve njene korisnike.

Politikom dubokog pristupa smatraju se i rješenja po kojima su u naknade za korištenje mreže u značajnom iznosu uključene komponente naknada koje predstavljaju lokacijske signale. Najveću poteškoću u primjeni dubokog pristupa naknadi za priključak predstavlja složenost analitike i postupka utvrđivanja troškova dogradnje i pojačanja po dubini mreže, i još je više otežana ponovljivost i dosljednost provedbe tih postupaka u slučaju više kupaca i proizvođača koji se priključuju na različitim mjestima u mreži.

2.4 Model mješovitog ili hibridnog pristupa naknadi za priključak

Mješoviti ili hibridni pristup, pri čemu se u konačnici uvijek radi o nekoj od varijanti modificiranog ili proširenog plitkog pristupa, nastoji pomiriti dva ranije navedena krajnja pristupa i zadržati njihove prednosti, tj. jednostavnost i poticajnost plitkog pristupa, te obuhvatnost i efikasnost dubokog pristupa. Načelno, mješoviti ili hibridni pristup ima u obuhvatu sljedeće komponente: sam priključni vod i pripadajuće instalacije i opremu, tzv. posljednju petlju mreže na istoj ili prvoj višoj naponskoj razini, te dodatne instalacije i opremu kojima se mreža dograđuje i pojačava po dubini, u pravilu uključujući samo prvu višu naponsku razinu. Troškovi te dvije posljednje komponente kupcu ili proizvođaču pridjeljuju se u reduciranom obliku, tj. dijele se između više kupaca ili proizvođača koji se priključuju, a u konačnici mogu se znatnim dijelom uključiti u naknade za korištenje mreže. Dakle, načelno obuhvat kod mješovitog pristupa su pozicije 1, 2, 3 i 4 na

2.3 Model of the deep connection charge principle

In the case of the deep connection charge principle, it is not only the access line to the appropriate point in the network that is included in the scope, but also deep assets of the network, or parts of the network of higher voltage levels. Thus the connection charge includes the costs of developing the actual connection, costs of development of the last loop of the net, and costs of augmenting and reinforcing deep asset lines, installations and equipment.

The deep connection charge principle policy in essence means that all the costs in connection with the connections are paid one time in the full amount, which means that the total costs of the project are enlarged by the full amount of the investment in the connection. In some cases, for example, when it is a generating plant, these additional investments can have an essential impact on the justification and financial sustainability of the project. However, the larger the part of the costs that is covered by the connection investment, the lower are the risks for the operator of the transmission and the operator the distribution system, and the smaller are the network use charges for all its users.

Approaches in which the network use charges include to a considerable extent components of charges that constitute location signals are considered deep principle policy. The complexity of analysing and the procedures for determining the costs of augmentation and reinforcement of deep assets constitutes the greatest difficulty in the application of the deep connection charge principle, and the repeatability and consistency of the implementation of these procedures is still more difficult if there are several consumers or generators that connect at different points in the network.

2.4 Model of a shallowish connection charge principle

A shallowish principle, which ultimately always consists of one of the variations of the modified or expanded shallow principle, endeavours to reconcile the two earlier stated extreme principles and contain their individual advantages, i.e., the simplicity and inbuilt incentives of the shallow approach and the scope and efficiency of the deep principle. In principle, the shallowish approach covers the following components: the actual access line and pertaining installations and equipment, the final loop of the network on the same or first higher voltage level, and additional installations and equipment with which the network is developed or reinforced in deep assets, in principle including only the first higher voltage level. The costs of these two last components are allocated to the customer slici 2. Veliku poteškoću u primjeni mješovitog pristupa predstavlja složenost analitike i postupka utvrđivanja troškova dogradnje i pojačanja po dubini mreže.

Najveći problem u svezi s priključkom, a to naročito vrijedi za primjenu mješovitog pristupa naknadi za priključak, je utvrditi razinu troškova posljednje petlje, odnosno dogradnje i pojačanja mreže za novi ili povećani priključni kapacitet na velikom broju točaka u mreži gdje se priključak može zatražiti. Još je veći problem definirati utemeljene, razvidne i pravedne kriterije za pridjeljivanje (alokaciju) tih troškova, npr. u obliku odgovarajućih lokacijskih signala. Troškovi i kapacitet posljednje petlje mogu se podijeliti i pridijeliti jednom proizvođaču i/ili kupcu koji traži priključak, ili većem broju proizvođača, odnosno kupaca, što se po unaprijed poznatim kriterijima još i može relativno jednostavno učiniti. Međutim, troškovi za dodatni, dograđeni ili zamijenjeni dio instalacija i opreme po dubini mreže, odnosno troškovi dogradnje i pojačanja mreže općenito, bilo da se prema korisnicima dijele po njihovom stvarnom doprinosu odgovarajućim troškovima, ili pak prema unaprijed utvrđenom omjeru, u oba slučaja kao podloge i dokaze traže složene analize cijele mreže i prilika u mreži. To vrijedi čak i u slučajevima kada obuhvat po dubini mreže ne ide dalje od prve više naponske razine. Smisao i svrha te komponente naknade za priključak je da se uputi odgovarajuća poruka i signal proizvođaču i kupcu koja će njihov odabir priključnog kapaciteta učiniti racionalnim. Ona je dakako i svojevrsna pristupnica u sustav.

U pogledu rješenja ranije navedenih problema, općenito su moguće tri varijante mješovitog pristupa. Prva je da se utvrdi odgovarajući trošak vezan za lokaciju u odnosu na mrežu, uključujući dakle i adekvatne troškove dogradnje i pojačanja mreže, i u većem ili manjem iznosu pridijeli naknadi za priključak koja se plaća jednokratno. Druga je da se u svezi s lokacijom u odnosu na mrežu i dodatnim troškovima dogradnje i pojačanja mreže uvedu zasebne ulazne i izlazne naknade, koje predstavljaju izmijenjeni način plaćanja troškova posljednje petlje i dijela troškova dogradnje i pojačanja mreže. Ulazna naknada plaća se jednokratno ili kao godišnji trošak kapaciteta, a za proizvodni objekt može biti pozitivna ili negativna. Izlazne naknade pokrivaju sve ostale troškove mreže.

Treća, najsloženija, ali i vjerojatno najpravednija varijanta mješovitog pristupa sastoji se u uvođenju posebnih kriterija vrednovanja, odnosno metodološki potpuno nezavisne obrade troškova i kapaciteta posljednje petlje i dijela mreže koji

or generator in a reduced form, i.e., they are shared among several customers or generators that are connecting, and ultimately can to a considerable extent be included into network use charges. Thus, in principle the coverage of the shallowish principle is represented in positions 1, 2, 3 and 4 in Figure 2. In the application of the shallowish principle, the complexity of analysis and the procedures for determining the costs of network deep asset augmentation and reinforcement constitutes a major barrier in the application of the shallowish principle.

The biggest problem in connection with a connection, which holds particularly true for the application of the shallowish connection charge principle is to establish the level of the costs of the final loop, i.e., those incurred by the augmentation and reinforcement of the network by the new or augmented connection capacities at a large number of points in the network where a connection can be sought. It is an even greater problem to define well-founded, transparent and equitable criteria for the allocation of these costs, e.g., in the form of appropriate location signals. Costs and capacities of the final loop can be shared and allocated to only one generator and/or consumer seeking a connection, or a larger number of generators or customers, which can still be done according to criteria defined in advance relatively simply. However, costs for additional, extended or replaced parts of installations and equipment in deep assets or the costs of augmenting and reinforcing the network in general, whether they are shared among the users according to their real contribution to the corresponding costs, or according to some ratio set in advance, in both cases base and evidence require complex analyses of the whole network and conditions in that network. This holds true even in cases when the scope at remote locations does not go further than the first higher voltage level. The point and purpose of this component of the connection charge is to send an appropriate message and signal to generator and to customer that will make their choice of connection capacity rational. It is then a kind of membership ticket into the system.

In connection with resolving the problems stated earlier, in general there are three possible variations of the shallowish principle. The first is to determine the appropriate cost related to the location vis-à-vis the network, including then the adequate costs for augmenting and reinforcing the network, and to allocate it in a greater or smaller amount to the connection charge, which is a one-off payment. The second is to introduce, in connection with the location with respect to the network and with the additional costs of augmenting and reinforcing the network, separate entry and exit charges, which se pojačava i dograđuje. U tom slučaju polazište pristupa i obrade, a u konačnici i ključni kriterij po kojem se odgovarajući troškovi uključuju u naknade za priključak je kapacitet samog priključka. Naime, kapacitetom kao ključnim parametrom i značajkom priključka, uz njegovu dužinu od kupca i proizvođača do najbliže točke u mreži, u potpunosti su određeni, ne samo priključak, nego i traženi uvjeti u mreži kojima se osigurava trajno korištenje odgovarajućeg kapaciteta. No, ostaje problem načina, odnosno metodologije i matematičkog modela kako taj pristup i realizirati u složenim realnim mrežama. Iako taj specifični problem nije uži predmet obrade ovog rada, u nastavku se daju elementi za njegovo rješenje, što se ilustrira odgovarajućim rješenjima i primjerima u svezi s mrežnim cjevovodnim sustavima za prirodni plin i toplinsku energiju. U svakom slučaju, u pogledu dodatnog priključnog kapaciteta treba se platiti onaj adekvatni dio socijaliziranih troškova priključka koji odgovara trošku tog dodatnog ili marginalnog kapaciteta u odnosu na ukupni kapacitet mreže ili instalirani kapacitet konzuma [5].

U svezi s prethodnim nužno je riješiti i problem realne valorizacije mogućeg doprinosa proizvođača električne energije u odnosu na elektroenergetsku mrežu. Činjenica je da dodatni proizvedeni kapacitet na nekom mjestu u mreži može znatno smanjiti tokove energije iz udaljenih dijelova i s viših naponskih razina mreže (iz tzv. upstream-a) na odnosnu lokaciju, čime se smanjuju gubici energije u mreži i povećavaju raspoloživi kapaciteti za nove priključke na tom istom mjestu. Proizvodnja postrojenja u okružju poticajnog vrednovanja distribuirane proizvodnje mogu stvoriti i znatne dodatne povoljnosti za pogon i održavanje mreže, što se kroz naknadu za priključak mora adekvatno valorizirati i iskazati. Treća varijanta mješovitog pristupa to i omogućuje.

constitute a modified manner of paying the costs of the final loop and part of the costs for augmenting and reinforcing the network. The entry charge is paid once or as an annual capacity cost, and for generating plant can be positive or negative. The exit charges cover all the other costs of the network.

The third, most complex, but probably the most equitable variation of the shallowish approach consists of the introduction of separate evaluation criteria, or a methodologically completely independent processing of the costs and capacities of the final loop and the part of the network that is being extended and reinforced. In this case the point of departure for the principle and the processing, and ultimate the key criterion according to which the appropriate costs are incorporated into the connection charge, is the capacity of the actual connection. For it is capacity, the key parameter and feature of the connection, along with its length that represent the distance from the purchaser and generator to the nearest point in the network, that determines not only the connection but also the sought conditions in the network that ensure the permanent use of the appropriate capacity. But there is still the problem of the way, or the methodology and mathematical model with which to effectuate this principle in complex real-life networks. Although this specific problem does not come within the immediate terms of this paper, the sequence will provide elements for the solution of it, illustrated by appropriate solutions and examples in connection with network pipe systems for natural gas and thermal energy. In any event, in connection with additional connection capacity the adequate part of the socialised costs of the connection that corresponds to the cost of this additional or marginal capacity as against the total capacity of the net or the installed capacity of the total gross consumption has to be paid [5].

With reference to the above, it is also necessary to settle the problem of the realistic evaluation of the possible contributions of generators with respect to the electricity network. It is a fact that additional generated capacities in some place in the network can considerably reduce energy flows from distant parts and from higher voltage levels of the network (upstream) to the given location, by which losses of energy in the network are reduced and the available capacities for new connections in that same place are increased. A generating plants in the environment of an incentivising evaluation of distributed generation can bring considerable additional beneficial features for the operation and maintenance of the assets of the network, which through the connection charge has to be adequately evaluated and stated. The third version of the shallowish principle makes this possible.

2.5 Dodatno o izboru pristupa naknadi za priključak

Odabir temeljnog pristupa naknadi za priključak ovisi o nizu čimbenika, koji su ranije navedeni i pojašnjeni. U tablici 1 prikazani su struktura, značajke i posljedice pristupa naknadi za priključak, i to posebno za proizvodni objekt i operatora mreže, koji su važni za odabir temeljnog pristupa naknadi za priključak [2].

2.5 Additionally concerning selection of connection charge principle

The selection of the basic connection charge principle depends on a number of factors, as listed and explained above. Table 1 shows the structure, features and consequences of connection charge principles, separately for generating facility and for network operator, which are important for a choice of the fundamental connection charge principle [2].

Tablica 1 – Struktura, značajke i posljedice pristupa naknadi za priključak
Table 1 – Structure, features and consequences of connection charge principle

	Plitki pristup / Shallow approach	Duboki pristup / Deep approach	Mješoviti pristup / Shallowish approach
Proizvodni objekt / Generating facility	Niski troškovi priključka i poticajno okružje / Low costs of connection and incentivising environment	Visoki iznos plaćanja unaprijed koji negativno utječe na ukupan projekt / High amount to pay in advance which has negative impact on overall project	Niski troškovi priključka i godišnja naknada za kapacitet / Low costs of connection and annual capacity charge
Operator mreže / Network operator	Visoki rizik u pogledu odluka o izgradnji i visoki rizik pokrića ulaganja u budućnosti / High risk in connection with decisions about development and high risk of covering investment in the future	Niski rizik u pogledu odluka o izgradnji i niski troškovi ulaganja / Low risk in connection with decisions about development and low costs of investment	Srednja razina rizika ulaganja i povrat dijela ulaganja kroz razne naknade / Average level of risk in invstment and return of part of investment through various charges
Značajke / Characteristics	Jednostavan za primjenu / Simplicty of application Socijalizacija troškova posljednje petlje i dogradnje i pojačanja mreže / Socialisation of costs of final loop and augmentation and reinforcement of the network Mreža kao javno dobro i zajednička korist / Network as public good and common benefit Poticajan za projekte korištenja obnovljivih izvora energije / Gives incentives to projects using renewable sources	Troškovno utemeljen i poticajan za efikasno korištenje mreže / Costwise well founded and incentivising for effective use of the network Lokacijski signali / Location signals U skladu s principima konkurencije i tržišta / In line with principles of competition and the market Pravedno opterećuje sve sudionike tržišta / Equitably burdens all participants in the market Potencijalno ograničavajući za projekte korištenja obnovljivih izvora energije / Potentially constraining on projects of utilisation of renewable sources of energy	Ovisno o pristupu, relativno jednostavan za primjenu, ali traži dobru razradu svih dodatnih troškova / Depending on approach, relatively simple to apply, but requires good working out of all additional costs Socijalizacija dijela troškova posljednje petlje i troškova dogradnje i pojačanja mreže / Socialisation of part of the costs of the final loop and costs of augmenting and reinforcing the network Lokacijski signali u pogledu priključka / Location signals with respect to connections
Problemi / Problems	Nije u skladu s idejom slobodne konkurencije / Incompatible with ideas of free competition Nema lokacijskih signala i nije utemeljen na realnim troškovima / No location signals and not founded on realistic costs Povećane naknade za korištenje mreža / Increased network use charges Izaziva probleme u pogledu efikasnosti ulaganja u mrežu i pokrića troškova / Causes problems to do with effectiveness of investment in network and coverage of costs Povećanje regulirane imovinske osnovice / Increase in regulated asset base	Težak za primjenu / Hard to apply Veliki teret za proizvođača i kupca koji se prvi priključuje / Big burden on first connected producer and consumer Koristi za sve korisnike mreže / Benefits for all users of the network Prepreka za ulazak na tržište malih proizvodnih objekata i/ili obnovljivih izvora energije / Barrier to market entry for small generating facilities and/or renewable sources	Manje troškovno utemeljen nego duboki pristup / Less cost-grounded than deep approach Problem utvrđivanja i vrednovanja dodatnih troškova i naknada / Problem of determining and evaluating additional costs and charges Problemi razvidnosti i ponovljivosti proračuna / Problem of transparency and repeatability of calculations Povećani troškovi analiza mreže / Increased costs of network analyses

3 POSEBNI ASPEKTI ODNOSA TRŽIŠTA I PRISTUPA NAKNADI ZA PRIKLJUČAK

U radu se ne obrađuje problem pristupa naknadi za priključak u tržišnom okružju sam po sebi. Ipak, kako je ranije istaknuto, primjena principa dubokog pristupa naknadi za priključak za novog proizvođača, pogotovo ako isti koristi dislocirani obnovljivi izvor energije, npr. vjetropotencijal, može značiti izuzetno velike dodatne troškove za investicije u dogradnju i pojačanje mreže, tolike da studija opravdanosti pokaže da je određeni projekt zapravo neopravdan. Energetski subjekt i investitor projekta suočeni s visokim početnim troškovima ulaganja, a kasnije i očekivanom ugroženom ekonomičnošću projekta vjerojatno će odustati od tog projekta. Svakako je to posebno naglašeno kod kapitalno-intenzivnih projekta kao što je to projekt izgradnje vjetroelektrane. Na već postojeće proizvodne objekte u sustavu taj problem nema utjecaja. U tržišnom i konkurentnom okružju postojeći proizvodni objekt vjerojatno će htjeti zadržati stečenu poziciju i neće dozvoliti da problem vezan uz priključak novih postrojenja ni na koji način utječe na tu stečenu poziciju. Naime, prednost lokacije i korištenja resursa na lokaciji postojećih proizvodnih objekata vjerojatno će se uzeti stečenim, te oni s takvih pozicija vjerojatno neće pristati na bilo kakvu podjelu troškova s novim proizvodnim objektima koji traže priključak i koji će im vrlo brzo postati tržišni takmaci.

Šire gledajući, i sva ostala postrojenja s tehnologijama proizvodnje električne energije koja su više ili manje neovisna o lokacijama, pogotovo ako njihovi transportni sustavi primarnog energenta ne zauzimaju velike površine ili prirodne resurse i značajno ne utječu na okoliš, zbog fleksibilnosti lokacije već u startu imaju značajnu prednost. Velika je početna prednost i pogodnost ako do lokacije proizvodnog objekta postoji već izgrađena mreža. Međutim, u tržišnim uvjetima sve takve situacije mogu biti označene oblikom narušavanja ili prepreke razvoju tržišta električne energije. S druge strane, problem lokacije, bilo proizvodnog objekta bilo kupca, tj. potrošača, u novom tržišnom okružju može se razmatrati i u potpuno drugačijem kontekstu. Vrlo malo, ili sve manje garancija može se dati proizvođaču električne energije da će se energija koju isti proizvede predati kupcima na istoj ili najbližoj lokaciji, ili kupcima da će im se energija dobaviti upravo iz najbližeg proizvodnog objekta. Taj novi kontekst važan je i za operatore prijenosne, odnosno distribucijske mreže i sustava.

3 PARTICULAR ASPECTS OF THE RELATION BETWEEN THE MARKET AND THE CONNECTION CHARGE PRINCIPLE

This paper does not discuss the problem of connection charge principle in the market environment in itself. Nevertheless, as stated earlier, application of the deep connection charge principle for new entrant generators, particularly if they are using remote, renewable sources of energy, such as wind potentials, can mean exceptionally large additional costs for investment in the augmentation and reinforcement of the network, so much that a feasibility study will show that a given project is in fact not merited. The energy firm and investor of the project faced with very high initial investment costs and later with the expected marginal economics of the project will probably withdraw from this project. This is particularly marked in the case of capital-intensive projects, such as the project of building a wind electricity generating station. This problem has no impact on generating facilities already existing in the system. In a market and competitive environment existing generating facilities will probably want to retain the position they have acquired and will not allow a problem related with the connection of new plants to impact this acquired position in any way. The advantage of location and use of resources at the location of existing generating facilities will probably be taken as acquired, and from such positions such an entity will probably not consent to any kind of sharing of costs with new generation facilities looking for a connection and likely very soon to become their rivals.

Looking at things more broadly, all the other plant with electricity generation technologies that are more less independent of location, particularly if their primary fuel transport systems do not occupy large areas or major natural resources and do not impact the environment, already have an important advantage from the very start because of their flexibility with regard to location. It is a large initial advantage and benefit if the network is already developed as far as the location of the generating facility. However, in market conditions, all such situations can be labelled as a form of distortion of or barrier to the development of the electricity market. On the other hand, the problem of location, whether or generating facility or of a consumer, can be considered in the new market environment in a completely different context. There are very few and increasingly smaller guarantees that can be given to a generator that the energy that it produces will be delivered to customers at the same or even the closest location, or to demand that the energy supplied will be actually from the closest generating facility, and this new context is also important for transmission and distribution networks and systems operators.

Duboki pristup, tj. situacija u kojoj novi proizvođač operatoru mreže plaća puni iznos troškova koje izaziva svojim priključkom na mrežu, za operatora mreže svakako znači i puno manja ulaganja unaprijed i puno manji rizik poslovanja u budućnosti. Plitki pristup, tj. situacija u kojoj novi proizvođač kroz naknadu priključka operatoru mreže plaća samo izgradnju priključka, a ostali troškovi se socijaliziraju i prenose u naknadu za korištenje mreže, za operatora mreže znači veća ulaganja unaprijed i znatno veći rizik po poslovanje u budućnosti. Naime, zbog prirode nekih primarnih izvora, njihove dostupnosti, stalnosti, cijene i sl., tehničkih i tehnoloških rizika u svezi s postrojenjima, ili naprosto stanja na tržištu, ne mogu se unaprijed dati garancije da će planirana proizvodnja energije u proizvodnom objektu doista i biti ostvarena. Svaki podbačaj ili rizik pogona i poslovanja proizvodnog objekta time ima negativan utjecaj na prihod operatora mreže i sustava.

Neosporno je da duboki pristup rezultira dobrim posljedicama za operatora mreže i efikasnost njegova poslovanja, smanjuje potrebu za velikim investicijama u mrežu unaprijed, povećava efikasnost planiranja i izgradnje mreže, te svim postojećim korisnicima rezultira u nižim naknadama za korištenje mreže. Međutim, kada se sustav restrukturira, kada se uvodi tržište i prostor energetskih djelatnosti otvara konkurenciji, što se odnosi i na sustav cijena, neke elemente pri odabiru pristupa nužno je preispitati [6] i [7]. Prijenosna i distribucijska mreža su javno dobro, u svezi s kojim se postavlja problem i pitanje načina realizacije opće prihvaćenih načela o dostupnosti, pravednosti, prihvatljivosti i javnosti u svezi s prirodnim monopolom ili javnom uslugom. Tako, npr. od svake investicije u pogledu izgradnje i dogradnje mreže i od svake aktivnosti koja povećava kapacitet mreže i njenu pouzdanost imaju koristi svi njeni korisnici, ne samo novi proizvodni objekt i novi kupac. Nadalje, tokovi električne energije u mreži su stohastičkog karaktera i nemoguće ih je u svakom momentu pridijeliti svakom korisniku. I tokovi planiranih i neplaniranih tranzita unose znatne negativne posljedice, od neplaniranih gubitaka do nestabilnosti mreže. Nije izvjesno niti se na bilo koji način može unaprijed tvrditi da bi za uska grla i ograničenja u mreži bili odgovorni dislocirani proizvodni objekti prema kojima bi se u krajnjem slučaju gradili radijalni vodovi. Budući da struktura i iznosi naknada za priključak mogu utjecati i na izbor dobavljača, odnosno opskrbljivača ili drugih tržišnih sudionika i posrednika, niski iznosi naknada za priključak mogu biti razlogom izbora, čak i u situacijama znatnih prikrivenih ili neprikrivenih kratkoročnih i dugoročnih rizika koje taj izbor donosi.

The deep principle, i.e., a situation in which a new entrant generator pays the network operator the full amount of costs entailed by its being connected to the network means for the network operator much smaller prior investments and much small operating risk in the future. The shallow principle, i.e., the situation in which the new generator pays the network operator through the connection charge only for the development of the actual connection with the other costs being socialised and transformed into network use charge means that the network operator has to make greater advance investment and bear a much larger operating risk in the future. Because of the nature of some primary sources, their accessibility, stability, prices and so on, the technical and technological risks in connection with the plant, or simply the state on the market, no guarantees can be given in advance that the planned generation of energy in the generating facility will really be effectuated. Every malfunction or risk in plant or operations of the generating facility will thus have a negative effect on the revenue of the network and system operator.

It is incontestable that the deep principle will produce good consequences for the network operator and contribute to the efficiency of its operations, will reduce the need for big investment in the network in advance, will increase the effectiveness of planning and developing the network and will result for all existing users in lower network use charges. However, when the system is restructured, when the market is introduced and the energy activities space is opened up to competition, which will also affect the pricing system, some elements of the selection of principle have to be re-examined [6] and [7]. The transmission and distribution systems are a public good, in connection with which the issue and problem of the manner of putting into practice universally accepted principles about accessibility, equitability, acceptability and the publicness of a natural monopoly or public service come into play. Thus, for example, from each investment with respect to development and augmentation of the network and from each activity that augments the capacity of the network and its reliability, all its users have some benefits, and not just the new generating facility and the new demand taker. Then, electric flows in the network are of a stochastic nature, and it is impossible at any given moment to allocate them to each user. Flows of planned and unplanned transits bring markedly negatively consequences, from unplanned losses to network instability. Nor it is certain, or in any way at all to determine in advance that bottlenecks and constraints in the network can be laid at the door of distant generating facilities to which in an extreme case radial access lines would be built. Since the structure and amounts of connection charges can affect the choice of supplier

Ranije je naznačena nužnost i potreba da odabir pristupa naknadi za priključak u novim okolnostima mora podržati i zahtjeve za razlikovanjem naknada za priključak proizvodnih objekata od naknada za priključak kupaca. Navedeni doprinosi pogotovo su vezani za distribuirane proizvodne objekte koji se priključuju na srednjim i niskim naponskim razinama, tj. u distribucijskoj mreži. Budući da se načelno može uzeti da se negativni utjecaji koje distribuirani proizvodni objekti, kao npr. vjetroelektrane, imaju na pogonske parametre mreže mogu kompenzirati smanjenjem negativnih utjecaja na okoliš i drugim pozitivnim socijalnim i društvenim utjecajima koje ta postrojenja donose i budući da se prijenosna i distribucijska mreža u pravilu smatraju javnim dobrom i uslugom, nije opravdano u svim slučajevima već kod priključenja opteretiti takav novi proizvodni objekt baš svim posljedicama i troškovima, pa i onim koje se tek očekuju u budućnosti.

Uostalom, duboki pristup naknadi za priključak je od nekih autora označen da nije konzistentan s principima pravednosti i razvidnosti. Iz svega prethodnog nedvojben zaključak može biti da je određeni stupanj socijalizacije troškova priključka na prijenosnu i distribucijsku mrežu, naročito onih za unaprjeđenje i dogradnju mreže, u konačnici i nužan i opravdan.

U konačnici, važno je adekvatno zaštititi i pozicije operatora prijenosne i distribucijske mreže. Naime, budući da oni snose troškove investicija u imovinu u svrhu dogradnje i pojačanja mreže do kojih dolazi zbog novih priključaka na mrežu, a da te troškove ne pokrivaju u trenutku priključka, nužno je osigurati da se novonastali dodatni troškovi adekvatno valoriziraju kroz naknadu za korištenje mreže. To u pravilu znači adekvatno uključenje te dodatne imovine u regulatornu imovinsku osnovicu (regulatory asset base RAB) na koju se u njenom životnom vijeku primjenjuje odgovarajuća stopa povrata. Problem može nastati kada se te dodatne investicije operatora prijenosne i distribucijske mreže ili vrijednost nepokrivene imovine zbog novih priključaka, zbog značajnog porasta ne pokrivaju odgovarajućom dinamikom ili u odgovarajućem iznosu. Prema tome, nužno je voditi računa do koje razine će se pojedine poticajne sheme primjenjivati, odnosno već od samog početka krajnje racionalno izvršiti izbor pristupa naknadi za priključak.

U posljednjem desetljeću distribucijske mreže su iz pasivnog sudionika postale aktivni sudionik sustava i tržišta, tj. aktivno upravljane distribucijske mreže sa značajnim udjelom priključene distribuirane proizvodnje, najčešće obnovljivih izvora energije i kogeneracija, ili

or distributor and other market participants and agents, low amounts of connection charges can be a reason for choice, even in situations of considerably covered or uncovered short-term or long-term risks that such a choice will entail.

Earlier on, mention was made of the necessity that the selection of connection charge principle in the new circumstances had to be supported by demands for differentiating generation facility connection charges from consumer connection charges. These contributions are particularly related to embedded generating facilities that are connected at medium or low voltage levels, that is, in the distribution network. Since in principle it can be considered that the negative effects that embedded generating facilities such as wind generating plants can have on the operating parameters of the network can be compensated for by the reduction of the negative impacts on the environment and other positive social impacts that come with such plant, and since the transmission and distribution network is on the whole considered a public good and a public service, it is not justified in all cases to burden such new entrants with absolutely all the consequences and costs attended by them, and not those that can only be expected sometime in the future.

After all, the deep connection charge principle is labelled by some authors as being inconsistent with the principles of equity and transparency. From all that has gone before, the undoubted conclusion must be that a certain degree of socialisation of the costs of connecting up to the transmission and distribution network, particularly those for developing and extending the network, is ultimately necessary and justified.

Ultimately, though, it is important properly to protect the positions of the transmission and distribution network operators. Since they bear the costs of investing into the assets for the purpose of augmenting and reinforcing the network that are caused by the new connections to the network, and that they do not cover these costs at the moment of connection, it is necessary to make sure that the incurred additional costs are given a proper valuation through a the network use charge. In principle this means adequate incorporation of this additional asset into the regulatory asset base (RAB) to the lifetime of which a certain appropriate rate of return is applied. A problem can arise when these additional investments of the transmission and distribution network operator or the value of the uncovered asset because of the new connections, because of a significant rise are not covered by corresponding dynamics or in a corresponding amount. Accordingly, it is necessary to take account of the level to which individual incentive schemes will be applied, or right at the beginning to make an extremely rational selection of connection charge principle.

geografski definiranih zona sa značajnim brojem velikih gospodarskih subjekata, novih tehnoloških procesa i drugih oblika aktivnosti koje se mogu zasebno upravljati i optimirati, naravno zajedno s distribucijskom mrežom. U takvim slučajevima nužno je pristup naknadi za priključak prilagoditi tim specifičnim organizacijskim i funkcionalnim ustrojima.

4 NEKA SVJETSKA ISKUSTVA I NAČELA PRISTUPA NAKNADI ZA PRIKLJUČAK

U pogledu prethodno navedenog vrlo ilustrativna su i odgovarajuća svjetska iskustva. Prvenstveno zahvaljujući politici plitkog pristupa naknadi za priključak, ali i politici poticanja obnovljivih izvora energije, u Danskoj vrlo brzo raste udio električne energije proizvedene u vjetroelektranama i danas je na razini oko 20 % ukupne potrošnje električne energije. Za razliku od Danske, na području SAD kojeg pokriva neovisni operator prijenosnih sustava PJM (Pennsylvania, New Jersey, Maryland, Delaware i Washington D.C.), primijenjen je duboki pristup naknadi za priključak, a udio obnovljivih izvora energije iznosi svega 0,21 %. U Englskoj i Walesu primjenjuje se plitki pristup, koji uz jake lokacijske signale kroz naknade za korištenje mreže, i to zbog zagušenja mreže na pravcima prijenosa od sjevera prema jugu, u konačnici rezultira u mješovitom pristupu koji je zapravo znatno bliže dubokom pristupu. Udio kapaciteta obnovljivih izvora energije u ukupnom proizvodnom kapacitetu u Engleskoj i Walesu sveukupno je ispod 1 %.

U Velikoj Britaniji napravljene su i odgovarajuće studije nekoliko mogućih različitih pristupa naknadi za priključak, te je izvršena njihova usporedba s onim koje su u operativnoj primjeni. Analizom su bila obuhvaćena trideset i četiri projekta proizvodnih objekata snage do 70 MW koji koriste obnovljive izvore energije, neki već u pogonu, a drugi u fazi izgradnje. Rezultati analiza su vrlo znakoviti. U svakom slučaju, duboki pristup kod svakog projekta rezultirao je najvišim, a varijanta čistog plitkog pristupa najnižim iznosima naknada za priključak. Tek kod dva projekta naknada za priključak utvrđena po dubokom pristupu bila je znatno (nekoliko puta) viša od naknada utvrđenih po drugim razmatranim opcijama. Samo kod jednog projekta naknade utvrđene po različitim pristupima, odnosno opcijama međusobno su se znatnije razlikovale. U odnosu na duboki pristup naknadi za priključak mješoviti pristup u velikom broju slučajeva u realnosti uopće ne rezultira nižim naknadama za priključak. Kako bi se neki

In the last decade distribution networks, from being passive participants, became active participants in the system and market, i.e., actively managing the distribution network with a considerable share of embedded generation, most often from renewable sources of energy and cogeneration, or geographically defined zones with a large number of large economic entities, new technological processes and other forms of activity that can be separately managed and optimised, naturally together with the distribution network. In such cases it is necessary to adjust the connection charge principle to these specific organisational and functional structures.

4 SOME EXPERIENCE AND APPROACHES TO CONNECTION CHARGE IN THE WORLD

With respect to what has been stated above, corresponding experience in the world at large is most instructive. Primarily thanks to policies of a shallow connection charge principle, as well as to policies incentivising renewable sources of energy, in Denmark the share of electricity produced in wind electricity generation stations is rising very rapidly, and today it is at the level of about 20 % of all consumption of electricity. Unlike Denmark, in the area of the USA covered by PJM Interconnection a deep connection charge principle is applied, and the share of renewable sources of energy come to no more than 0,21 %. In England and Wales the shallow principle is applied, that with strong location signals through network use charges, because of congestion in transmission flowing from north to south, in the end resulted in a shallowish approach which is actually much closer to the deep connection charge principle. The share of renewable sources of energy in the overall generating capacity in England and Wales is all told below 1 %.

In the UK, corresponding studies have been made of several possible approaches to connection charges, and a comparison of them has been made with those that are employed operationally. Thirty four projects of generating facilities of up to 70 MW using renewable sources of energy, some already on-stream and some in the development phase were covered by the analysis. The results of the analysis are extremely significant. In any event, the deep approach, in every project, resulted in the highest, and a variant of the shallow approach, in the lowest amounts of connection charge. Only in the case of two projects the connection charge determined by the deep connection charge principle is much (several times) higher than the charges determined od projekata obnovljivih izvora uopće i realizirali, nužne su i posebne političke i promotivne mjere.

Konačni zaključak bio je da se u pogledu problema pristupa naknadi za priključak proizvodnih postrojenja ipak treba prvenstveno ograničiti samo na izbor između plitkog i dubokog pristupa naknadi za priključak. U odnosu na veliki broj projekata ne čini se prevelika pogreška ako se unaprijed napravi opredjeljenje za jedan od tih pristupa. Štoviše, zbog jednostavnosti i razvidnosti primjene, sve govori u prilog plitkog ili modificiranog plitkog pristupa naknadi za priključak.

5 ANALOGIJA I PRISTUP NAKNADI ZA PRIKLJUČAK KOD CJEVOVODNIH SUSTAVA

Svrha izlaganja u ovom dijelu je na primjerima metodološkog rješenja problema pristupa naknadama za priključak kod cjevovodnih sustava transporta i distribucije plina, te distribucije vrele vode i vodene pare unijeti više svjetla i napraviti daljnji korak u pojašnjenju i obradi problema pristupa naknadi za priključak proizvođača i kupaca na prijenosnu i distribucijsku mrežu. Iskustvo obrade navedenog problema ilustrira se i odgovarajućim rezultatima proračuna. Dakle, ovdje je cilj odgovoriti na pitanja: koji troškovi čine naknadu za priključak, na što i koga se troškovi odnose, tko i u kojem iznosu te troškove snosi, koje su relacije odabranog pristupa i utvrđene naknade za priključak u odnosu na tarife ili naknade za korištenje mreža, koji su prihvatljivi uvjeti i stupanj socijalizacije troškova izgradnje i pojačanja mreže zbog priključka kroz naknade za korištenje mreže koje plaćaju svi korisnici i sl.

5.1 Osnovno o značajkama pristupa i metodologije utvrđivanja naknada za priključak na cjevovodne sustave

Danas se već uobičajeno govori o znatnoj analogiji i komplementarnosti elektroenergetskog i plinskog sustava. Svjetski je fenomen da su se ta dva sustava i tržišta u znatnoj mjeri približila i po rješenjima kroz energetsko zakonodavstvo. Naravno, to je vidljivo i izričito naglašeno kroz europsko energetsko zakonodavstvo, europske direktive, odnosno smjernice i uredbe za plin i električnu energiju. No, u ovom radu nije cilj istražiti sve zakonodavne i regulatorne okvire i značajke koje dovode u blisku paralelu dva sustava i tržišta, nego pokazati i utvrditi one značajke koje stvaraju pretpostavke da se problemima naknade za priključak kod sva tri energetska sustava koji su nesporno umreženi ili mrežni sustavi, što znači da

by other options considered. Only in one project the charge determined by various approaches showed the significant variation among the options. As compared with the deep connection charge principle, the shallowish approach in a great number of cases did not at all result in lower connection charges. For some of the renewable resource projects to be able to get off the ground at all, especial promotional and political measures were necessary.

The ultimate conclusion would be that with respect to the problems of connection charge principles for generating facilities, the choice should be primaly restricted to only the deep or the shallow principle. With respect to a large number of projects, no very great mistake is made if an a priori option is made for one of these principles. What is more, because of the simplicity and transparency of application, everything speaks in favour of a shallow or a modified shallow approach to connection charges.

5 AN ANALOGY AND CONNECTION CHARGE PRINCIPLES IN THE CASE OF PIPELINE SYSTEMS

The point of the discussion in this part of the paper is to use examples of the methodological solution of the problem of connection charges in the case of pipelines systems for the transportation and distribution of gas, and the distribution of hot water and steam, to throw more light on the topic and to take a further step in the explanation and processing of the problem of the charge made to generator and consumer for connections to the transmission and distribution network. Experience in dealing with this problem is illustrated with appropriate results of calculations. Thus, the objective here is to respond to the question what costs make up the connection charge, to what and whom do these costs refer, what are the relations between the approach chosen and the connection charge actually established as against the tariffs or charges for using the network, what are the acceptable conditions and degree of the socialisation of the costs of augmenting and reinforcing the network because of new connections through the network use charges that are paid by all users, and so on.

5.1 Fundamentals of the features of approach and methodology to the determination of pipeline system connection charges

Today it is quite usual to speak of the considerable analogy between and complementariness of electricity and gas systems. It is a world phenomenon that these two systems and markets have come very close je plinu i električnoj energiji na ovom mjestu nužno dodati i centralizirane toplinske sustave vrele vode i pare, priđe na jedinstven metodološki način. Time bi se u znatnoj mjeri u svezi s priključkom i pristupu tim sustavima ustanovile pretpostavke za njihovu međusobnu komparaciju, postavili jasniji kriteriji njihove međusobne konkurentnosti i na razvidan način definirali okviri uređenja od strane energetskog regulatornog tijela.

U nastavku izloženi metodološki pristup primjenjiv je na sve navedene sustave, a ilustriran je rezultatima primjene na plinskim i toplinskim mrežnim sustavima. Njegovu osnovu čini prethodno elaborirani prošireni plitki ili mješoviti pristup naknadi za priključak [8] i [9]. Radi se o pristupu koji tehničkim obuhvatom zapravo nije širi od plitkog pristupa, ali kao njegovo proširenje vrednuje komponentu naknade koja se odnosi na pokriće troškova za stvaranje tehničkih i energetskih uvjeta u distribucijskoj mreži za novi ili povećani priključni kapacitet. Preko te komponente naknade za priključak daje se odgovarajući signal kupcu ili proizvođaču koji traži priključak, ali ga se istodobno ne opterećuje izuzetno visokim troškovima dogradnje i pojačanja mreže. Jednako važno, navedeni pristup i obuhvat naknade za priključak razvidno interferira s odgovarajućim sustavom naknada za korištenje mreža.

5.2 Metodologija pristupa naknadi za priključak na energetske cjevovodne sustave

Izloženi metodološki pristup rješenju problema utvrđivanja i vrednovanja elemenata naknade za priključak instalacija i građevina putem novog ili povećanog priključnog kapaciteta već postojećeg kupca ili proizvođača, temelji se na tehničkim, energetskim i ekonomskim značajkama realne mreže. Tim značajkama u konačnici pridjeljuju se odgovarajući troškovi koje plaća korisnik transportne, prijenosne ili distribucijske mreže. Po principu plitkog pristupa naknadi za priključak, tehnički obuhvat u smislu prethodnog je najbliža točka priključenja na odgovarajuću mrežu po kriteriju dostatnosti kapaciteta. Međutim, u smislu proširenja toga pristupa u pogledu vrednovanja komponente za stvaranje odgovarajućih tehničkih i energetskih uvjeta u mreži, obuhvat ili pogled je s mjesta priključka po dubini mreže, pri čemu je horizont gledanja prva viša razina, tj. prijenosna ili transportna mreža, glavna magistralna petlja ili postrojenje za proizvodnju energije.

U svezi s osiguranjem odgovarajućeg kapaciteta moguća su dva stanja energetske mreže: prvo, da u mreži već postoji dostatan dodatni kapacitet za pokriće novih potreba, što je u pravilu najčešće i

together through solutions through energy legislation. Of course, this is visible and particularly emphasised in the European energy legislation, the EC directives or guidelines and orders for gas and electricity. But the objective in this paper is not to explore all the legislative and regulatory frameworks and features which put these two systems and markets into relationships of close parallels, but to show and determine those features that create presumptions for approaching all three energy systems, all of them network systems, which means that in this place it is necessary to add to gas and electricity centralised heating systems of hot water and steam, in a single methodological manner. This would to an important extent, in connection with connections and approaches to these systems, enable the establishment of the presumptions for their mutual comparison, establish clearer criteria for their mutual competitiveness, and in a transparent manner define the governing frameworks by the energy regulatory body.

The methodological approach set out below is applicable to all the said systems, and is illustrated with results applied in gas and thermal network systems. The basis of it consists of the previously elaborated shallow or shallowish connection charge principle [8] and [9]. This is a principle that in its technical scope does not actually go beyond the shallow approach, but, by way of expansion of it, evaluates the component of the charge that relates to covering the costs for the creation of the technical and energy conditions in the distribution network for new or augmented connection capacities. Via this component of the connection charge, an appropriate signal is given to purchaser or generator seeking a connection, but does not at the same time overburden it with exceptionally high costs for augmenting or reinforcing the network. Equally important, this scope and principle for the connection charge is transparent in its interference with the corresponding system of network use charges.

5.2 Methodology of approach to energy pipeline system connection charge

The methodological approach for a solution of the problem of determining and evaluating the elements of the charge for connecting installations and buildings through new or augmented connection capacity of an already existing customer or producer set out is based on technical, energy and economic features of the real network. Ultimately, corresponding costs are allocated to these features, which are paid by the user of the transport, transmission or distribution network. According to the principle of the shallow connection charge, the technical scope as defined above is the closes connection point to the corresponding network according to the criterion of sufficiency of capacity. However, from the ostvareno u već postojećim velikim distribucijskim mrežama, i drugo, da se odgovarajući traženi dodatni kapacitet u mreži tek treba osigurati, tj. izgraditi. U svakom slučaju, po principu plitkog pristupa uz novi priključak i traženi dodatni kapacitet ne utvrđuju se i ne vežu svi zasebni troškovi koji nastaju po dubini distribucijske mreže koji su izazvani potrebom dogradnje postojećih objekata, instalacija i opreme. Primarno se glavnina troškova distribucijske mreže, uključujući izgradnju i dogradnju objekata, instalacija i opreme, uključuje u odgovarajuće naknade za korištenje mreže i raspodjeljuje na sve korisnike mreže. Onaj dio troškova iz toga općeg korpusa koji se ne pokriva ili još uvijek ne pokriva tarifnim sustavom ili naknadama za korištenje mreže, plaća se kroz naknade za priključak, i to kroz komponentu koja se odnosi na stvaranje tehničkih i energetskih uvjeta u distribucijskoj toplinskoj mreži.

Metodološka razrada polazi od tehničkih i energetskih značajki, te vrijednosti svih cjevovoda cjevovodne toplinske ili plinske mreže, i tim cjevovodima pripadajuće ostale opreme i instalacija u realnoj mreži. Ostala oprema i instalacije u energetskoj mreži pridodaju se cjevovodima s kojim su u tehnološkoj i funkcionalnoj svezi, tj. služe da bi se osigurali i koristili odgovarajući kapaciteti cjevovoda. Navedene značajke dovode se u svezu s kapacitetima pojedinačnih cjevovoda, što znači kapacitetima mreže na njenim pojedinim točkama s kojih se osiguravaju traženi priključni kapaciteti, te konačno i kapacitetom mreže u cjelini koji je predstavljen kapacitetom konzuma plina, vodene pare ili vrele vode. Prirodno je svojstvo i značajka umreženih energetskih sustava da, kako pojedinačno tako i kumulativno, u pravilu specifični troškovi kapaciteta padaju kako se ide prema cjevovodima sve većih nazivnih promjera i kapaciteta, što jednako vrijedi i za priključne cjevovode. S druge strane, kako se ide prema dijelovima mreže sve većih nazivnih promjera cjevovoda, smanjuju se i faktori istovremenosti korištenja raspoloživih kapaciteta cjevovoda (slika 3). Sve su to razlozi da je, ako se druge značajke priključka i distribucijske mreže bitno ne pogoršavaju, npr. zbog bitnog porasta duljine, a time i troškova samog priključka, u smislu stvaranja tehničkih i energetskih uvjeta u distribucijskoj mreži, priključak novog korisnika energije povoljno realizirati u dijelovima mreže što većih nazivnih promjera cjevovoda i što bliže proizvodnim, transportnim ili skladišnim postrojenjima.

Naknadu za priključak ili povećanje priključnog kapaciteta čini iznos koji za priključak na energetske objekte za transport i distribuciju energije kupac i proizvođač, odnosno korisnik

point of view of expanding this approach with respect to evaluating the components for the creation of the appropriate tehnical and energy conditions in the network, the scope or viewpoint is from the place of connection to remote locations, in which the horizon of view is the first higher level, i.e., the transmission or transport network, the main loop or energy generation plant.

In connection with the provision of appropriate capacity, two conditions of the energy network are possible: firstly, that in the network there is already sufficient extra capacity to cover the new needs, which is as a rule most often realised in already existing large distribution networks, and secondly, that the appropriate additional capacity in the network will have to be provided, that is, developed. In any case, according to the shallow approach, not all of the separate costs that are incurred at remote locations of the distribution network caused by the need to augment existing facilities, installations and equipment are determined and linked to the new connection. Primarily, the main part of the costs of the distribution network, including the development and augmentation of facilities, installations and equipment, is included in the corresponding the network use charges and is distributed among all users of the network. The part of the costs from this general scope that is not covered or that is still not covered by the tariff system or by network use charges is paid through the connection charge, through the component that relates to the creation of the technical and energy conditions in the thermal distribution network.

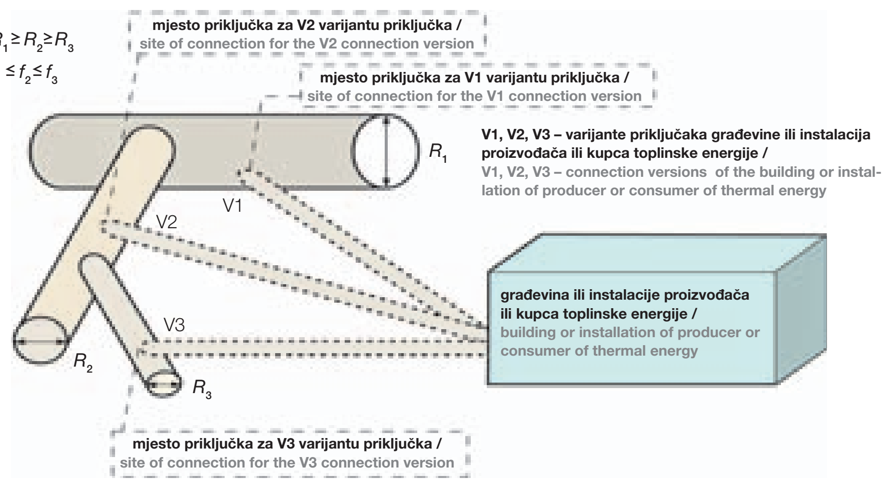
The methodological elaboration takes its point of departure from the technical and energy characteristics and the values of all the pipelines of the thermal or gas pipeline network, and the other equipment in the real network that belong to these pipelines. Other equipment and installations in the energy network are added to the pipelines with which they are functionally and technologically connected, i.e., they are used to ensure and employ the appropriate capacities of the pipeline. These characteristics are connected with the capacities of given pipelines, which means with the capacities of the network at the given points from which the sought connection capacities are supplied, and finally with the capacity of the network as a whole, which is represented by the gross consumption of gas, steam or hot water. It is a natural feature and property of networked energy systems that, both individually and cumulatively, as a rule the specific costs of the capacity fall as the direction of flow is to pipelines with increasingly large nominal diameters and capacities, which equally holds true for connection pipes. On the other hand, as the direction of flow is towards the parts of network with increasingly energije plaća poduzeću i energetskom subjektu koji obavlja energetsku djelatnost distribucije ili transporta energije. Općenito, naknada za priključak najopćenitije sastoji se od četiri komponente:

– naknade za stvaranje tehničkih uvjeta u mreži,
– naknade za pokriće troškova komunalnih davanja i obveza,
– naknade za pokriće troškova same (fizičke) izgradnje odgovarajućeg priključka, te
– naknada za pokriće zakonom propisanih, odnosno dodatnih i zasebnih zahtjeva po projektu ili elaboratu o priključku.

large nominal diameters of pipelines, the factors of simultaneity of use of the available capacities of the pipeline tend to fall (Figure 3). These are all reasons, if other features of the connections and distribution network do not essentially deteriorate, e.g. because of an essential rise in the length, and hence the costs of the connection itself, in the sense of the creation of the technical and energetic conditions in the distribution network, the connection of the new energy user will be favourably effectuated in parts of the network with as large as possible nominal pipeline diameters, and as close as possible to the generation, transport or storage plants.

A connection charge or a charge for an augmentation of a connection capacity consists of the amount that the purchaser and generator, that is, the user of the energy, pays the energy entity or company that carries out the energy activity of distributing or transporting energy. In general, a connection charge in most general terms consists of four components:

– a charge for creating the technical conditions in the network,
– a charge for covering the costs of municipal dues and liabilities,
– a charge for covering the costs of the actual physical construction of the appropriate connection and
– a charge to cover the statutorily required or additional and special requirements according to the project or the connection study.



Slika 3
Moguća mjesta priključka na distribucijsku toplinsku mrežu i odnosi uvjeta u mreži
Figure 3
Possible sites of connection to s thermal distribution network and relations and conditions in the network

Dodatne naknade u svezi s priključkom građevine ili instalacija kupca ili proizvođača mogu se odnositi na posebne zakonom propisane, ili specifične uvjete i zahtjeve u svezi s priključkom, kao što je npr. ugradnja posebnih zaštitnih, regulacijskih, mjernih, nadzornih i upravljačkih sustava i opreme. Takve dodatne naknade određuju se za svaki

Additional charges for the connection of a building or installations of purchaser or generator can refer to special statutorily prescribed or specific conditions and requirements for the connection, such as for example the incorporation of special protective, regulatory, metering, monitoring and control systems and equipment. Such additional pojedinačni slučaj, a temeljem odgovarajućeg elaborata o priključivanju. Zbog toga za predmetno izlaganje ta četvrta komponenta nije od bitne važnosti te se ne uzima u razmatranje.

Naknada za priključenje kupca i proizvođača na energetsku mrežu ima sljedeći opći oblik:

charges are determined for each individual case, and pursuant to the appropriate connection study. For this reason for the current discussion, this fourth component is not of essential importance and will not be taken into consideration.

A charge for connection a purchaser or generator to the energy network has the following general form:

$$N\text{prik}_n = N\text{stuv}_n + N\text{nkdo}_n + N\text{izpr}_n + N\text{doda}_n, (n = 1, \ldots, N). \quad (1)$$

gdje je:

- $N\text{prik}_n$ – naknada za priključak kupca i proizvođača,
- $N\text{stuv}_n$ – naknada za stvaranje tehničkih i energetskih uvjeta u mreži,
- $N\text{nkdo}_n$ – naknada za pokriće troškova komunalnih davanja i obveza,
- $N\text{izpr}_n$ – naknada za pokriće troškova same (fizičke) izgradnje odgovarajućeg priključka,
- $N\text{doda}_n$ – naknada za pokriće dodatnih i zasebnih zahtjeva po projektu ili elaboratu o priključku,
- n – redni broj područja kapaciteta u rastućem nizu kapaciteta priključaka i mreže,
- N – ukupan broj područja kapaciteta u rastućem nizu kapaciteta priključaka i mreže.

Podloge i podaci za izračun komponenti u osnovi unaprijed su poznati, bilo da se zasnivaju na elementima koji se javno objavljuju, bilo da su posljedica naknada koje se propisuju, bilo da proizlaze iz odgovarajućih projekata i analiza ekonomske opravdanosti, te se njihova daljnja obrada svodi se na odgovarajuće pojednostavljene obrasce za izračun. Naglasak u daljnjem izlaganju je na obradi i vrednovanju komponente naknade za stvaranje tehničkih i energetskih uvjeta za priključenje kupca i proizvođača na odgovarajuću energetsku mrežu.

Svi cjevovodi realne mreže, odnosno njima odgovarajući nazivni promjeri i kapaciteti svrstaju se u odjelita područja kapaciteta, koja su određena minimalnim i maksimalnim, odnosno donjim i gornjim graničnim kapacitetima. U pravilu, granični kapaciteti odgovaraju cjevovodima odgovarajućih nazivnih promjera. Cjevovodi mreže grupiraju se tako da njihovi nazivni promjeri i pripadajući kapaciteti tvore rastući niz grupa nazivnih promjera i kapaciteta, od najmanjih do najvećih, pri čemu je maksimalni kapacitet jednog područja kapaciteta jednak minimalnom

where:

- $N\text{prik}_n$ – consumer and generator connection charge,
- $N\text{stuv}_n$ – creation of technical and energy conditions in the network charge,
- $N\text{nkdo}_n$ – coverage of costs of municipal dues and liabilities charge,
- $N\text{izpr}_n$ – coverage of costs of only physical construction of the appropriate connection charge,
- $N\text{doda}_n$ – coverage of additional and special requirements according to the project or the connection study charge,
- n – ordinal number of capacity zone in a rising series of capacities of connections and the network,
- N – total number of capacity zones in a rising series of capacities of connections and network.

The base and data for the calculation of components are essentially known a priori, whether they are grounded on publicly published elements, or whether they are a consequences of charges that are fixed, whether they derive from appropriate projects or economic justifiability analyses, and their further treatment comes to appropriately simplified patterns for calculations. The emphasis in the discussion below is on the treatment and evaluation of the component of the charge for the creation of the technical and energy conditions for connection of consumer and generator to the appropriate energy network.

All the pipelines of the real network, or those that correspond to them in nominal diameter and capacity, are classified into separate capacity zones, which are determined by the minimum and maximum or lower and upper limiting capacities. As a rule, the limiting capacities correspond to pipelines of appropriate nominal diameters. Pipelines of the network are grouped in such a way that their nominal diameters and pertaining capacities create a rising kapacitetu prvog sljedećeg višeg u rastućem nizu područja kapaciteta.

Maksimalne i minimalne veličine, odnosno granice područja kapaciteta ili protoka medija nositelja odgovarajućeg oblika energije, kada su u pitanju plin i toplinska energije, uvjetovane su nazivnim promjerima cjevovoda, ali i brzinama strujanja medija u cjevovodima, te ostalim tehničkim i tehnološkim značajkama cjevovoda.

5.2.1 Naknada za stvaranje tehničkih i energetskih uvjeta u mreži

Za svako područje kapaciteta utvrđuje se specifični trošak jedinice dodatnog kapaciteta ili jedinični dodatni trošak područja kapaciteta. Budući da je namjera rada obrada i ilustracija temeljnog metodološkog pristupa problemu i rješenju sadržaja naknade za priključak općenito, ovdje se ne ulazi u teoretsku, dakle matematičku obradu i proceduru za utvrđivanje jediničnih dodatnih troškova kapaciteta po nizu područja kapaciteta mreže i priključka, nego se obrazlažu podloge i elementi, odnosno rezultati razrađenog postupka.

Naknada za stvaranje tehničkih i energetskih uvjeta u mreži za priključak novog, odnosno za povećanje kapaciteta već postojećeg kupca i proizvođača, tj. dodatnog kapaciteta koji pripada određenom u rastućem nizu područja kapaciteta, određuje se kao suma naknade za stvaranje tehničkih i energetskih uvjeta za minimalni kapacitet odnosnog područja i umnoška jediničnog dodatnog troška odnosnog područja kapaciteta s razlikom traženog kapaciteta i minimalnog kapaciteta odnosnog područja. Dakle, izraz ima sljedeći oblik:

series of groups of nominal diameters and capacities, from smallest to largest, the maximum capacity of one capacity zone being equal to the minimum capacity of the first subsequent higher area in the rising series of capacity zones.

Maximum and minimum magnitudes, or limits of capacity zones or flows of media of bearers of the appropriate form of energy, when gas and thermal energy are concerned, are conditioned by the nominal diameters of the pipeline, as well as by media flow velocities in the pipelines and other technical and technological characteristics of the pipeline.

5.2.1 Creation of technical and energy conditions in the network charge

For each capacity zone the specific costs of a unit of additional capacity or the unit additional cost of the capacity zone are established. Since the intention of this paper is the treatment and illustration of the fundamental methodological approach to the problem and the solution of the content of the connection charge in general, here no theoretical or mathematical treatment and procedure for establishing the unit additional costs of capacity according to a series of capacity zones of the network and connection is embarked upon, rather the base and the elements are explained, or the results of the procedure once worked out.

The charge for creation of the technical and energy conditions in the network for the connection of a new or for an enlarged capacity of an already existing consumer or generator, i.e., of an additional capacity that belongs to a certain one in a rising series of capacity zones, is determined as the sum of charges for the creation of the technical and energy conditions of the minimum capacity of a given zone and the product of the unit additional cost of the given capacity zone and the difference of the sought capacity and minimum capacity of the given zone. Thus the expression has the following form:

$$N\,\mathrm{stuv}_n = N\,\mathrm{stuv}_n^{\min} + C_n \times (P_n^{\mathrm{trk}} - P_{n-1}^{\max}),\ (n = 1,\dots,N)\,, \qquad (2)$$

gdje je:

$N\,\mathrm{stuv}_n$ – naknada za stvaranje tehničkih i energetskih uvjeta u mreži za priključak dodatnog kapaciteta koji pripada n-tom u nizu područja kapaciteta,

$N\,\mathrm{stuv}_n^{\min}$ – naknada za stvaranje tehničkih i energetskih uvjeta u mreži za minimalni kapacitet n-tog područja kapaciteta,

where:

$N\mathrm{stuv}_n$ – charge for creating the technical and energy conditions in the network for the connection of an additional capacity that belongs to the n^{th} in a series of capacity zones,

$N\mathrm{stuv}_n^{\min}$ – charge for the creation of technical and energy conditions in the network for the

C_n – jedinični dodatni trošak n-tog u nizu područja kapaciteta,

P_n^{prik} – traženi dodatni energetski kapacitet ili protok novog kupca i proizvođača,

P_{n-1}^{max} – maksimalni kapacitet (n–1.)-og u nizu područja kapaciteta, koji je jednak minimalnom kapacitet n-tog u nizu područja kapaciteta.

Naknada za stvaranje tehničkih i energetskih uvjeta u mreži za minimalne energetske kapacitete ili protoke n-tog u nizu područja kapaciteta ili protoka računa se na sljedeći način:

minimum capacity of the n^{th} capacity zone,

C_n – unit additional cost of the n^{th} in a series of capacity zones,

P_n^{prik} – sought additional energy capacity or flow of new consumer or generator,

P_{n-1}^{max} – maximum capacity of the n–1st in a series of capacity zones that is equal to the minimum capacity of the n^{th} in a series of capacity zones.

The charge for the creation of the technical and energy conditions in the network for the minimum energy capacities or flows of the n^{th} in a series of capacity zones or flows is calculated in the following way:

– **za** / for n = **1**, $Nstuv_{n=1}^{min} = 0{,}00$, (2.1)

– **za** / for n = **2**, $Nstuv_{n=2}^{min} = Nstuv_1^{min} + C_1 \times P_1^{max}$, (2.2)

– **za** / for n = **3**, $Nstuv_{n=3}^{min} = Nstuv_2^{min} + C_2 \times (P_2^{max} - P_1^{max})$, (2.3)

. . . . (2.n)

– **za** / for n > **3**, $Nstuv_n^{min} = Nstuv_{n-1}^{min} + C_{n-1} \times (P_{n-1}^{max} - P_{n-2}^{max})$,

gdje je:

$N\,stuv_n^{min}$ – naknada za stvaranje tehničkih i energetskih uvjeta u mreži za minimalni energetski kapacitet n-tog u nizu područja kapaciteta,

C_1 – jedinični dodatni trošak 1.-og u nizu područja kapaciteta,

C_2 – jedinični dodatni trošak 2.-og u nizu područja kapaciteta,

C_{n-1} – jedinični dodatni trošak (n–1.)-og u nizu područja kapaciteta,

P_1^{max} – maksimalni kapacitet 1.-og u nizu područja kapaciteta,

P_2^{max} – maksimalni kapacitet 2.-og u nizu područja kapaciteta,

P_{n-1}^{max} – maksimalni kapacitet (n–1.)-og, odnosno minimalni kapacitet n-tog u nizu područja kapaciteta,

P_{n-2}^{max} – maksimalni kapacitet (n–2.)-og, odnosno minimalni kapacitet (n–1.)-og u nizu područja kapaciteta.

Dakle, za vrijednosti kapaciteta ili protoka kojeg traži kupac i proizvođač energije, a koji se nalazi unutar granica minimalnog i maksimalnog kapaciteta određenog područja kapaciteta, naknada za stvaranje tehničkih i energetskih uvjeta u mreži koji omogućuju priključak računaju se jednostavnom linearnom aproksimacijom primjenom izraza (2).

where:

$N\,stuv_n^{min}$ – is the charge for the creation of technical and energy conditions in the network for the minimum energy capacity of the n^{th} in a series of capacity zones,

C_1 – unit additional cost of the 1st in a series of capacity zones,

C_2 – unit additional cost of the 2nd in a series of capacity zones,

C_{n-1} – unit additional cost of the n–1st in a series of capacity zones,

P_1^{max} – maximum capacity of the 1st in a series of capacity zones,

P_2^{max} – maximum capacity of the 2nd in a series of capacity zones,

P_{n-1}^{max} – maximum capacity of the n–1st or the minimum capacity of the n^{th} in a series of capacity zones,

P_{n-2}^{max} – maximum capacity of the n–2nd or minimum capacity of the n–1st in a series of capacity zones.

Thus for the value of capacity or flow that a consumer or generator of energy seeks, and which is within the borders of the minim and maximum capacities of a given capacity zone, the charge for creating the technical and energy conditions in the network that enable the connection are calculated with a simple linear approximation by the application of expression (2).

U odnosu na specifične aspekte koji su izloženi u uvodnom dijelu, moguće su tri varijante pristupa. Po prvoj ili osnovnoj varijanti obrade problema troškova stvaranja uvjeta u mreži polazište za utvrđivanje energetskih i troškovnih odnosa među područjima kapaciteta su kumulativni odnosi duljina i vrijednosti cjevovoda mreže s ostalim pripadajućim instalacijama i opremom. Obrada polazi od kumulativnih duljina i vrijednosti svih cjevovoda distribucijske mreže n-tog i svih viših u nizu područja kapaciteta. Dakle, kumulativna duljina cjevovoda za n-to područje kapaciteta računa se kao suma ukupnih duljina svih cjevovoda koji pripadaju n-tom u nizu području kapaciteta i kumulativne duljine cjevovoda za prvo više ($n+1$.)-vo u niz područja kapaciteta, odnosno kao suma ukupnih duljina svih cjevovoda koji pripadaju n-tom u nizu područja kapaciteta i ukupne duljine svih cjevovoda većih nazivnih promjera.

Po drugoj varijanti, na ranije dobivene jedinične cijene i cjenovne odnose dodatnih jedinica kapaciteta po nizu područja kapaciteta dobivene po osnovnoj metodološkoj varijanti, uvode se dodatni težinski odnosi, koji odgovaraju načinu i odnosima korištenja raspoloživih kapaciteta cjevovoda i ostale opreme po dubini realnih mreža. Energetski parametar, a ujedno i najpotpuniji opći kriterij vrednovanja načina i odnosa korištenja raspoloživih kapaciteta umreženih sustava, je faktor istovremenosti korištenja kapaciteta. Kod druge varijante, kao polazište uzima se jedinični dodatni trošak najvećeg iznosa iz prve varijante, a to je jedinični dodatni trošak najnižeg u nizu područja kapaciteta, koji se zatim po nizu područja kapaciteta množi odgovarajućim faktorima istovremenosti korištenja kapaciteta odnosnih područja.

Faktori istovremenosti korištenja kapaciteta imaju vrijednost jednaku ili manju od jedinice, i općenito sve brže padaju kako se ide prema višim u rastućem nizu područja kapaciteta. Time su i vrijednosti odgovarajućih specifičnih dodatnih troškova kapaciteta po toj varijanti općenito niže od vrijednosti odgovarajućih specifičnih dodatnih troškova kapaciteta koji su izračunati po osnovnom metodološkom pristupu, tj. prvoj varijanti. Namjera je da se uvodeći odgovarajući dodatni energetski parametar i kriterij u obliku faktora istovremenosti korištenja kapaciteta po dubini mreže još dodatno naglasi pogodnost, pa čak i potakne korištenje raspoloživih i u pravilu nedovoljno korištenih kapaciteta što bliže glavnim magistralnim petljama i izvorima energije. Poteškoću kod te druge varijante obrade predstavlja potreba dugoročnog praćenja i sustavne analize cjevovoda po dijelovima transportne i distribucijske mreže kako bi se došlo do dobrih parametara i pokazatelja

In relation to specific aspects that are expounded in the introductory part, three variants of the approach are possible. According to the first or basic version of the treatment of the problem of the costs of creating the conditions in the network the point of departure for determining the energy and cost relations among capacity zones are cumulative relations of length and values of the pipelines of the network with the other pertaining installations and equipment. The treatment starts out from the cumulative lengths and the values of all the pipelines of the distribution network of the n^{th} and all zone capacities higher in a series. Thus the cumulative length of the pipeline for the n^{th} capacity zone is calculated as the sum of total lengths of all pipelines that belong to the n^{th} in a series of capacity zones and the cumulative length of pipelines for the first higher $n+1^{st}$ in a series of capacity zones, i.e., as the sum of total lengths of all pipelines that belong to the n^{th} in a series of capacity zones and the total length of all pipelines of greater nominal diameters.

In the second version, additional weightings that correspond to the manner and relations of using the available capacities of the pipeline and other equipment at in deep assets of the real networks are introduced into the earlier obtained unit prices and price relations of the additional units of capacity per series of capacity zones obtained by the basic methodological version. The energy parameter, and at the same time the most complete general criterion for evaluating the manner and relation of use of the available capacities of the networked systems is the factor of the simultaneity of the use of the capacities. In the second version, the unit additional cost of the greatest amount of the first version is taken as point of departure, and this is the unit additional cost of the lowest in a series of capacity zones, which then according to the series of capacity zones is multiplied by the corresponding factors of simultaneity of use of the capacities of the given zones.

Use of capacity simultaneity factors have a value equal to or less than one, and in general all of them decline rapidly as the direction is towards a higher in a rising series of capacity zones. Hence the values of the corresponding specific additional costs of capacities according to this version are in general lower than the values of the corresponding specific additional costs of capacities that are calculated according the basic methodological approach, i.e., the first version. The intention of introducing appropriate additional energy parameters and criteria in the form of the simultaneity factor for capacity utilization in deep assets in the network is to give additional stress to the advantage and even to foster the use of available and as a rule insufficiently used capacities as close as possible to the main loops and značajki energetskih mreža, prvenstveno faktora istovremenosti korištenja kapaciteta.

Dakle, po toj varijanti obrade jedinični dodatni troškovi po područjima kapaciteta dobiju se tako da se ranije (po prvoj varijanti) dobiveni najviši jedinični dodatni trošak kapaciteta, a to je onaj za najniže (prvo) u rastućem nizu područja kapaciteta, množi s odgovarajućim kumulativnim faktorima istovremenosti korištenja kapaciteta odnosnog područja kapaciteta u rastućem nizu. Odgovarajućim faktorom istovremenosti korištenja n-tog područja kapaciteta uzima se analizom dobiveni prosječni faktor istovremenosti korištenja svih cjevovoda mreže koji pripadaju n-tom u nizu područja kapaciteta. Dakle, jedinični izraz ima sljedeći oblik:

sources of energy. One difficulty in this second version of the treatment is the need for long-term monitoring and systematic analysis of the pipelines according to parts of the transport and distribution network in order to arrive at good parameters and indicators of the characteristics of the energy network, primarily of capacity utilization simultaneity factor.

Thus according to this version of the treatment the unit additional costs per capacity zones are obtained in such a way that the earlier (first version) highest unit additional cost of capacity obtained, which is that for the lowest (first) in a rising sequence of capacity zones multiplied with the appropriate cumulative simultaneity factors of the utilization of the capacity of the given capacity zone in a rising series. The appropriate simultaneity factor for utilization of the n^{th} zone capacity is taken by the analysis-derived mean simultaneity factor for the utilization of all the pipelines of the network that belong to the n^{th} in a series of capacity zones. Thus the unit expression has the following form:

$$C_n^2 = C_1^1 \times f_n^{cap}, \ (n = 1, \ldots, N). \qquad (3)$$

gdje je:

- C_n^2 – jedinični dodatni trošak n-tog u nizu područja kapaciteta po drugoj varijanti,
- C_1^1 – jedinični dodatni trošak 1.-og u rastućem nizu područja kapaciteta izračunat po prvoj varijanti,
- f_n^{cap} – faktori istovremenosti korištenja kapaciteta n-tog u nizu područja kapaciteta.

Kod treće varijante, polazeći od podloga i rezultata obrade u prvoj varijanti, najprije se utvrđuje jedinični dodatni trošak kapaciteta za stvaranje tehničkih i energetskih uvjeta u mreži za najniže područje kapaciteta. Taj jedinični trošak jednak je jediničnom trošku najnižeg područja koji je dobiven u prvoj varijanti i reduciran odgovarajućim koeficijentom odnosa jediničnih dodatnih troškova najvišeg i najnižeg u rastućem nizu područja kapaciteta iz prve varijante. Spomenuti koeficijent dalje postaje jedan od težinskih faktora vrednovanja jediničnih dodatnih troškova po rastućem nizu područja kapaciteta u odnosu na jedinični dodatni trošak najnižeg u nizu područja kapaciteta. Kumulativna obrada ide od najnižeg prema višim u rastućem nizu područja kapaciteta.

Kod te treće varijante namjera je, ne narušavajući ranije navedene osnovne principe i kriterije, utvrditi jedinične dodatne troškove kapaciteta

where:

- C_n^2 – unit additional cost of the n^{th} in a series of capacity zones according to the second version,
- C_1^1 – unit additional cost of the 1^{st} in a rising series of capacity zones calculated according to the first version,
- f_n^{cap} – utilization of the capacity of the n^{th} in a series of capacity zones simultaneity factor.

With the third version, starting off from the base and the results of the treatment in the first version, first of all the unit additional cost of capacity for creation of the technical and energy conditions in the network for the lowest zone capacity is determined. This unit cost is equal to the unit cost of the lowest zone that is obtained in the first version and reduced by the appropriate coefficient of ratios of unit additional costs of the highest and lowest in a rising series of capacity zones from the first version. This coefficient then becomes one of the weighting factors for evaluating the unit additional costs in the rising series of capacity zones compared to the unit additional cost of the lowest in a series of capacity zones. Cumulative treatment moves from lowest to higher in a rising series of capacity zones.

With the third version the intention is, without distorting the earlier stated basic principles and za stvaranje tehničkih i energetskih uvjeta u transportnoj i distribucijskoj mreži na način da specifični dodatni trošak najvišeg u nizu područja kapaciteta predstavlja svojevrsnu osnovu i mjeru prema kojoj se reduciraju jedinični dodatni troškovi svih područja kapaciteta. Time se dobiva svojevrsni okvir za pogled u dubinu energetske mreže od strane glavne magistralne petlje ili najvišeg područja kapaciteta, odnosno odgovor na sljedeće pitanje: ako se na mjesto priključka na nekom mjestu u energetskoj mreži priključi kapacitet jediničnog iznosa, koliki dodatni kapacitet se vidi i prepoznaje od strane glavne magistralne petlje ili energetskog izvora? Energetski izvor, da bi zadovoljio tu potražnju, uz već postojeći trebat će osigurati upravo taj dodatni iznos kapaciteta. Mjera redukcije jediničnog troška prvog u rastućem nizu područja kapaciteta je upravo relativni odnos jediničnog troška najvišeg prema jediničnom trošku najnižeg u rastućem nizu područja kapaciteta. Budući da se i u ovom slučaju vrednuju značajke strukture energetske mreže i troškovni odnosi po dubini te mreže, te da se uz jedinični dodatni trošak najnižeg područja kapaciteta uzima i jedinični dodatni trošak najvišeg u nizu područja kapaciteta iz prve varijante, može se reći da treća varijanta obrade predstavlja svojevrsni nastavak prve varijante i metodološke obrade iz prve varijante.

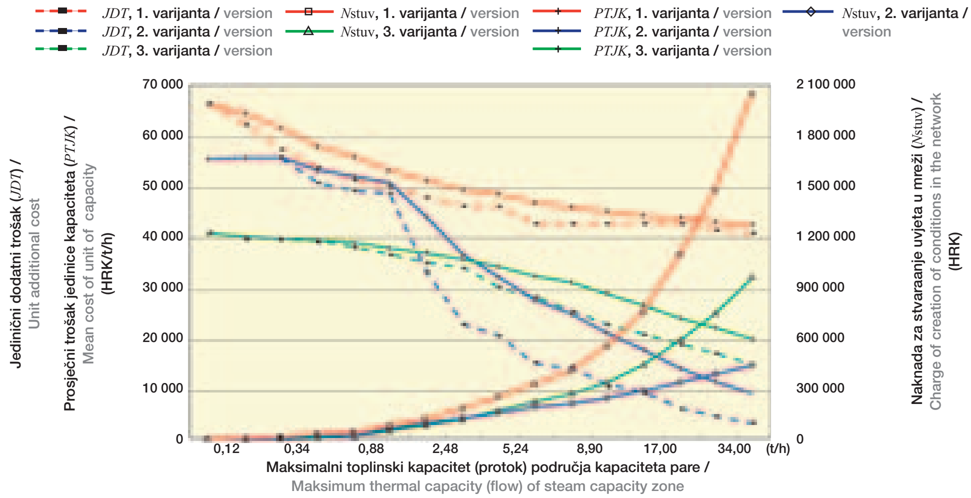
Smisao predmetne varijante je da se, slično kao i kod druge varijante dodatno vrednuje povoljnost priključka što bliže ulazu u transportnu i distribucijsku mrežu od strane glavnih magistralnih petlji ili izvora energije, ali u ovom slučaju iz podloga, tj. tehničkih, energetskih i ekonomskih značajki same distribucijske mreže koje su identične onima iz prve varijante.

Rezultati obrada po drugoj i trećoj varijanti zapravo su naknade za priključak za proizvođače energije. Rezultati primjene varijanti izračuna jediničnih dodatnih troškova kapaciteta vrele vode, odnosno protoka vodene pare, i odgovarajućih naknada za stvaranje tehničkih i energetskih uvjeta u distribucijskoj toplinskoj mreži po tri navedene varijante, za realnu parovodnu i vrelovodnu distribucijsku toplinsku mrežu, prikazani su na slikama 4. i 5.

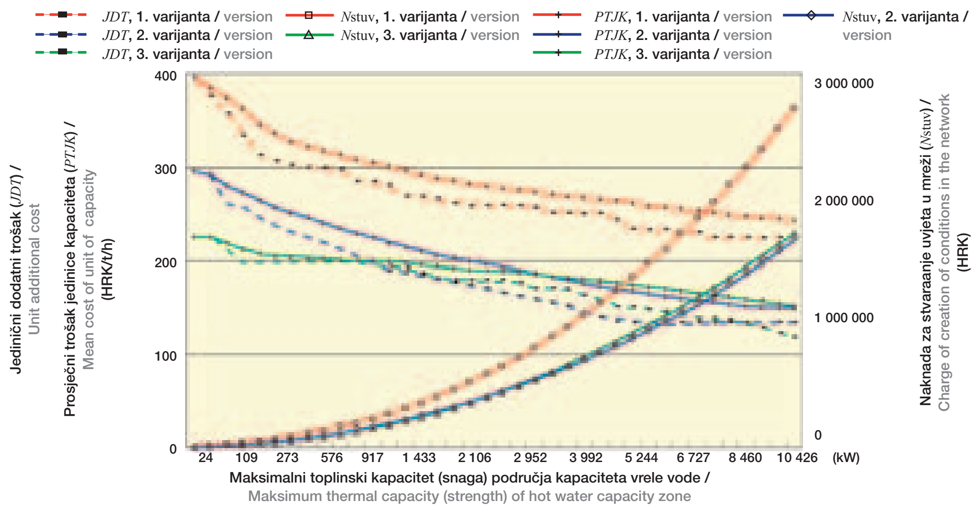
criteria, to determine unit additional costs of capacities for creating the technical and energy conditions in the transport and distribution network in such a manner that the specific additional cost of the highest in a series of capacity zones presents a kind of basis and yardstick according to which the unit additional costs of all capacity zones are reduced. This provides a kind of framework for looking into remote locations of the energy network from the main loop or from the highest capacity zone, or the answer to the following question: if at the site of a connection at a certain place in the energy network a capacity of a unit amount is connected, how much additional capacity can be seen and recognised from the main loop or energy source? The energy source, to meet the demand, alongside that already in existence, will have to ensure this additional amount of capacity. The measure of the reduction of the unit cost of the first in a rising series of capacity zones is actually the relative ratio of unit cost of the highest to the unit cost of the lowest in a rising series of capacity zones. Since in this case the characteristics of the structure of the energy network and the cost ratios at remote locations of this network are being evaluated, and that beside unit additional cost of the lowest zone capacity the unit additional cost of the highest in the series of capacity zones from the first version is taken, it can be said that the third version of the treatment is a kind of continuation of the first version and the methodological treatment of the first version.

The point of this version is so that, similarly to the second version, the advantage of a connection as close as possible as the entry to the transport and distribution network from the main loops or energy sources can be additionally valued, but in this case from the base, i.e., the technical energy and economic characters of the actual distribution network, which are identical to those in the first version.

The results of the treatment according to the second and third versions are actually connection charges for energy generators. The results of the application of the versions of the calculation of unit additional costs of capacities of hot water, or flow of steam, and appropriate charges for the creation of technical and energy conditions in the distribution thermal network according to the three versions stated, for a real steam and hot water thermal distribution network are shown in Figures 4 and 5.



Slika 4
Jedinični dodatni i prosječni troškovi kapaciteta te naknade za stvaranje tehničkih i energetskih uvjeta u distribucijskoj parovodnoj mreži
Figure 4
Unit additional and mean costs of capacity and charges for the creation of the technical and energy conditions in a steam distribution network



Slika 5
Jedinični dodatni i prosječni troškovi kapaciteta te naknada za stvaranje tehničkih i energetskih uvjeta u distribucijskoj vrelovodnoj mreži
Figure 5
Unit additional and mean costs of capacity and charge for the creation of the technical and energy conditions in a hot water distribution network

5.2.2 Naknada za pokriće troškova komunalnih davanja i obveza

Troškove komunalnih davanja i obveza čine troškovi zauzeća i korištenja komunalnih površina i prostora, troškovi za sanaciju zahvata i pogoršanja u komunalno ili infrastrukturno okruženje i okoliš, te troškovi pripreme i ishođenja odgovarajućih odobrenja i suglasnosti u svezi s izgradnjom. Polazište za njihov izračun je prosječni iznos komunalnih davanja po m^2 površine prostora na kojem se gradi, a koja se plaćaju gradskom ili lokalnom upravnom tijelu.

Naknada za pokriće troškova komunalnih davanja i obveza u svezi s izgradnjom priključka na distribucijsku mrežu za n-to u nizu područja kapaciteta određuje se prema sljedećem izrazu:

5.2.2 Charge to cover costs of municipal dues and liabilities

The costs of municipal economy dues and liabilities consist of the costs of occupying and using municipal zones and spaces, costs for repairs to operations and deterioration of the municipal or infrastructural environment, and costs of preparation and obtaining appropriate approvals and consents in connection with the development. The point of departure for this calculation is the mean amount of municipal dues per square metre of zone in which the construction is going on, and which are paid to the city or local government body.

A charge to cover the costs of municipal dues and liabilities related to the construction of a connection to the distribution network for the n^{th} in a series of capacity zones is determined according to the following expression:

$$N_n^{nkdo} = K_n \times L \times S_n, \quad (n = 1, ..., N), \tag{4}$$

gdje je:

- N_n^{nkdo} – naknada za pokriće troškova komunalnih davanja i obveza u svezi s izgradnjom priključka odgovarajućeg kapaciteta koji pripada n-tom u nizu područja kapaciteta,
- K_n – prosječni jedinični iznos sveukupnih troškova komunalnih davanja i obveza po četvornom metru zauzete komunalne površine priključka na energetsku mrežu koji pripada n-tom u nizu područja kapaciteta,
- L – duljina priključka (cjevovoda) od odgovarajuće točke u energetskoj mreži do objekta proizvođača ili kupca energije,
- S_n – prosječna širina zauzete komunalne površine po jediničnoj duljini priključka odgovarajućeg kapacitet koji pripada n-tom u nizu područja kapaciteta.

5.2.3 Naknada za pokriće troškova izgradnje odgovarajućeg priključka

Troškove nabave i polaganja priključnog cjevovoda i sve ostale priključne opreme nužno je jasno odvojiti od izgradnje dijelova energetske mreže, iako se u nekim slučajevima zbog veličine sustava, zbog uvjeta u dijelovima energetske mreže koja se gradi, te zbog provedbe poticajne politike razvoja energetske mreže, polaganje dijela priključnog cjevovoda, a time i pokriće dijela pripadajućih troškova može izvesti kao dio energetske mreže. Ovdje se polazi od pretpostavke da proizvođač ili kupac energije plaća puni iznos troškova izgradnje odgovarajućeg priključka od svoje građevine i instalacija do odgovarajućeg najbližeg mjesta u energetskoj mreži s kojeg je moguće osigurati traženi kapacitet. Za određenu realnu mrežu u pravilu su poznati jedinični iznosi troškova izgradnje priključka, odnosno jedinični iznosi troškova materijala, radova i usluga po dužnom metru priključka cjevovodom kapaciteta koji pripada n-tom u nizu područja kapaciteta. Isti se u pravilu godišnje provjeravaju i aktualiziraju, te najčešće i objavljuju.

Naknada za pokriće troškova izgradnje priključka traženog kapaciteta ili protoka određuje se prema sljedećem izrazu:

where:

- N_n^{nkdo} – charge for covering the costs of municipal dues and liabilities in connection with the development of a connection of an appropriate capacity that belongs to the n^{th} in a series of capacity zones,
- K_n – mean unit amount of total costs of municipal dues and liabilities per square metre of occupied municipal land of the connection to the energy network that belongs to the n^{th} in a series of capacity zones,
- L – length of connection (pipeline) from the appropriate point in the energy network to the facility of the generator or consumer of energy,
- S_n – average width of the occupied municipal land per unit length of connection of appropriate capacity that belongs to the n^{th} in a series of capacity zones.

5.2.3 Charge for coverage of costs of construction of the appropriate connection

Costs for procuring and laying down the connection pipeline and all other connection equipment must necessarily be clearly separated from the development of parts of the energy network, although in all cases because of the size of the system, because of the conditions in parts of the energy network that is being built, and because of the implementation of incentive policies for the development of the energy network, the laying down of part of the connection pipeline, and hence the coverage of part of the appropriate costs can be carried out as part of the energy network. Here the point of departure is the assumption that the generator or consumer of energy pays the full amount of the costs of the construction of the appropriate connection from its own building or installations to the appropriate closest place in the energy network from which it is possible to provide the required capacity. For a certain real network as a rule the unit amounts of the costs of making connections are known, or the unit amounts of costs of materials, works and services per metre of connection with a pipeline that belongs to the n^{th} in a series of capacity zones. These are usually annually tested and brought up to date, and are commonly published as well.

The charge for covering the costs of constructing a connection of a required capacity or flow is determined according to the following expression:

$$N_n^{izpr} = JTI_n \times L \ , \quad (n = 1, \dots, N), \qquad (5)$$

gdje je:

N_n^{izpr} – naknada za pokriće troškova fizičke izgradnje priključka na energetsku mrežu odgovarajućeg kapaciteta koji pripada n-tom u nizu područja kapaciteta,

JTI_n – jedinični iznos troškova izgradnje priključka na energetsku mrežu, odnosno jedinični iznos troškova radova i usluga po dužnom metru priključka koji ima kapacitet koji pripada n-tom u nizu područja kapaciteta,

L – duljina priključka (cjevovoda) od odgovarajuće točke u energetskoj mreži do objekta proizvođača ili kupca energije.

5.2.4 Ukupna naknada za priključak

Ukupna naknada za priključak jednaka je sumi odgovarajućih komponenti naknade za priključak prema izrazu (1). Rezultati izračuna komponenti naknade za priključak, ukupne naknade za priključak na energetske mreže, te ukupne cijene jedinica kapaciteta ili protoka za priključke duljina 100 m, dobivene primjenom izloženog metodološkog pristupa na realnim distribucijskim toplinskim mrežama vrele vode i vodene pare prikazani su na slikama 6 i 7, a transporta i distribucije plina na slikama 8 (duljina 10 km) i 9.

where

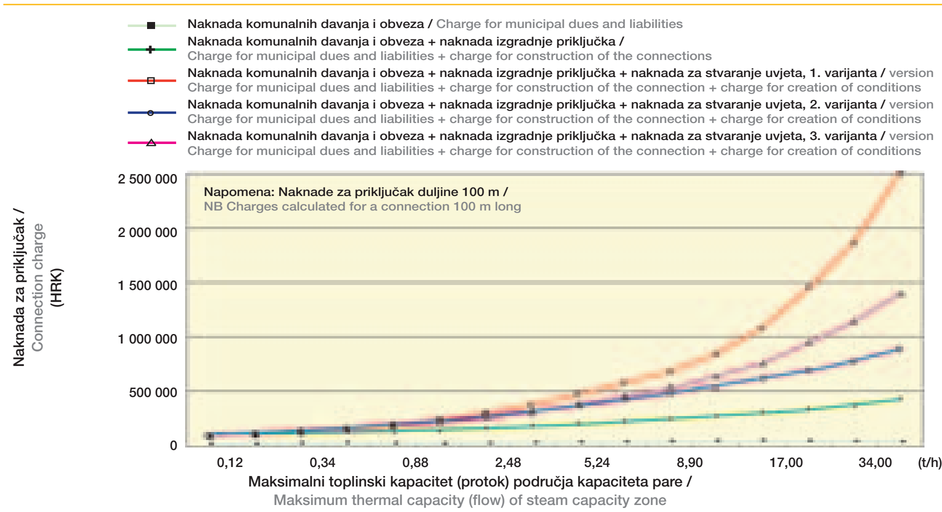
N_n^{izpr} – charge to cover costs of physical construction of connection to the energy network of appropriate capacity that belongs to the n^{th} in a series of capacity zones,

JTI_n – unit amount of costs of construction of a connection to the energy network, or unit amount of costs of works and services per metre of connection that has a capacity that belongs to the n^{th} in a series of capacity zones,

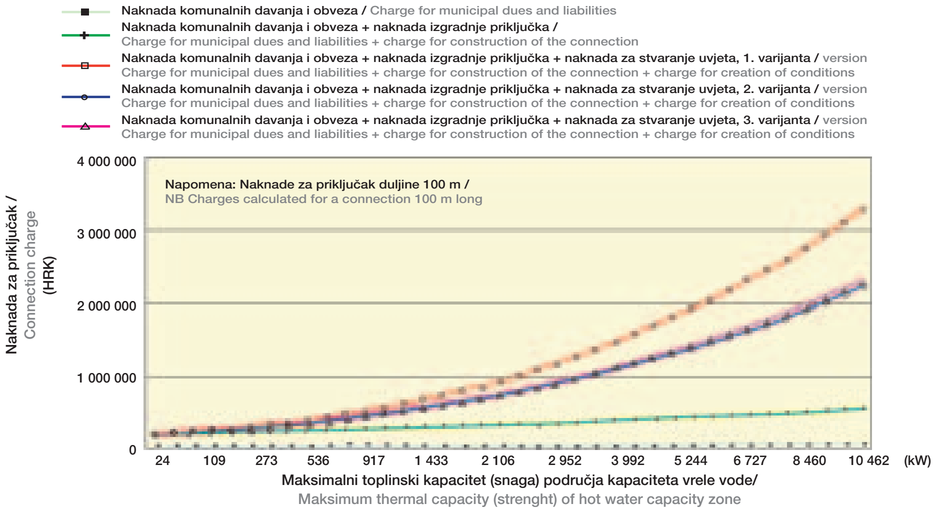
L – length of a connection (pipeline) from an appropriate point in the energy network to the facility of generator or consumer of energy.

5.2.4 Total connection charge

Total connection charge is equal to the sum of the appropriate components of the connection charge according to expression (1). The results of the calculation of the components of the connection charge, of the total charge for a connection to the energy network, and of the total price of units or capacity or flow for a connection of 100 m in length, obtained by the application of the methodological approach set out in real distribution thermal networks, of hot water and steam, are shown in Figures 6 and 7, and of the transport and distribution of gas in Figures 8 (10 km in length) and 9.

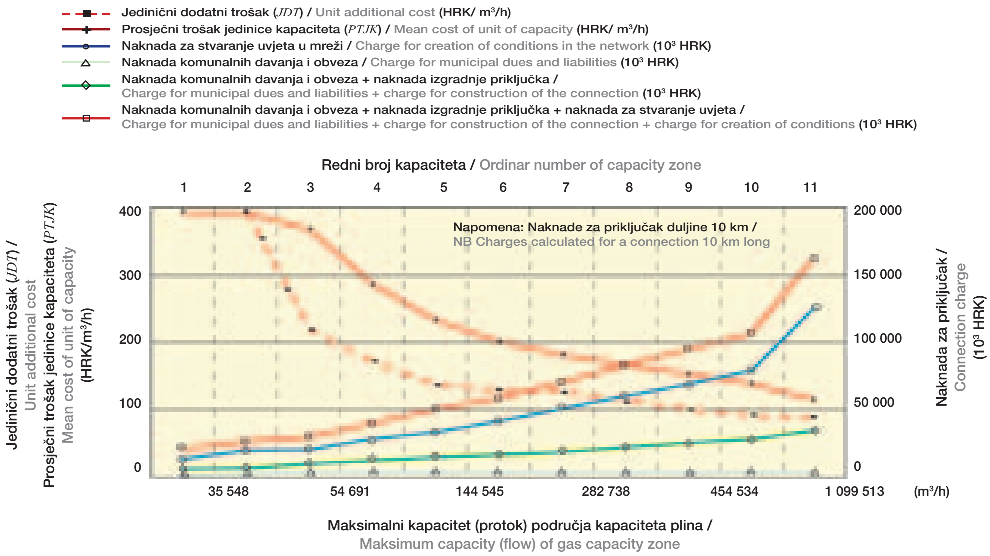


Slika 6
Ukupni iznos naknade za priključak na distribucijsku parovodnu mrežu (duljina priključka 100 m)
Figure 6
Total amount of charge for connection to a steam distribution network (length of connection 100 m)



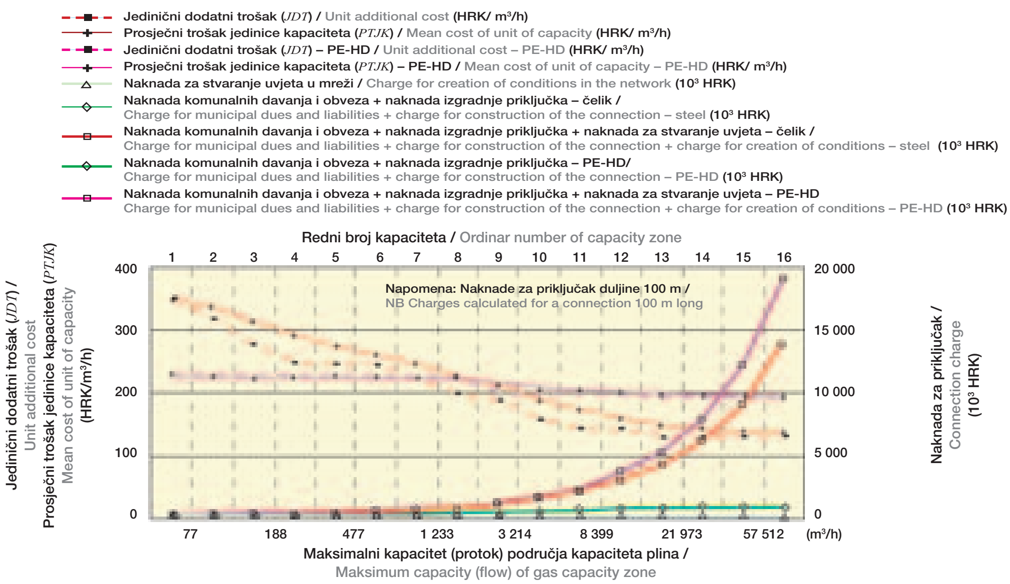
Slika 7
Ukupni iznos naknade za priključak na distribucijsku vrelovodnu mrežu (duljina priključka 100 m)

Figure 7
Total amount of charge for connection to a hot water distribution network (length of connection 100 m)



Slika 8
Jedinični dodatni trošak i ukupni iznos naknade za priključak na transportnu plinsku mrežu (duljina priključka 10 km)

Figure 8
Unit additional cost and total amount of connection charge for a gas transport network (connection 10 km long)



Slika 9
Jedinični dodatni trošak i ukupni iznos naknade za priključak na transportnu plinsku mrežu (duljina priključka 100 m)

Figure 9
Unit additional cost and total amount of connection charge for a gas transport network (connection length 100 m)

6 ZAKLJUČAK

U radu su izloženi različiti pristupi i značajke pristupa naknadi za priključak. Posebno je izložen problem metodološke obrade i valorizacije najsloženije komponente u svezi s naknadom za priključak, a to je naknada za stvaranje tehničkih i energetskih uvjeta u energetskoj mreži za novi priključak i osiguravanje traženog kapaciteta korištenja mreže. Opći zaključak je da su uvjeti pristupa naknadi za priključak važni s više aspekata, te da u pogledu politike i pristupa naknadi za priključak sve više prevladava stajalište da je model plitkog ili proširenog plitkog pristupa najpravedniji i najprihvatljiviji, naročito kada se ima u vidu razvoj tržišta i poticanje većeg korištenja obnovljivih izvora energije i kogeneracija.

6 CONCLUSION

The work sets out various approaches and features of approaches to connection charges. Particularly discussed is the problem of the methodological treatment and evaluation of the most complex component in connection with the connection charge, which is the charge for creating the technical and energy conditions in the energy network for a new connection and ensuring the required capacity of network utilisation. The general conclusion is that the conditions of approach to the connection charge are important from a number of aspects, and that with respect to policy and principles to connection charges the view increasingly prevails that the model of shallow or extended shallow connection principle is the most equitable and the most acceptable, particularly when development of the market and incentives to greater utilisation of renewable sources of energy and cogeneration are borne in mind.

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BIODIZEL KAO ALTERNATIVNO MOTORNO GORIVO

BIODIESEL AS ALTERNATIVE ENGINE FUEL

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Gotovo sve zemlje Europske unije, a i većina zemalja u tranziciji u posljednjem su desetljeću, a neke i ranije, pokrenule proizvodnju biogoriva i to biodizelskoga goriva i etanola. Na temelju pregleda brojnih rezultata istraživanja u svijetu, u ovom se radu analiziraju najvažnija svojstva biodizelskoga goriva, njegova dosadašnja primjena kao alternativnog goriva za dizel motore, te utjecaj njegova sagorijevanja na okoliš u odnosu na mineralno dizel gorivo. Kako je osnovna sirovina za proizvodnju biodizela iz obnovljivih resursa ulje uljane repice, detaljno se analizira postojeća struktura sjetve i udio uljane repice na obradivim površinama u Hrvatskoj, te realne mogućnosti proizvodnje ove kulture za neprehrambeni lanac, odnosno mogućnosti proizvodnje biodizela u Hrvatskoj.

Practically all the countries in the European Union and most of the transition countries have in the last decade, and some even earlier than that, started off the production of biofuels, that is, of biodiesel fuel and ethanol. On the basis of a survey of numerous results of investigations in the world, in this work the most important properties of biodiesel fuel are reviewed, its employment to date as alternative fuel for diesel engines, and the environmental impact of its combustion as compared with that of mineral diesel fuel. Since the basic raw material for the production of biodiesel from renewable resources is the oil of oilseed rape, a detailed analysis is given of the existing structure of the crop and the percentage of the cultivable land in Croatia given over to oilseed rape, as well as the realistic opportunities for the production of this crop for the non-food chain, in other words, the opportunity for the production of biodiesel in Croatia.

Ključne riječi: biljno ulje, biodizel, sačma, transesterifikacija, uljana repica
Key words: biodiesel, cake, oilseed rape, plant oil, transesterification


FUEL

1 UVOD

Gotovo sve zemlje Europske unije, a i većina zemalja u tranziciji u posljednjem su desetljeću, a neke i ranije, pokrenule proizvodnju biogoriva i to biodizelskoga goriva i etanola. Takav trend nastavit će se i u budućnosti što pokazuje i Direktiva Europske unije (2003/30/EC) o alternativnim gorivima u cestovnom prijevozu te mjerama za promociju biogoriva [1]. U navedenom se dokumentu predlažu sljedeće mjere:

- do 2020. treba 20 % tradicionalnih goriva u prometu zamijeniti alternativnim,
- zemlje članice Europske unije imaju pravo primjenjivati diferenciranu poreznu stopu na biogoriva, kako bi se potaknulo njihovo korištenje,
- do 2005. udio biogoriva u Europskoj uniji trebao je iznositi minimalno 2 %. Nakon toga udio u svakoj zemlji članici morat će iznositi:

2006.	2007.	2008.	2009.	2010.
2,75 %	3,5 %	4,25 %	5 %	5,75 % .

Navedeni zahtjevi su obvezujući, što znači da se prije navedena zamjena mora izvršiti. Sve su ih članice Europske unije prihvatile uz dinamiku primjerenu svojim mogućnostima, ali ih moraju prihvatiti i buduće članice, što znači da navedene obveze mora prihvatiti i Republika Hrvatska, kao jedna od budućih članica Europske unije.

1 INTRODUCTION

Practically all the countries in the European Union and most of the transition countries have in the last decade, and some even earlier than that, started off the production of biofuels, that is, of biodiesel fuel and ethanol. Such a trend will be continued in future as well, as shown by the European Union Directive (2003/30/EC) concerning alternative fuels in road transportation and measures for the promotion of biofuels [1]. This document proposes the following measures:

- up to the year 2020, 20 % of the traditional fuels in transportation will have to be replaced with alternative fuels,
- European Union member countries have the right to apply differential tax rates to biofuels in order to foster their use,
- by 2005 biofuels must account for a minimum of 2 % of European Union fuel use. After that the percentage in each member country will have to come to:

2006	2007	2008	2009	2010
2,75 %	3,5 %	4,25 %	5 %	5,75 % .

These requests are binding, which means that the substitution mentioned above must be carried out. All the members of the European Union have accepted them, along with dynamics appropriate to their own capacities, but they also have to be accepted by future members, which means that the Republic of Croatia also has to accept these obligations, as one of the future member of the European Union.

Tablica 1 – Procjene proizvodnje biodizela i kapaciteta za proizvodnju u EU 25 2004. i 2005. [2]
Table 1 – Estimates of the production of biodiesel and production capacities in the EU 25 in 2004 and 2005 [2]

Zemlja / Country	Proizvodnja / Production 2004. (10^3 t)	Proizvodnja / Production 2005. (10^3 t)	Kapaciteti / Capacities 2004. (10^3 t)	Kapaciteti / Capacities 2005. (10^3 t)
Njemačka / Germany	1 035	1 669	1 903	2 681
Francuska / France	348	492	532	775
Italija / Italy	320	396	827	857
Češka / Czech Republic	60	133	188	203
Poljska / Poland	0	100	100	150
Austrija / Austria	57	85	125	134
Slovačka / Slovakia	15	78	89	89
Španjolska / Spain	13	73	100	224
Danska / Denmark	70	71	81	81
Velika Britanija / UK	9	51	129	445
Slovenija / Slovenia	0	8	17	17
Estonija / Estonia	0	7	10	20
Letonija / Latvia	5	7	10	10
Litva / Lithuania	0	5	5	8
Grčka / Greece	0	3	35	75
Malta / Malta	0	2	2	3
Belgija / Belgium	0	1	55	85
Cipar / Cyprus	0	1	2	2
Portugal / Portugal	0	1	6	146
Švedska / Sweden	1,4	1	12	52
Ukupno / Total	1 933,4	3 184	4 228	6 069

Prema podacima European Biodiesel Board (tablica 1) ukupna proizvodnja biodizela u EU 25 je porasla sa 1,9 milijuna tona u 2004. na blizu 3,2 milijuna tona u 2005. ili za 65 %. Broj zemalja s industrijom biodizela se gotovo udvostručio u 2005. [3] u odnosu na 2004. [4]. Proporcionalno su tome rasli i kapaciteti za proizvodnju biodizela te su u 2006. iznosili više od 6 milijuna tona, što će omogućiti daljnju ekspanziju industrije biodizela u Europskoj uniji. Kako biodizel čini oko 80 % biogoriva u Europskoj uniji – ostalo je bioetanol – ovi podaci potvrđuju činjenicu da globalni cilj od 2 % biogoriva u 2005. godini postavljen u Direktivi Europske unije 2003/30/EC još nije dostignut. Ako se uzme samo tržište dizela u Europskoj uniji, proizvodnja biodizela je uz postojeći trend porasta blizu očekivanog cilja od 2 %. Danas tržišni udio biodizela iznosi približno 1,5 % od tržišta konvencionalnog dizelskog goriva u Europskoj uniji.

According to European Biodiesel Board figures (Table 1) the total production of biodiesel in the EU 25 rose from 1,9 million tons in 2004 to close on 3,2 million tons in 2005, that is, by 65 %. The number of countries with a biodiesel industry almost doubled in 2005 [3] over 2004 [4]. Capacities for the production of biodiesel have also risen proportionally and in 2006 came to more than 6 million tons, which will enable further expansion of the biodiesel industry in the European Union. Since biodiesel comprises about 80 % of the biofuel in the European Union – the rest is accounted for by ethanol – these figures confirm the fact that the global objective of 2 % biofuels in 2005 established in European Union Directive 2003/30/EC has not yet been attained. If only the diesel market in the European Union is taken, the production of biodiesel given the existing trend of growth is close to the expected target of 2 %. Today the market share of biodiesel comes to about 1,5 % of the market for conventional diesel in the European Union.

U budućem korištenju biogoriva u Europskoj uniji podjednaku će ulogu imati i biodizelsko gorivo i bioetanol, pri čemu će za njihovu proizvodnju biti angažirano više milijuna hektara poljoprivrednih površina i to prema scenariju prikazanom u tablici 2 [5].

In future use of biofuel in European Union, biodiesel and bioethanol will have equal roles, with over a several million hectares of agricultural land earmarked for their production, according to the scenario presented in Table 2 [5].

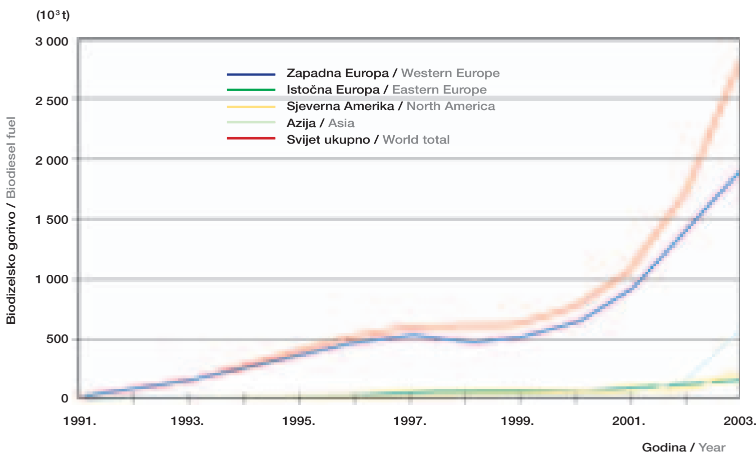
Tablica 2 – Poljoprivredne površine predviđene za proizvodnju biogoriva u Europskoj uniji u budućnosti
Table 2 – Agricultural land envisaged for the production of biofuel in the European Union in future

Ukupne površine za biogoriva / Total land area for biofuels (10^6 ha)	Površine za biodizelsko gorivo / Land for biodiesel (10^6 ha)	Površine za bioetanol / Land for bioethanol (10^6 ha)
20	10	10

Konačno, može se zaključiti da je biodizelsko gorivo široko prihvaćeni obnovljivi izvor energije, o čemu osim svega navedenog svjedoče i podaci o rastu proizvodnje istog u svijetu do 2003. godine (slika 1).

Finally, it can be concluded that biodiesel fuel is a widely accepted renewable source of energy, as indicated, apart from the facts stated above, by the data concerning the growth in production of this fuel in the world up to 2003 (Figure 1).

Slika 1
Svjetska proizvodnja biodizelskoga goriva [6]
Figure 1
World production of biodiesel fuel [6]



Poseban naglasak u procesu proizvodnje biodizelskoga goriva u svijetu dan je na korištenju svih nusproizvoda. Uporaba pogače i sačme u ishrani stoke danas je sve veća zbog pojave bolesti Bovina spongiformna encefalopatija (kravlje ludilo), koja se prenosi hranom za stoku animalnog podrijetla. Zbog sve većih zahtjeva prema poljoprivredi, vezanih za proizvodnju ekološki ispravne hrane, upravo su pogača i sačma zbog svojih energetsko-nutritivnih vrijednosti uspješno zamijenile spornu komponentu animalnog podrijetla u hrani za stoku. Sve veće cijene pogača i sačme omogućile su da njihov plasman uopće nije upitan. Dapače, upravo je njihova proizvodnja u nekim postrojenjima za proizvodnju biodizelskoga goriva u Europskoj uniji postala primarni proizvod, koji uspješno pridonosi pozitivnoj ekonomskoj bilanci proizvodnje [6].

A special emphasis is placed in the process of the production of biodiesel in the world on the use of all the by-products. The use of the cake and meal in fodder is increasingly important because of the appearance of the disease bovine spongiform encephalitis (mad cow disease) which is transmitted with fodder of animal origin. Because of the ever greater demands made on agriculture related to the production of ecologically acceptable food, the cake and meal, because of their energy and nutritive values, have successfully replaced the disputable component of animal origin in fodder. The increasingly high prices of cake and meal have enabled their sales to be not at all a matter of doubt. Indeed, in some of the biodiesel fuel plants in European Union they have become the primary products, which have successfully contributed to the achievement of a positive economic balance for this production [6]

2 SVOJSTVA BIODIZELSKOGA GORIVA

Prednost biodizelskoga goriva u odnosu na mineralno dizelsko gorivo, s ekološkog stajališta, proizlazi iz povoljnije bilance ugljikovog dioksida. Osnova za proizvodnju biodizelskoga goriva jest sjeme, odnosno ulje neke uljane kulture, a poznato je da biljka za svoj rast troši određenu količinu ugljikovog dioksida. Pri uzgoju tih kultura koriste se razni poljoprivredni strojevi koji svojim radom proizvode ugljikov dioksid, a isti nastaje i u procesu prerade ulja u biodizelsko gorivo. Slična je situacija i s proizvodnjom mineralnoga dizela. Međutim, razlika je u tome što se za daljnji uzgoj uljane repice iz atmosfere preuzima dio ugljikovog dioksida nastalog izgaranjem i proizvodnjom biodizelskoga goriva, dok se kod mineralnoga dizelskoga goriva nastali ugljikov dioksid neprestano akumulira u atmosferi. Uzgojem uljane repice, proizvodnjom ekološki ispravnoga goriva, njegovim izgaranjem te ponovnim uzgojem, stvara se djelomično zatvoren i ekološki povoljan lanac nastajanja i potrošnje ugljikovog dioksida [7] i [8].

Pri razmatranju bilance ugljikovog dioksida nastalog izgaranjem u motoru i proizvodnje biodizelskoga goriva s jedne strane i mineralnoga goriva s druge strane, procjenjuje se da je produkcija ugljikovog dioksida biodizelskoga goriva na razini od 40 do 50 % produkcije ugljikovog dioksida pri proizvodnji i izgaranju mineralnoga dizelskoga goriva [9].

U literaturi se nalaze podaci prema kojima se emisija ugljikovog dioksida nastalog izgaranjem biodizelskoga goriva kreće u rasponu od 20 % do 25 % emisije ugljikovog dioksida nastalog izgaranjem mineralnoga dizelskoga goriva, a neki autori čak navode da se sav ugljikov dioksid nastao proizvodnjom i izgaranjem biodizelskoga goriva ponovno apsorbira iz atmosfere od strane biljaka, što je moguće samo pri uporabi sirovoga repičinog ulja kao goriva, što nije slučaj s biodizelskim gorivom [10]. Ukupna bilanca stakleničnih plinova pokazuje da se izgaranjem i proizvodnjom 1 kg mineralnoga dizela emitira 4,01 kg CO_{2ekv}, dok se proizvodnjom i korištenjem biodizelskoga goriva i njegovih nusproizvoda emitira [11]:

- 0,916 kg CO_{2ekv}/kg biodizela,
- 0,314 kg CO_{2ekv}/kg ostatka repice (stočna hrana),
- 0,420 kg CO_{2ekv}/kg glicerola.

Jedno od najvažnijih svojstava dizelskoga goriva je njegova sposobnost samozapaljenja, svojstvo koje definira cetanski broj, i što je on veći to se

2 THE PROPERTIES OF BIODIESEL FUEL

The advantages of biodiesel fuel as compared with mineral diesel fuel derives, from the ecological point of view, is in a more favourable carbon dioxide balance. The basis for the production of biodiesel fuel is seed, that is, the oil of certain oil crops, and it is well known that a plant, for its growth, has to make use of a certain amount of carbon dioxide. In the cultivation of these crops, various farm machines are used that produce carbon dioxide in their work, and the same thing happens in the process of converting oil into biodiesel fuel. A similar situation applies with the production of mineral diesel oil. However, the difference lies in the fact that for the further cultivation of oilseed rape some of the carbon dioxide created by the combustion and production of biodiesel fuel is taken from the atmosphere, while with the use of mineral diesel fuel, the carbon dioxide produced incessantly goes on accumulating in the atmosphere. Through the cultivation of oilseed rape, with the production of ecologically acceptable fuel, through its combustion and re-cultivation, a partially closed and ecologically favourable chain of the generation and consumption of carbon dioxide is thus created [7] and [8].

In the consideration of the balance of carbon dioxide created by combustion in an engine and in the production of biodiesel fuel on the one hand and of mineral fuel on the other, it is estimated that the production of carbon dioxide of biodiesel fuel is at the level of 40 to 50% of the production of carbon dioxide during the production and combustion of mineral diesel fuel [9].

Data can be found in the literature according to which the emission of carbon dioxide created by the combustion of biodiesel fuel ranges between 20 to 25 % of the emission of carbon dioxide from the combustion of mineral diesel fuel, and some authors go as far as to say that all the carbon dioxide created by the production and combustion of biodiesel fuel is reabsorbed from the atmosphere by the plants, which is possible only in the use of raw rapeseed oil as fuel, but is not the case with biodiesel fuel [10]. The overall balance of greenhouse gases shows that with the combustion and production of 1 kg of mineral diesel fuel 4,01 kg CO_{2ekv} is emitted, while with the production and use of biodiesel fuel and its by-products the following are emitted [11]:

- 0,916 kg CO_{2ekv}/kg biodiesel,
- 0,314 kg CO_{2ekv}/kg rapeseed residue (fodder),
- 0,420 kg CO_{2ekv}/kg glycerol.

gorivo brže zapali. Istraživanja su pokazala da je prosječan cetanski broj biodizelskoga goriva 48 u usporedbi s cetanskim brojem mineralnog dizela koji iznosi 50.

Mazivost, još jedno važno svojstvo dizelskoga goriva, definira njegova maziva svojstva. Biodizelsko gorivo ima bolju mazivost od mineralnog dizelskoga goriva s niskom koncentracijom sumpora od 500 ppm.

Od ukupne mase B100 (100 % biodizelsko gorivo), 11 % te mase jest kisik. Prisustvo kisika u biodizelskom gorivu poboljšava njegovo izgaranje, čime se smanjuje količina ugljikovog dioksida, CO i emisija krutih čestica. Međutim, oksigenirana goriva mogu povećati emisiju dušikovih oksida. Testovi na motorima potvrdili su ta očekivana povećanja, ali i smanjenja ispušnih plinova i krutih tvari iz motora.

Biodizelsko gorivo ima i određenih nedostatka. Svojstva biodizelskoga goriva u hladnim uvjetima lošija su od svojstava dizelskoga goriva. Pri niskim temperaturama, biodizelsko gorivo formira kristale voska, koji mogu dovesti do začepljenja u sustavu motora. Pri još nižim temperaturama, biodizelsko gorivo dobiva svojstva gela što znači da se isto ne može crpsti iz spremnika. U vozilima koja se pogone mješavinom biodizelskoga goriva i mineralnoga dizelskoga goriva nastaju problemi s opskrbom motora gorivom pri manje negativnim temperaturama nego kod onih vozila koja se pogone dizelskim gorivom. Zbog toga je potrebno biodizelsko gorivo dodatno aditirati, čime bi njegova uporaba bila moguća i pri niskim temperaturama.

Biodizelsko gorivo kod automobila starijih godišta djeluje poput otapala i može uzrokovati otapanje boje. Biodizelsko gorivo također kod automobila starijih godišta agresivno djeluje na brtvila u motorima. To znači da je brtvila potrebno zamijeniti ako se u takvim automobilima želi koristiti kao pogonsko gorivo biodizelsko gorivo.

Uporaba B20 (mješavina 20 % biodizelskoga goriva i 80 % mineralnog dizela) i B100 u bilo kojem vozilu zahtijeva određeni oprez. Zbog loše kakvoće dizelskoga goriva izgaranjem u motoru stvaraju se naslage. One, uporabom biodizelskoga goriva mogu promijeniti konzistenciju, te zbog toga može doći do njihove migracije i začepljivanja filtara čija je zadaća pročišćavanje pogonskog goriva. Zato je potrebno nakon izvjesnog vremena po prelasku na biodizelsko gorivo obaviti servis.

Biodizelsko gorivo ima nešto veću potrošnju u odnosu na potrošnju mineralnoga dizelskoga goriva pri istom broju prijeđenih kilometara. Ako se promatra energetska iskoristivost motora, a to

One of the most important properties of diesel fuel is its capability for self-ignition, a property that is defined by the cetane number, and the greater this is, the faster the fuel ignites. Research has shown that the average cetane number of biodiesel is 48, as compared with the cetane number of mineral diesel, which is 50.

Lubricity, another important property of diesel oil, defines its lubricative characteristics. Biodiesel fuel has better lubricity than mineral diesel fuel with a low sulphur concentration of 500 ppm.

Of the total mass of B100 (100 % biodiesel fuel), 11 % is oxygen. The presence of oxygen in biodiesel fuel improves its combustion, thus reducing the quantity of carbon dioxide, CO and the emission of solid particles. However, oxygenated fuels can increase the emission of nitrogen oxides. Engine tests have confirmed this expected increase, as well as the reduction of exhaust gases and solid matter from engines.

Biodiesel also has certain drawbacks. The properties of biodiesel fuels in cold conditions are poorer than those of fossil diesel. At low temperatures, biodiesel fuel forms wax crystals, which can lead to blockage in the engine. At still lower temperatures, biodiesel fuel takes on the properties of a gel, which means that it cannot be pumped from the fuel tank. In vehicles driven by a mixture of biodiesel and fossil diesel, problems arise with the fuel supply to the motor at less negative temperatures than in those vehicles that are driven with fossil diesel alone. Because of this reason biodiesel has to be supplemented with additives to make it usable at low temperatures.

In automobiles made some time ago, biodiesel fuel acts as a solvent and can dissolve the paint. Biodiesel fuel, also with cars of older years of production, acts aggressively against the gaskets. This means that gaskets must be changed if it is wished to use biodiesel fuel as the drive fuel in these vehicles.

The use of B20 (a mixture of 20 % biodiesel fuel and 80 % fossil diesel) and B100 in any vehicle at all requires a certain amount of caution. Because of poor quality diesel fuel, deposits are created in the engine on combustion. With the use of biodiesel, these deposits can change their consistence, and because of this they can migrate and block the filters the function of which is to refine the drive fuel. For this reason it is necessary a certain time after changing over to biodiesel fuel to have a service done.

Consumption of biodiesel is slightly higher than that of fossil diesel fuel for the same mileage. If the energy use of the engine is considered, that is je postotak toplinske energije goriva koju oslobađa motor, biodizelsko gorivo nije pokazalo signifikantan učinak na energetsku iskoristivost niti jednog istraživanog motora. Za razliku od energetske, volumetrijska iskoristivost koja se uglavnom izražava kao kilometri po litri goriva pokazala je da udio energije po litri biodizelskoga goriva iznosi otprilike 11 % manje nego kod dizelskoga goriva. Nadalje, očekuje se da će vozila koja koriste B20 postizati 2,2 % manje kilometara po litri goriva. Međutim, taj nedostatak kompenzira se udjelom kisika u biodizelskom gorivu.

U tablici 3 prikazane su za izgaranje najvažnije značajke standardnoga dizelskoga goriva i metilnog estera ulja uljane repice – biodizela [12].

the percentage of thermal energy of the fuel that is released by the engine, biodiesel did not show a significant effect on the energy use of a single engine investigated. Unlike the energy, the volumetric use which is on the whole expressed as kilometres driven per litre of fuel, it was shown that the energy share per litre of biodiesel fuel comes to about 11 % less than with fossil diesel fuel. Further, it is expected that vehicles that use B20 will attain 2,2 % fewer miles per litre of fuel. However, this drawback is compensated for by the proportion of oxygen in biodiesel fuel.

Table 3 shows the properties of standard diesel fuel and the methyl ester of rapeseed oil – biodiesel that are most important for combustion [12].

Tablica 3 – Značajke mineralnoga dizelskoga goriva i metilnog estera ulja uljane repice
Table 3 – Properties of fossil diesel oil and of the methyl ester of rapeseed oil

Značajke / Properties	Jedinica / Unit	Mineralni dizel / Fossil diesel	RME*
Približna kemijska formula / Approximate chemical formula		$CH_{1,85}$	$C_{19}H_{35,2}O_2$
Molekularna masa / Molecular mass	g/mol	120–320	296
Sadržaj ugljika / Carbon content	% mase / mass	86,5	76,5
Sadržaj vodika / Hydrogen content	% mase / mass	13	12,3
Sadržaj kisika / Oxygen content	% mase / mass	0	11,0
Sadržaj sumpora / Sulphur content	% mase / mass	0,14	0,002
Sadržaj dušika / Nitrogen content	% mase / mass	0,015	0,1
Sadržaj pepela / Ash content	% mase / mass	0,01	0,02
Stehiometrijska količina zraka / Stoichiometric quantity of air	kg zraka/kg goriva / kg air/kg fuel	14,4	12,8
Gustoća / Density (15 °C)	kg/m^3	835	878
Promjena gustoće / Density change	kg/m^3K	0,73	0,83
Ogrjevna vrijednost / Thermal value	MJ/kg	42,50	37,10
Početak isparivanja / Start of evaporation	°C	~ 180	~ 320
Kraj isparavanja / End of evaporation	°C	~ 350	~ 360
Cetanski broj / Cetane number		50	~ 48
Kinematička viskoznost / Kinematic viscosity (20 °C)	mm^2/s	6,65	7,07
Kinematička viskoznost / Kinematic viscosity (40 °C)	mm^2/s	2,31	4,35
Kinematička viskoznost / Kinematic viscosity (100 °C)	mm^2/s	0,8	1,78
Temperatura stinjavanja / Gel temperature	°C	–24	–12
Plamište / Ignition point	°C	70–90	110–140

* Metilni ester ulja uljane repice / Methyl ester of rapeseed oil (Rapeseed methyl ester)

Početne teškoće u primjeni biodizelskoga goriva s početka desetljeća u međuvremenu su prevladane te svi današnji dizelski motori mogu rabiti biodizelsko gorivo bez ikakve opasnosti za sam motor ili prateće uređaje [13].

Initial difficulties in the application of biodiesel from the beginning of the decade have been overcome in the meantime and all current diesel engines can use biodiesel fuel without any danger to the engine itself or to ancillary equipment [13].

2.1 Biorazgradivost biodizelskoga goriva

U proteklim se godinama zakonskim regulativama u većini država nastoji smanjiti udio sumpora i aromata u mineralnim dizelskim gorivima radi poboljšavanja kakvoće zraka. Nažalost, u procesu odstranjivanja sumpora i aromata te ostalih komponenata (poliaromata i dušičnih komponenata) izdvajaju se i komponente koje imaju zadaću podmazivanja u motoru. To rezultira smanjenom sposobnošću podmazivanja nisko-sumpornih mineralnih goriva, koja se na neki način mora nadomjestiti. Rješenje se našlo u dobrim mazivim svojstvima biodizelskoga goriva. Samo 0,4 % biodizelskoga goriva u mineralnom dizelu omogućava minimum potrebne mazivosti koju zahtijeva standard za mineralno dizelsko gorivo. Maksimalna mazivost postiže se mješavinama približno 10 % biodizelskoga u mineralno dizelsko gorivo [11].

Biorazgradivost biodizelskoga goriva može se uvidjeti kroz podatke o COD (kemijska potrošnja kisika), BOD_5 (biokemijska potrošnja kisika), biorazgradivost u vodenim otopinama i biorazgradivost u tlu. Općenito, metilni i etilni esteri imaju visoke COD i BOD_5 vrijednosti, što je poželjno kada se radi o biorazgradnji, jer to znači da se materijal vrlo brzo razgrađuje. Istraživanjem COD vrijednosti, utvrđeno je da ona nije bila značajno različita između RME (metilni ester ulja uljane repice), REE (etilni ester ulja uljane repice) i 2-D (Phillips 2-D diesel). Suprotno tomu, BOD_5 vrijednosti za RME i REE bile su dvostruko veće od BOD_5 vrijednosti za 2-D. Signifikantno manja ($p<0,01$) BOD_5 vrijednost kod 2-D upućuje na prisustvo mnogo manje količine mikrobno biorazgradive organske tvari u tome gorivu. Manja BOD_5 vrijednost 2-D također bi se mogla odraziti na mikrobnu toksičnost dizelskoga goriva ili njegovih komponenti.

Sva biodizelska goriva su dobro razgradiva u vodi i tlu. Istraživanja su pokazala da se u razdoblju od 28 dana biodizelsko gorivo u vodi razgradilo 84 %, a u tlu 88 %, što su gotovo dvostruko veće vrijednosti u odnosu na dizelsko gorivo. Rezultati također upućuju da je povećanje koncentracije REE u mješavinama uzrokovalo linearno povećanje vrijednosti ukupne biorazgradnje. Nakon 4 do 6 tjedana od ulaska biodizelskoga goriva u tlo biljke su normalno klijale i rasle.

2.2 Toksičnost biodizelskoga goriva

Testovi toksičnosti pokazali su da je biodizelsko gorivo značajno manje toksično od dizelskoga goriva, ali su potrebne određene mjere opreza kod rukovanja njime. Iako su zabilježeni neki negativni učinci na testovima sa zečevima i štakorima,

2.1 Biodegradability of biodiesel fuel

In recent years, statutory regulations in most countries have endeavoured to reduce the proportions of sulphur and aromatics in fossil diesel fuels for the sake of air quality improvement. Unfortunately, in the process of removing sulphur and aromatic and other components (polyaromatics and nitrogen components) components that have a lubrication function in the engine have also been removed. This has resulted in decreased lubrication capacity in low sulphur fossil fuels, which has to be replaced in some manner. A solution was found in the good lubricating qualities of biodiesel fuel. Only 0,4 % of biodiesel in fossil diesel enables the minimum necessary lubrication required by fossil diesel fuel standards. Maximum lubrication is achieved with a mixture of about 10 % biodiesel in fossil diesel fuel [11].

The biodegradability of biodiesel fuel can be seen through the COD data (chemical oxygen demand), BOD_5 (biochemical oxygen demand), biodegradability in aqueous solutions and biodegradability in soil. In general methyl and ethyl esters have high COD and BOD_5 values, which is desirable where biodegradability is concerned, for it means that the material is degraded very rapidly. COD value research has shown that there was no significant difference with respect to this among RME (rapeseed methyl ester), REE (rapeseed ethyl ester) and 2-D (Phillips 2-D diesel). As against this the BOD_5 values of RME and REE were twice as great as that of 2-D. A significantly lower ($p<0.01$) BOD_5 value in 2-D indicates the presence of far fewer amounts of microbially biodegradable organic substances in this fuel. The lower BOD_5, value of 2-D might also be reflected on the microbial toxicity of diesel fuel or components of the fuel.

All biodiesel fuels are satisfactorily degradable in water and soil. Research has shown that in a period of 28 days biodiesel fuel degrades 84 % in water and 88 % in the soil, which is almost twice the value of fossil diesel. These results also indicate that an increase in the concentration of REE in mixtures caused a linear increase in the value of total biodegradability. After 4 to 6 weeks from entry of biodiesel into the soil, plants normally germinated and grew.

2.2 Toxicity of biodiesel fuel

Toxicity tests have shown that biodiesel fuel is significantly less toxic than fossil diesel, but certain safety measures are required in handling it. Although some negative effects have been shown on tests with rabbits and rats, no animal has died as a result of contact with biodiesel or fossil diesel fuel. Animals that were in contact with fossil diesel nijedna životinja nije uginula zbog kontakta s biodizelskim ili dizelskim gorivom. Životinje koje su bile u dodiru s dizelskim gorivom imale su lošiju kliničku sliku. Oralna LD_{50} vrijednost (letalna doza za 50 % populacije) svake istraživane tvari (REE, RME, 2-D) veća je od 5000 mg/kg, što je granična doza. Doza od 2000 mg/kg pokazala se kao NOAEL (No Observed Adverse Effect Level), dakle kao doza kod koje nisu zamijećene promjene. Praćenjem akutne oralne toksičnosti, 100 % RME se pokazao najmanje opasnim, dok je kod akutne dermalne toksičnosti najmanje opasan bio 100 % REE.

Istraživanje toksičnosti na vodenom organizmu Daphnia Magna koji je osjetljiv na naftne mrlje te referentan za navedena istraživanja pokazalo je da je dizelsko gorivo 2,6 puta toksičnije od NaCl, dok je biodizelsko bilo manje toksično od NaCl [14].

2.3 Utjecaj izgaranja biodizelskoga goriva na okoliš

Jedno od najvažnijih svojstava biodizelskoga goriva kao pogonskog goriva je smanjena emisija štetnih ispušnih plinova za više od 50 % u odnosu na dizelsko gorivo te činjenica da ono gotovo nema sumpora, fosfora i olova, pri čemu je količina čađi u ispušnim plinovima smanjena za oko 50 % u odnosu na dizelsko gorivo. Dakle, biodizelsko gorivo u odnosu na dizelsko ima značajno niži stupanj onečišćenja okoliša pri eksploataciji, što je od velike važnosti napose za gradove i velegradove u kojima se gradski prijevoz odvija njegovom uporabom.

Korisnici goriva su zapazili da ispušni plinovi koji nastaju prilikom izgaranja biodizelskoga goriva nemaju neugodan miris, za razliku od ispušnih plinova koji nastaju izgaranjem mineralnoga dizelskoga goriva.

Američki Nacionalni laboratorij za obnovljivu energiju (National Renewable Energy Laboratory, NREL) radi na istraživanjima emisije dušikovih oksida iz biodizelskoga goriva. Istraživanja koja provodi ovaj laboratorij idu u smjeru pronalaženja određenog omjera biodizelskoga goriva i drugih spojeva kojim se neće povećavati emisija dušikovih oksida.

Emisiju dušikovih oksida iz biodizelskoga goriva moguće je smanjiti miješanjem s kerozinom. Procjenjuje se da bi mješavina kerozina i biodizelskoga goriva u omjeru 60:40 (60 % kerozina i 40 % biodizelskoga goriva) imala emisiju dušikovih oksida na razini dizelskoga goriva. Dušikovi oksidi i ugljikovodici su preteče ozona. Ugljikov monoksid (CO) također je prekursor ozona, ali od manjeg značenja. Iz tog razloga potrebno je napraviti scenarij o kakvoći zraka, odnosno da li

had bad clinical results. The oral LD_{50} value (a lethal dose for 50 % of the population) for each investigated substance (REE, RME, 2-D) is greater than 5000 mg/kg, which is the borderline dose. A dose of 2000 mg/kg proved to be NOAEL or at the no observed adverse effect level, as a dose, then, at which no changes were noted. When acute oral toxicity was measured, 100 % RME was the least hazardous, while in the case of acute dermal toxicity the least dangerous was 100 % REE.

Investigation of the toxicity to the aquatic organism Daphnia Magna, which is susceptible to oil slicks and a reference for the said research showed that fossil diesel is 2,6 times more toxic than NaCl, while biodiesel was less toxic than NaCl [14].

2.3 Biodiesel combustion environmental impact

One of the most important properties of biodiesel fuel as drive fuel is a 50 % reduction in the emission of harmful exhaust gases and the fact that it has practically no sulphur, phosphor and lead, with the quantity of soot in the exhaust gases being cut about 50 %. Thus as against fossil, biodiesel has a significantly lower degree of environmental pollution in use, which is of great importance particularly for cities and conurbations in which city transport is carried out with the use of this fuel.

Users of the fuel have noted that the exhaust gases created during the combustion of biodiesel fuel do not have the unpleasant smell associated with the exhaust gases created by the combustion of fossil diesel fuel.

NREL, the American National Renewable Energy Laboratory is working on research into the emission of nitrogen oxides from biodiesel fuel. The research carried out by this laboratory is aimed at finding a given ratio of biodiesel and other compounds at which the emission of nitrogen oxides will not be increased.

It is possible to reduce the emission of nitrogen oxides from biodiesel by mixing it with kerosene. It is estimated that a mixture of kerosene and biodiesel in a ratio of 60:40 (60 % kerosene and 40 % biodiesel) would have a nitrogen oxide emission at the level of fossil diesel. Nitrogen oxides and carbohydrates are ozone precursors, as is carbon monoxide (CO), but of less importance. For this reason it is necessary to produce an air quality scenario, that is, to find out whether there will be an increase or a reduction in the ozone level if biodiesel fuel is used without additives.

The use of biodiesel fuel in conventional diesel engines has resulted in an important reduction of će doći do povećanja ili smanjenja razine ozona ako se koristi biodizelsko gorivo bez aditiva.

Uporaba biodizelskoga goriva u konvencionalnim dizelskim motorima rezultira značajnim smanjenjem nesagorjelih ugljikovodika, CO i krutih čestica. Emisija dušikovih dioksida je ili blago smanjena ili blago povećana, ovisno o metodi istraživanja. Uporabom biodizelskoga goriva u konvencionalnim dizelskim motorima, smanjuje se količina čestica ugljika (budući da kisik u gorivu omogućuje sagorijevanje do CO_2), eliminira se frakcija sumpora (budući da u gorivu nema sumpora), a topiva frakcija vodika ostaje ista ili je malo povećana.

Biodizelsko gorivo je prvo i jedino biogorivo za koje postoje rezultati istraživanja emisije čestica u zrak te potencijalni učinci na zdravlje ljudi, a koje je predočila Američka agencija za zaštitu okoliša (EPA) nakon primjene najstrožih pravila. Kako je već spomenuto, uporabom biodizelskoga goriva količina smoga smanjuje se za oko 50 % u odnosu na dizelsko gorivo. Emisija inhalirajućih čestica, koje predstavljaju rizik za ljudsko zdravlje, smanjena je za oko 40 % u odnosu na emisiju istih tih čestica iz mineralnoga dizela, a emisija ukupnih ugljikovodika je niža za oko 68 %.

Kod uporabe čistog (100 %) biodizelskoga goriva, emisija NO_x je povećana za oko 6 %, no budući da biodizelsko gorivo gotovo i nema sumpora moguća je primjena kontrolnih metoda i postupaka, pri čemu se emisija NO_x iz biodizelskoga goriva u određenim uvjetima može učinkovito nadgledati i smanjiti tijekom korištenja.

2.4 Usporedba svojstava izgaranja biodizelskoga goriva sa svojstvima izgaranja mineralnog dizela

Tijekom ciklusa proizvodnje uljane repice i korištenja biodizelskoga goriva proizvodi se približno 80 % manje CO_2 i gotovo 100 % manje SO_2 u usporedbi s proizvodnjom i uporabom mineralnog dizela. Iz tablice 4 vidljivo je da biodizelsko gorivo ima izrazito poboljšane karakteristike emisija za gotovo sve (regulirane i neregulirane) zagađivače u usporedbi s mineralnim dizelskim gorivom.

Jedino je emisija NO_x u porastu kod biodizelskoga goriva. Koncentracija NO_x povećava se s povećanjem udjela biodizelskoga goriva u mješavini biodizelskoga i mineralnog dizelskog goriva. Do povećanja koncentracije NO_x može doći zbog visokih temperatura u procesu potpunog izgaranja, a zbog kisika u gorivu. Novija istraživanja nagovješćuju da se povećane emisije NO_x mogu smanjiti korištenjem tehnologija prikladnijih proizvodnji biodizelskoga goriva.

uncombusted hydrocarbons, CO and solid particles. The emission of nitrogen dioxides has been slightly reduced or slightly increased, depending on the research methodology. When biodiesel fuel is used in conventional diesel engines, the quantity of carbon particles is reduced (since the oxygen in the fuel enables it to be combusted to CO_2), the sulphur fraction is eliminated (since there is no sulphur in this fuel) and the soluble hydrogen fraction remains the same or is slightly elevated.

Biodiesel is the first and only biofuel for which there are results of research into the emission of particles into the air and the potential effects on human health, presented by the American Environmental Protection Agency (EPA) after application of the most stringent rules. As already mentioned, with the use of biodiesel fuel, the amount of smog is reduced by about 50 % as compared with the situation resulting from fossil diesel. The emission of inhalable particles, which are a human health hazard, is reduced by about 40 % as against the emission of the same particles from fossil diesel, and the emission of total hydrocarbons is about 68 % lower.

In the case of the use of pure (100 %) biodiesel fuel, the NO_x emission is increased by about 6 %, but since biodiesel has practically no sulphur, it is possible to employ control methods and procedures, so that the emission of NO_x from biodiesel fuel in certain conditions can be effectively supervised and reduced during use.

2.4 Comparison of the combustion properties of biodiesel with those of fossil diesel

During the oilseed rape production and biodiesel use cycle about 80 % less CO_2 and practically 100 % less SO_2 is produced than in the production and use of fossil diesel. Table 4 reveals that biodiesel has markedly improved emission characteristics for practically all (regulated or non-regulated) contaminants over fossil diesel.

Only the NO_x emission is elevated in the case of biodiesel fuel. The concentration of NO_x is increased with the increase in the proportion of biodiesel in a mixture of biodiesel and fossil diesel. An increase in NO_x concentration can arise because of the high temperatures involved in the process of total combustion, as well as because of the oxygen in the fuel. More recent research suggests that the increased emissions of NO_x can be reduced by using technologies more suitable to the production of biodiesel fuel.

Tablica 4 – Prosječna emisija iz biodizelskoga goriva u usporedbi s konvencionalnim dizelskim gorivom [15]
Table 4 – Average emission of biodiesel as compared with conventional diesel fuel [15]

Tip emisije / Type of emission	B100 (100 % biodizela / biodiesel)	B20 (20 % biodizela / biodiesel)
Regulirano / Regulated		
Ukupno neizgoreni ugljikovodici / Total uncombusted hydrocarbons	– 67 %	– 20 %
CO	– 48 %	– 12 %
Čestice / Particles	– 47 %	– 12 %
NO_x	+10 %	+2 %
Neregulirano / Unregulated		
Sulfati / Sulphates	– 100 %	– 20 %*
PAH (policiklički aromatski ugljikovodici) / PAH (polycyclical aromatic hydrocarbons)*	– 80 %	– 13 %
nPAH (nitrirani PAH) / (nitrated PAH) **	– 90 %	– 50 %
Mogućnost formiranja smoga / Smog formation	– 50 %	– 10 %

* procjena iz rezultata B 100 / estimated from B100 results
** prosječno smanjenje svih izmjerenih komponenti / average reduction of all components measured

Rezultati istraživanja ECOTEC-a o emisijama NO_x tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva potvrdili su saznanja ETSU (Energy Technology Support Unit) i njihovu višu vrijednost od emisija NO_x iz dizelskoga goriva. Glavni razlog tomu su emisije iz poljoprivrednih vozila koja se koriste tijekom uzgoja uljane repice. ECOTEC-ove analize emisija tijekom ekstrakcije i rafinacije biodizelskoga goriva pokazale su više vrijednosti nego što su to vrijednosti koje je procijenio ETSU [4] i [16].

Emisije nastale tijekom faze uporabe bile su približno iste za vozila koja su koristila dizelsko gorivo kao i ona koja su koristila biodizelsko gorivo – oboje su imali emisije neznatno iznad 1 000 mg/km, a razlike nisu bile statistički značajne. Istraživanje provedeno u Austriji ukazuje na moguće smanjenje emisija NO_x iz biodizelskih motora od 25 %, poboljšanjem vremena ubrizgavanja goriva. Istraživanje pak provedeno na Sveučilištu u Limericku potvrdilo je ETSU-ova saznanja o sličnosti emisija NO_x iz biodizelskih i dizelskih motora (bez mijenjanja vremena ubrizgavanja).

Neki od zaključaka različitih znanstvenih studija su sljedeći:

- prilagodba vremena ubrizgavanja i temperature djelovanja motora rezultirat će smanjenjem emisije NO_x iz biodizelskoga goriva ispod razine emisije NO_x iz mineralnog dizela [17],
- različiti istraživači zapazili su povećanje emisije NO_x iz biodizelskoga goriva. Međutim,

Results of ECOTEC into NO_x emissions during the production and use of biodiesel fuel cycle have confirmed the findings of ETSU (Energy Technology Support Unit) and its higher value than the emission of NO_x from fossil diesel. The main reason for this is the emissions from farm vehicles that are used during the cultivation of oilseed rape. ECOTEC analyses of emissions during the extraction and refining of biodiesel have shown higher values than those estimated by ETSU [4] and [16].

Emissions created during the use phase were approximately similar for vehicles using fossil diesel and those using biodiesel – both had emissions slightly above 1000 mg/km, the differences being statistically insignificant. Research carried out in Austria shows that it is possible to reduce NO_x emissions from biodiesel engines for a 25 % with improvement in the fuel injection time. Research carried out at the University of Limerick has confirmed the ETSU results about the similarity of emissions of NO_x from biodiesel and fossil diesel engines (without changing injection times).

Some of the conclusions of different scientific studies are as follows:

- the adjustment of the injection time and the temperature at which the engine works will result in a reduction of the emission of NO_x to below the level of NO_x from fossil diesel [17],
- various researchers have noticed an increase in the emission of NO_x from biodiesel fuel.

podaci pokazuju dosljedno smanjenje NO_x u svim testovima s dinamometrom [14],
– povećanjem razine NO_x došlo je do smanjenja čestica, CO i ukupnih ugljikovodika, a usporavanjem vremena ubrizgavanja smanjila se i emisija NO_x [18].

Istraživanje emisija SO_x, prema ETSU , koje je provedeno tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva, postavilo je sumnju da je emisija SO_x iz biodizelskoga goriva viša od dizelskoga goriva. Tome, prema njihovom mišljenju uvelike je doprinio postupak istiskivanja ulja iz sjemenke. Međutim, istraživanja agencije ECOTEC [4] su pokazala da je ova pretpostavka netočna.

Prema njihovim istraživanjima, emisije SO_x su tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva bile od 20 % do 30 % manje od onih dizelskoga goriva. Ova saznanja su u suprotnosti sa saznanjima ETSU, koji su uočili visoke razine emisija tijekom tiještenja sjemenki uljarica uporabom električne energije. Uvođenje dizelskih goriva s niskom i vrlo niskom koncentracijom sumpora moglo bi dovesti do smanjenja emisija SO_x iz konvencionalnih motora, ali će omjer ciklusa i dalje biti veći kod dizelskoga goriva nego kod biodizelskoga zbog emisija nastalih tijekom proizvodnje goriva [4] i [16].

Emisija čestica uvelike ovisi o trenutačnoj aktivnosti vozila. Sagorijevanje slame i rad poljoprivredne mehanizacije također su značajni izvori emisija. ETSU nije zabilježila čimbenike emisije u ekstrakciji i rafinaciji dizelskoga goriva. Analiza u kojoj se koristi procjena okoliša upućuje da emisije iz navedenih izvora iako su signifikantne, nisu dovoljno velike da bi utjecale na analize ciklusa proizvodnje i uporabe [15].

Emisija hlapivih organskih tvari znatno se povećava tijekom proizvodnje goriva. Analiza ciklusa proizvodnje i uporabe upućuje da emisija iz biodizelskoga goriva iznosi 44 % do 56 % emisije iz dizelskoga goriva.

Emisija CO tijekom ciklusa proizvodnje i uporabe biodizelskoga goriva je 20 %, odnosno 40 % veća od emisije dizelskoga goriva i to zbog korištenja mineralnoga dizelskoga goriva tijekom uporabe poljoprivredne mehanizacije i sakupljanja i uporabe slame. Vjerojatno je za očekivati da će dizelski motori biti manje važan izvor emisije CO zbog striktnih standarda novih vozila vezanih za emisiju tvari, a koji su poboljšali performanse motora.

Istraživanje EPA (Environmental Protection Agency) o sastavu čađi iz dizelskoga i biodizelskoga goriva

However, data show a consistent reduction of NO_x in all tests with a dynamometer [14],
– with an increase in the NO_x level came a reduction in particles, CO and total hydrocarbons, and with a deceleration of the injection time the emission of NO_x was reduced [18].

Research into SO_x emissions according to ETSU, carried out during the whole biodiesel fuel production and use cycle raised the suspicion that the SO_x emissions from biodiesel fuel were higher than those of fossil diesel. In their opinion, this was greatly contributed to by the procedure for pressing the oil from the seeds. However, researchers by ECOTEC [4] showed that this assumption was incorrect.

According to their research, SO_x emissions during the whole biodiesel fuel production and use cycle were 20 % to 30 % lower than those of fossil diesel fuel. This result is opposite to that of ETSU, who observed high levels of emissions during the pressing of oilseeds with the use of electricity. The introduction of diesel fuels with low and very low concentrations of sulphur might lead to the reduction of the emissions of SO_x from conventional engines, but the ratio of cycles will still be greater with fossil diesel fuel than with biodiesel because of emissions produced during the production of the fuel [4] and [16].

The emission of particles greatly depends on the activity of a vehicle at a given time. Burning straw and the work of farm machinery are also important sources of emissions. ETSU has not recorded the factors of emissions in the extraction and refining of fossil diesel. Analysis using environmental evaluation suggests that emissions from these sources although very significant are not great enough to be able to affect analyses of the production and use cycle [15].

The emission of volatile organic substances is increased considerably during the production of the fuel. Analysis of the production and use cycle suggests that emissions from biodiesel fuel are between 44 % and 56 % of the emissions deriving from fossil diesel.

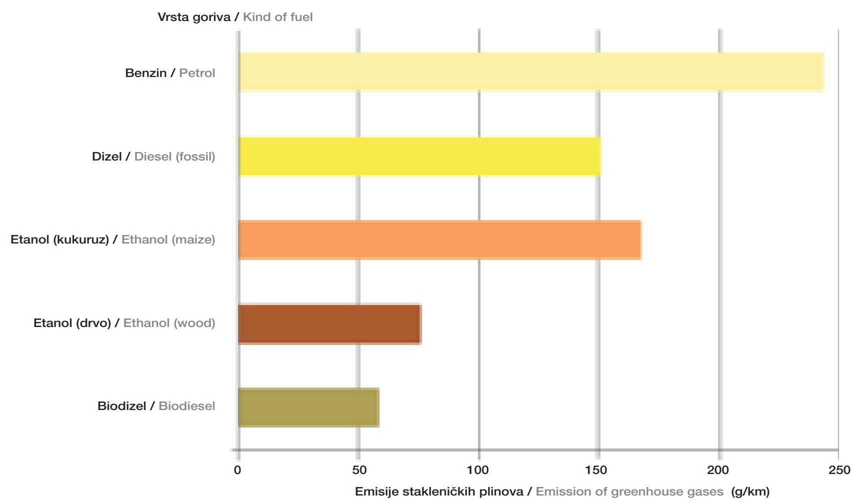
Emission of CO during the production and use cycle of biodiesel is 20 % or 40% up on emission from fossil diesel, which is the result of the use of mineral diesel while operating farm machinery and the collection and use of the straw. It is to be expected that diesel engines will be a less important source of CO emission because of the stringent standards for new vehicles related to the emission of substances and that have improved the performances of engines.

Research by the EPA (Environmental Protection Agency) concerning the composition of soot deriving from fossil and biodiesel fuels shows a reduction of ukazuje na smanjenje ukupne čađi pri uporabi biodizela za 17 %, odnosno za 21 % (hladni, odnosno vrući FTP – Federal Test Procedure). Kod uporabe biodizela emisija čađi (netopive čestice) značajno se smanjuje (za 54 % ili za 51 %), ali je udio emisije čestica sastavljenih od ugljikovodika (čestice topive u gorivu), mnogo veći. Navedeno ukazuje na mogućnost da biodizelsko gorivo ne izgara potpuno istom brzinom kao mineralno dizelsko gorivo, no također se mora napomenuti da su emisije plinovitih ugljikovodika smanjene prilikom uporabe biodizelskog goriva. Budući da se zabrinutost koja se odnosi na čestice povećava djelomično i zbog potencijalnih negativnih učinaka topive frakcije, može se činiti da bi emisije iz biodizelskoga goriva mogle biti još štetnije [15].

Usporedba emisija stakleničkih plinova pri proizvodnji i uporabi različitih goriva prikazana je na slici 2, s koje je vidljivo da su emisije stakleničkih plinova iz biodizelskoga goriva najniže, a slijedi ih bioetanolsko gorivo dobiveno iz drveta [15]. Emisije stakleničkih plinova tijekom proizvodnje dizelskoga goriva iznose 32 g/km, što je gotovo polovica emisija do kojih dolazi prilikom proizvodnje biodizelskoga goriva, čak i kada se umjesto električne energije u procesu proizvodnje koristi slama. Međutim, kada se govori o emisiji CO_2 tijekom izgaranja samog dizela (245 g/km) argumenti su izrazito na strani biodizela (75 g/ km).

total soot in the use of biodiesel of 17 % to 21% (cold, or hot FTP – Federal Test Procedure). In the case of biodiesel use, the emission of soot (insoluble particles) was significantly reduced (by 54 % or 51 %) but the proportion of the emission of particles composed of hydrocarbons (particles soluble in fuel) is much higher. This suggests the possibility that biodiesel does not combust at precisely the same speed as fossil diesel, but it should also be mentioned that the emissions of gaseous hydrocarbons are reduced because of the use of it. Since concern that relates to particles has increased partially because of the potentially negative effects of soluble fractions, it might seem that the emissions from biodiesel fuel might be even more harmful [15].

A comparison of the emissions of greenhouse gases in the production and use of differing fuels is shown in Figure 2, from which it can be seen that the emissions of greenhouse gases from biodiesel fuels are the lowest, after which comes bioethanol fuel obtained from wood [15]. Emissions of greenhouse gas during the production of diesel fuel come to 32 g/km, which is almost half the emissions arising during the production of biodiesel fuel, even when instead of electricity straw is used in the production process. However, when one talks of the emission of CO_2 during the combustion of the fossil diesel fuel itself (245 g/km), the arguments are markedly on the side of biodiesel (75 g/km).



Slika 2
Ciklus stakleničkih plinova pri proizvodnji i uporabi kod različitih goriva (CO_2-CO_2 ekvivalent ostalih zagađivača CH_4 i N_2O)
Figure 2
Cycle of greenhouse gases in the production and use of various fuels (CO_2-CO_2 equivalent of other polluters CH_4 and N_2O)

Mora se naglasiti da prikazani rezultati vrijede do trenutka dok poljoprivredna proizvodnja koristi dizelsko gorivo u svojoj primarnoj proizvodnji. Međutim, uporabom biodizelskoga goriva navedene vrijednosti past će za više od 60 %.

It has to be pointed out that the results shown hold true as long as agricultural production uses diesel fuel in its primary production. But when biodiesel is used, these values will drop by more than 60 %.

3 VEGETABILNA ULJA KAO SIROVINE ZA PROIZVODNJU BIODIZELA U SVIJETU

Četiri uljane kulture jasno dominiraju kao upotrebljeni izvori biljnog ulja za dosadašnju svjetsku proizvodnju biodizela. Na prvom mjestu je ulje uljane repice s oko 85 %, a slijede suncokretovo ulje, sojino ulje, palmino ulje i ostali izvori (laneno ulje, goveđi loj i reciklirano korišteno ulje iz kuhinja). Iz podataka u tablici 5 vidljivo je da su uljana repica, soja, suncokret i uljana palma glavne uljane kulture koje se kultiviraju za dobivanje ulja za humanu konzumaciju kao i druge različite proizvode prehrambene industrije.

3 VEGETABLE OILS AS RAW MATERIALS FOR THE PRODUCTION OF BIODIESEL WORLDWIDE

Four oil crops clearly dominate as sources used for vegetable oil in world experience of biodiesel production to date. In first place comes oilseed rape oil, which accounts for about 85% of the total, then sunflower oil, soy oil, palm oil and other sources (linseed, suet and recycled cooking oil). The figures in Table 5 shows that oilseed rape, soy, sunflower and palm oil are the main crops cultivated for oil for human consumption as well as other various diverse products of the food industry.

Tablica 5 – Sadašnja svjetska proizvodnja devet glavnih vegetabilnih ulja [19]
Table 5 – Current world production of nine main vegetable oils [19]

Vegetabilna ulja / Vegetable oils	Procijenjena proizvodnja / Estimated production 2003.–2004. (10^6 t)
Soja / Soy	31,83
Palma / Palm	28,13
Uljana repica / Oilseed rape	12,57
Suncokret / Sunflower	9,42
Zemni orašac / Groundnut	4,81
Sjeme pamuka / Cottonseed	3,90
Palmina jezgra / Palm kernel	3,50
Kokosov orah / Coconut	3,33
Maslina / Olive	2,81
Ukupno / Total	100,29

S uljanom repicom, suncokretom i sojom moguće je proizvoditi, odnosno dopuniti potrebe masnih kao i jednim dijelom bjelančevinastih komponenata hrane u vlastitoj zemlji. Pored hranidbenih masnih sastojaka, ulje se može upotrijebiti i u tehničke svrhe kao sirovina ili pogonsko gorivo. Mijenjanjem prehrambenih navika i prelaskom na vegetabilna ulja i masnoće značajno se povećala i njihova potrošnja. Tako su površine pod glavnim uljaricama u svijetu u poslijednjih 30 godina porasle 2,5 do 3 puta, a njihova ukupna proizvodnja – zbog povećanja prosječnih prinosa primjenom suvremene tehnologije – 4 do 6 puta (tablica 6).

With oilseed rape, sunflower and soy it is possible to produce or supplement the needs for fats and part of the needs for the protein components of food in the home country. In addition to the nutritious components of fats, oils can be used for process purposes as raw materials or drive fuel. With changes in food habits and a major shift to vegetable oils and fats, the consumption of these products has much increased. Thus the land areas devoted to the main oil producing plants in the world have risen some 2.5 to 3 times in the last 30 years in the world at large, and their total production – because of the increase in average yields with the use of contemporary technology – has gone up fourfold or sixfold (Table 6).

Tablica 6 – Trendovi zasijanih površina i proizvodnje glavnih uljarica u svijetu [20]
Table 6 – Trends in areas sown and production of the main oil bearing plants in the world [20]

Godina / Year	Zasijana površina / Areas sown (10^3 ha)			Proizvodnja / Production (10^3 t)		
	Uljana repica / Oilseed rape	Suncokret / Sunflower	Soja / Soy	Uljana Repica / Oilseed rape	Suncokret / Sunflower	Soja / Soy
1975.	9 911	9 246	38 767	8 768	9 873	64 248
1980.	10 992	12 424	50 648	10 757	13 656	81 039
1985.	14 756	14 842	53 066	19 241	18 856	10 156
1990.	17 610	16 999	57 184	24 428	22 666	108 453
1995.	23 816	20 894	62 510	34 185	26 255	126 981
2000.	25 833	21 087	74 399	39 515	26 434	161 346
2005.	26 950	23 339	91 929	46 409	31 066	209 976

Stvaranje i uvođenje u proizvodnju novih 00 - kultivara uljane repice, poboljšane kakvoće ulja i sačme, omogućilo je brzo širenje ove kulture osobito u Europi, gdje je postala najvažnija uljarica. Samo u Njemačkoj i Francuskoj proizvodi se na preko 2,5 milijuna hektara, što su za preko milijun hektara veće površine u odnosu na one s početka devedesetih godina (tablica 7).

Interes za ovom kulturom još više je porastao utemeljenjem postupka dobivanja biodizelskoga goriva iz ulja uljane repice i izgradnje preradbenih kapaciteta u mnogim europskim državama (Austriji, Njemačkoj, Francuskoj, Češkoj i dr.). Procjenjuje se da je u Njemačkoj moguće biodizelom zamijeniti 5 % potrošnje mineralnog dizela, a da je ukupni potencijal zamjene dizela u Europskoj uniji čak 10 %. Pri postupku proizvodnje biodizela, kao nusproizvod ostaje sačma (1 000 kg sjemena uljane repice daje 380 l biodizel goriva i 620 kg sačme), koja se može koristiti u krmnim smjesama. Danas se u mnogim europskim državama planira sjetva uljane repice za potrebe prehrane ljudi i za kemijsku industriju (food and non-food rapeseed).

The creation and bringing into production of the new 00-cultivars of oilseed rape and the improved quality of oil and meal have enabled rapid expansion of this crop, particularly in Europe, where it has become the most important oil bearing plant. In France and Germany alone it is produced on over 2,5 million hectares, which is a million hectares more than that at the beginning of the nineties (Table 7).

The interest in this crop rose even more with the establishment of a process for obtaining biodiesel fuel from oilseed rape and the development of processing capacities in many European states (Austria, Germany, France, Czech Republic and elsewhere). It is estimated that in Germany it is possible to use biodiesel to replace 5 % of the fossil diesel oil used, and that the total potential for diesel replacement in European Union is as high as 10 %. In the production process for biodiesel, the meal is left as a by-product (1 000 kg of oilseed rape seeds yield 380 l of biodiesel and 620 kg of meal), which can be used in fodder mixtures. Today in many European countries it is planned to sow oilseed rape for human food and for the chemical industry (food and non-food rapeseed).

Tablica 7 – Trend površina pod uljanom repicom u najvećih proizvođača u svijetu [20]
Table 7 – Trend in areas devoted to oilseed rape in the world's major producers [20]

Zemlja / Country	Godina / Year				
	1985. (ha)	1990. (ha)	1995. (ha)	2000. (ha)	2005. (ha)
Svijet / World	14 756 000	17 610 000	23 816 000	25 833 000	26 950 000
Europa / Europe (25)	2 180 904	2 951 583	3 838 448	4 056 332	4 759 560
Australija / Australlia	74 154	72 886	376 558	1 459 000	1 080 000
Kanada / Canada	2 783 300	2 529 000	5 273 000	4 859 200	5 154 300
Kina / China	4 494 485	5 503 531	6 907 012	7 494 360	7 220 010
Indija / India	3 986 900	4 967 000	6 060 000	6 026 800	6 800 000
Francuska / France	473 700	679 600	864 000	1 186 255	1 211 000
Njemačka / Germany	409 605	722 393	973 886	1 078 010	1 345 300
Velika Britanija / UK	296 000	389 900	439 000	402 000	603 000
Poljska / Poland	467 021	500 374	606 382	434 768	544 490
SAD / USA	0	31 000	174 580	607 810	456 050

4 MOGUĆNOSTI PROIZVODNJE ULJANE REPICE I BIODIZELA U HRVATSKOJ

Uljanu repicu (Brassica napus L. ssp oleifera) izabrali su pioniri proizvodnje biodizela za eksperimente transesterifikacije zbog njene relativno niske cijene u odnosu na druge uljarice i dobre adaptibilnosti na različite uvjete. K tomu, repica je najraširenija uljana kultura u Europi, napose u Njemačkoj i Francuskoj koje su ujedno vodeće u proizvodnji biodizela.

Budući da ulje repice ima visok sadržaj mononezasićene oleinske kiseline i niski sadržaj obje zasićene i polinezasićene masne kiseline, ono je praktično idealna sirovina za proizvodnju biodizela s obzirom na karakteristike sagorijevanja, oksidativnu stabilnost i ponašanje na niskim temperaturama. Usto, vrlo je poželjna kultura u plodoredu jer svojim intenzivnim zakorjenjivanjem i prožimanjem tla poboljšava pedofizička svojstva tla, a budući da pokriva tlo gotovo 11 mjeseci smanjuje ispiranje hraniva.

Najznačajnije domaće kulture za proizvodnju biljnih ulja su suncokret, soja i uljana repica. U primorskom dijelu Hrvatske proizvodi se maslinovo ulje, dok je proizvodnja i potrošnja drugih ulja kao primjerice bućinog i ulja od klica kukuruza neznatna. Soja u odnosu na uljanu repicu i suncokret sadrži znatno više bjelančevina (oko 40 %), a manje ulja (oko 18 %), pa je pogodna za proizvodnju stočne hrane. U tu svrhu se koristi ili kao ekstrudirano sjeme ili u obliku sačme

4 OPPORTUNITIES FOR THE PRODUCTION OF OILSEED RAPE AND BIODIESEL IN CROATIA

Oilseed rape (Brassica napus L. ssp oleifera) was chosen by the pioneers of biodiesel production for transesterification experiments because of its relatively low cost as compared to other oil bearing plants and good adaptability to varying conditions. In addition, rape is the most widely distributed oil crop in Europe, particularly in France and Germany, which are the leaders in the field of biodiesel production.

Since oilseed rape has a large monounsaturated olein acid content and a low content of both saturated and polyunsaturated fatty acid, it is practically an ideal raw material for the production of biodiesel, because of its characteristics in combustion, its oxidative stability and behaviour at low temperatures. In addition, it is a very valuable crop in the rotation, for with its vigorous rooting and spread through the soil it improves the pedophysical properties of the soil and since it covers the ground for almost 11 months, it reduces nutrient run-off.

The most important Croatian crops for the production of vegetable oils are sunflower, soy and oilseed rape. In the coastal part of Croatia olive oil is also produced, while the production and consumption of other oils, such as from pumpkin and corn germ, are insignificant. Soy as compared with rape and sunflower contains much more protein (about 40 %) and less oil (about 18 %), and it is suitable for production for fodder. For this purpose it is used koja zaostaje nakon ekstrakcije ulja. Sojina sačma je glavna bjelančevinasta komponenta u krmnim smjesama, a kako njena proizvodnja nije dostatna za naše potrebe, soja se redovno i u velikim količinama uvozi. Sačma i pogače druge dvije uljarice može u smjesama zamjeniti soju, ali ni te količine nisu dostatne za potrebe stočarstva. Za sada se u nas malo napora ulaže za korištenje sojina sjemena u druge svrhe, prije svega za ljudsku prehranu, dok se u svijetu od soje proizvodi na stotine proizvoda.

Proizvodnja ulja i čvrstih biljnih masnoća iz ove tri uljarice osigurava osnovne prehrambene proizvode bez kojih je nezamisliva suvremena prehrana stanovništva, a bez sačmi i pogača iz njihova sjemena hranidba stoke. Osim toga, uljarice predstavljaju nužne kulture u plodoredu koje omogućuju optimalnu proizvodnju drugih ratarskih kultura.

Proizvodnju uljane repice najbolje je sagledati kroz strukturu zasijanih površina u Republici Hrvatskoj i udio uljarica u strukturi sjetve (slika 3). Prema podacima Državnog zavoda za statistiku u Hrvatskoj je 2003. godine zasijano 1 080 190 ha, a 379 810 ha (26 %) obradivih površina – oranica i vrtova je ostalo nezasijano. Od toga, u posjedu pravnih osoba (poduzeća i poljoprivrednih zadruga) ostalo je nezasijano 114 381 ha (30,1 %), a u posjedu obiteljskih poljoprivrednih gospodarstava 265 429 ha (69,9 %).

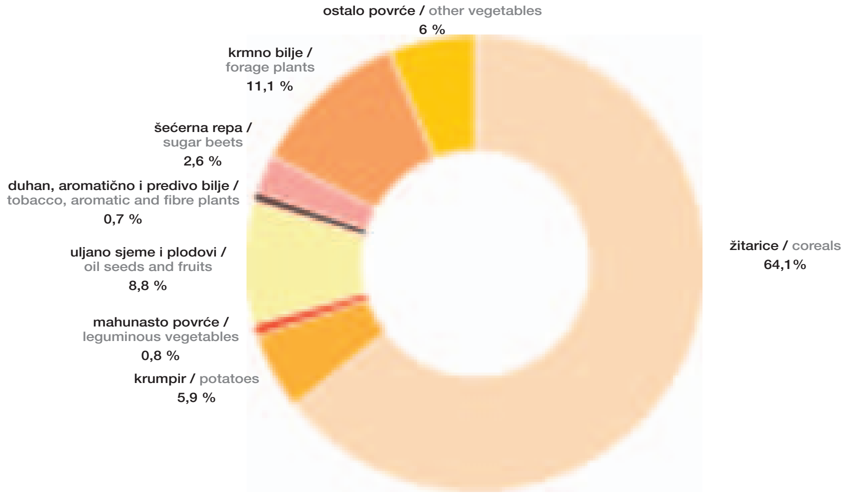
U strukturi sjetve najviše su zastupljene žitarice (64,1 %). Industrijskim biljem zasijano je 130 914 ha (12,1 %), a uljarice su bile zastupljene sa svega 8,7 %.

either as extruded seed or in the form of the meal that remains after the extraction of the oil. Soy meal is the main protein component in fodder mixes, and since the production of it is not enough for local needs, soy is regularly imported in large quantities. Meal and cake of the other two oil bearing plants can replace soy in mixes, but not even the quantities of them are enough for the needs of animal husbandry. For the moment, little effort is being made in this country to use soy beans for other purposes, above all for human food, while in the world at large hundreds of products are made from soy.

The production of oil and solid fats from these three oil bearing plants provides the basic food products without which contemporary diet of the population is unimaginable, and without the meal and cake from their seeds, the feeding of livestock. Apart from this, the oil bearing plants are necessary crops in the rotation, which enable optimum production of other arable crops.

The production of oilseed rape can be looked at via the structure of hectares sown in the Republic of Croatia, and the proportion of oil bearing plants in the structure of all crops sown (Figure 3). According to the data of the Croatian Bureau of Statistics, in Croatia all told 1 080 190 ha were sown, 379 810 ha (26 %) of cultivable land remained uncultivated (arable and horticultural land). Of this sum, 114 381 ha (30,1 %) of uncultivated land belonged to the corporate sector (firms and cooperatives) while 265 429 ha (69,9 %) of land belonging to small family farms were uncultivated.

In the structure of the sowing, cereals were most highly represented (64,1 %), while 130 914 ha were sown with industrial crops (12,1%) while oil-bearing crops accounted for no more than 8,7%.



Slika 3
Ukupno zasijane površine u Hrvatskoj u 2003. [21]
Figure 3
Total area of land sown in Croatia in 2003 [21]

Sva ekstenzivnost naše ratarske proizvodnje vidljiva je iz pregleda strukture sjetve na obiteljskim poljoprivrednim gospodarstvima. Na 78,4 % oraničnih površina obiteljskih poljoprivrednih gospodarstava zasijano je svega 8,8 % industrijskim kulturama, a uljaricama tek 5,1 %. Posebno je zapostavljena uljana repica, koja je na obiteljskim poljoprivrednim gospodarstvima bila zasijana na samo 4 430 ha (0,5 %). Dakle, individualni poljoprivredni proizvođači ne prihvaćaju uljanu repicu, iako je ona:

- kultura koja se biološki i organizacijski odlično uklapa u sustav ratarske proizvodnje (pšenica – uljana repica – kukuruz),
- relativno stabilnih i sigurnih prinosa koji u posljednja dva desetljeća gotovo da nisu padali ispod prosječno 2,0 t/ha, ni u klimatski ekstremno nepovoljnim godinama i uz vrlo nisku razinu primjenjene tehnologije,
- kultura koja daje kvalitetno ulje za humanu konzumaciju i po kriterijima najzahtjevnijih nutricionista, a uvođenjem 00-kultivara daje i sačmu bitno smanjenog sadržaja glukozinolata, koja se neškodljivo koristi u hranidbi većine vrsta i kategorija životinja [22].

Zastupljenost uljane repice, suncokreta i soje u strukturi biljne proizvodnje iznosila je 8,7 % od ukupno zasijanih površina 2003. godine (1 080 190 ha). Glavne tri uljarice uzgajale su se u Hrvatskoj te godine na ukupno 93 595 ha (tablica 8 i slika 4). U strukturi proizvodnje uljarica, uljana repica je sudjelovala s 15 524 ha (16,61 %), suncokret s 28 211 ha (30,0 %) i soja s 49 860 ha (53,4 %). Jedan dio soje gospodarski subjekti zadržavaju za vlastite potrebe (tržnost se kreće od 40 % do 80 % ovisno o godini) te su ukupno otkupljene količine uljarica za preradu manje od ukupno proizvedenih količina. Općenito se može reći da je proizvodnja uljarica u Hrvatskoj relativno niska i sa izrazitim variranjem i površina i prosječnih prinosa po godinama.

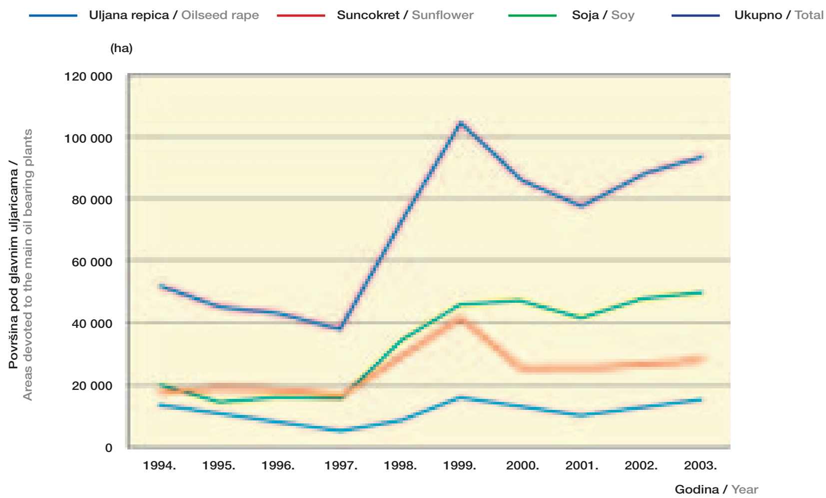
Just how extensive Croatian arable farming is can be seen from the survey of the structure of the crops on small family farms. On the 78,4 % of the total ploughland belonging to family farms, no more than 8,8 % industrial crops were planted, and only 5,1 % oil bearing plants. Oilseed rape was particularly neglected, and was sown on family farms on only 4 430 ha, or 0,5 %. Thus the individuals small farmers have not accepted oilseed rape, although it:

- is a crop that fits in excellently, biologically and in organisational terms, to the system of arable production (in a rotation consisting of wheat, oilseed rape and maize),
- has quite stable and certain yields, which in the last two decades almost have not fallen below an average of 2,0 t/ha, not even in climatically extremely unfavourable years, and with a very low level of technology applied,
- is a crop that gives a high quality oil for human consumption even according to the criteria of the most demanding nutritionists, and with the introduction of the 00-cultivar gives a meal with a highly reduced content of glucosynolate, which can be used without any downsides in the food of most species and categories of animals [22].

All told, oilseed rape, sunflower and soy amounted to 8,7% of the structure of plant production, from the 1 080 190 ha of land sown in 2003. These three oil bearing plants were cultivated in Croatia in that year on a total of 93 595 ha (Table 8 and Figure 4). In the structure of the production of oil bearing plants, oilseed rape accounted for 15 524 ha (16,61 %), sunflower for 28 211 ha (30,0 %) and soy for 49 860 ha (53,4 %). Some of the soy was kept by the farmers for their own needs (about 40 % to 80 % of the crop is placed on the market depending on the given year) and quantities of oil bearing plants bought for processing are less than the quantities totally produced. In general it can be said that the production of oil bearing plants in Croatia is quite low, with marked variations in areas and in average yields per year.

Tablica 8 – Površine pod glavnim uljaricama u Hrvatskoj [21]
Table 8 – Areas devoted to the main oil bearing plants in Croatia [21]

	Površine pod glavnim uljaricama / Areas devoted to the main oil bearing plants (ha)									
	1994.	1995.	1996.	1997.	1998.	1999.	2000.	2001.	2002.	2003.
Uljana repica / Oilseed rape	13 889	10 982	7 651	5 356	8 949	16 234	12 886	10 319	13 041	15 524
Suncokret / Sunflower	17 871	19 385	18 849	16 946	28 642	41 996	25 715	25 336	26 835	28 211
Soja / Soy	20 435	15 018	16 423	16 030	34 015	46 336	47 484	41 621	47 897	49 860
Ukupno / Total	52 195	45 385	42 923	38 332	71 606	104 566	86 085	77 276	87 773	93 595



Slika 4
Dinamika površina pod glavnim uljaricama u Hrvatskoj
Figure 4
Dynamics of areas devoted to the main oil bearing plants in Croatia

Tablica 9 – Prosječni prinosi uljarica u Hrvatskoj [21]
Table 9 – Average yields of oil bearing plants in Croatia [21]

	Prosječni prinosi uljarica / Average yields of oil bearing plants (t/ha)									
	1994.	1995.	1996.	1997.	1998.	1999.	2000.	2001.	2002.	2003.
Uljana repica / Oilseed rape	2,04	2,23	1,52	2,09	2,45	–	2,28	2,18	1,96	1,84
Suncokret / Sunflower	1,48	1,91	1,51	2,13	2,17	1,72	2,10	1,70	2,35	2,45
Soja / Soy	2,16	2,29	2,19	2,46	2,28	2,50	1,38	2,21	2,70	1,66

Prosječni prinosi uljane repice od 2,2 do 2,5 t/ha su vrlo niski. Ovo je razumljivo kada se zna da se repica najčešće uzgaja na najlošijim, neuređenim tlima, loših vodo-zračnih svojstava i s izraženim depresijama u kojima površinska voda stagnira, što dovodi do redukcije sklopa i stvaranja plješina u usjevu. Zastarjela i neadekvatna mehanizacija, niska razina primijenjene tehnologije, manjkava zaštita usjeva i nedovoljna educiranost obiteljskih gospodarstava, daljnji su važni razlozi malih površina pod repicom i niskih prosječnih prinosa, odnosno ukupne proizvodnje.

Glavnina proizvodnje uljane repice odvija se na proizvodnom području Osječko-baranjske županije.

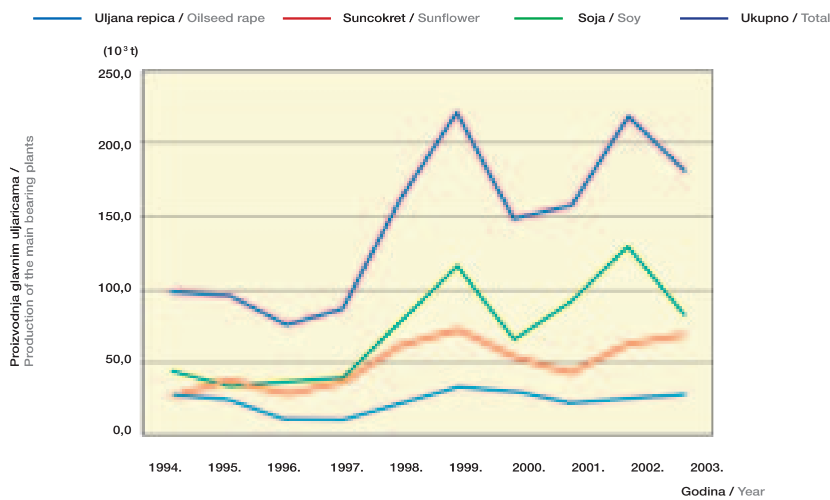
Average yields of oilseed rape of 2,2 to 2,5 t/ha are extremely low. This is understandable when one takes into consideration that rape is often grown on the worst and least improved soils, with poor water and air properties and with marked depressions in which the surface water tends to stagnate, which leads to a reduction of plant density and gap formation. Obsolescent and inappropriate machinery, low level of technology applied, poor pest control and insufficient education of family farms are further very important reasons for the small areas devoted to rape and to the small average yields, that is, of total production.

Most of the production of oilseed rape takes place in the area of the Osiječko-baranjska County,

Tablica 10 – Proizvodnja glavnih uljarica u Hrvatskoj [21]
Table 10 – Production of the main oil-bearing plants in Croatia [21]

	Proizvodnja glavnih uljarica / Production of the main oil-bearing plants (10^3 t)									
	1994.	1995.	1996.	1997.	1998.	1999.	2000.	2001.	2002.	2003.
Uljana repica / Oilseed rape	28,3	24,5	11,7	11,2	22,0	32,6	29,4	22,5	25,6	28,6
Suncokret / Sunflower	26,5	37,1	28,5	36,1	62,2	72,4	54,0	43,0	63,0	69,3
Soja / Soy	44,1	34,3	35,9	39,5	77,5	115,9	65,3	91,9	129,5	82,6
Ukupno / Total	98,9	95,9	76,1	86,8	161,7	220,9	148,7	157,4	218,1	180,5

Slika 5
Proizvodnja glavnih uljarica u Hrvatskoj
Figure 5
Production of the main oil bearing plants in Croatia



Ukupna proizvodnja uljane repice u posljednjih 10 godina u Republici Hrvatskoj najčešće se kretala od 11 000 t do 24 000 t, a tek je 1999. godine dostigla predratnu proizvodnju od preko 30 000 t sirovine (tablica 10 i slika 5). Nedovoljan interes i premalo sudjelovanje uljane repice u strukturi sjetve na našim oranicama posljedica su mjera ekonomske politike u području agrara, posebno politike cijena, te nedovoljne zainteresiranosti prerađivačke industrije.

Za podmirenje sadašnjih potreba potrošnje bilo bi potrebno osigurati godišnje 73 000 t sirovog ulja i to:

- sojina ulja 25 000 t ili 150 000 t sojina sjemena,
- ulja uljane repice 8 000 t ili 20 000 t sjemena uljane repice,
- suncokretova ulja 40 000 t ili 100 000 t suncokretova sjemena.

Procjenjuje se da su potrebe stočarstva Hrvatske oko 200 000 t sačmi godišnje i to:

- 160 000 t (do190 000 t) sojine sačme,

Total production of rape in the last 10 years in the Republic of Croatia has mostly ranged between 11 000 and 24 000 tons, and it was only in 1999 that the pre-war production of over 30 000 t of raw material was attained once again (Table 10 and Figure 5). Lack of interest and the insufficient proportion of oilseed rape in the structure of the crops in the ploughland of this country are the results of measures of economic policy in the agrarian domain, particularly the price policy, and the insufficient interest expressed by the processing industry.

To cover current needs for consumption it is necessary to provide annually 73 000 t of raw oil, as follows:

- soy oil, 25 000 t or 150 000 t of soy beans,
- oilseed rape oil, 8 000 t or 20 000 t of rapeseeds,
- sunflower soil, 40 000 t or 100 000 t of sunflower seeds.

It is estimated that the Croatian animal husbandry industry needs about 200 000 t of meal a year, as follows:

– 30 000 t suncokretove sačme,
– 10 000 t sačme uljane repice.

Uzmu li se u obzir postojeći zemljišni resursi, naše potrebe za sirovim uljem (i sačmom) za prehranu zadovoljili bi zasijavanjem 120 000 ha do 130 000 ha s uljaricama, tj. oko 12 % obradivih površina. Zbog svoje međusobne i samo-inkopatibilnosti u plodoredu (zajedničke bolesti) uljarice se mogu vratiti na isto tlo tek nakon 4 do 5 godina, što limitira njihovu proizvodnju na maksimalno 230 000 ha godišnje.

Daljnje povećanje površina pod uljanom repicom za neprehrambeni lanac (biodizel) moguće je, osim značajnijim povećanjem površina u postojećem uskom plodoredu, i rekultivacijom zapuštenih i neobrađivanih površina, čime bi se osigurale nove zasijane površine u pravilnom plodoredu od 60 000 do 70 000 ha, odnosno vlastita proizvodnja biodizelskoga goriva od 60 000 t do 70 000 t. Realna mogućnost povećanja ukupne proizvodnje repice je i povećanjem prosječnih prinosa na 3,0 do 3,5 t/ha, za što postoje i agroekološki i tehnološki uvjeti. Time bi se na spomenutim novozasijanim površinama repicom povećala proizvodnja za preko 30 %, odnosno osigurala sirovina za proizvodnju 90 000 t do 100 000 t biodizela. Za ostvarenje ovih ciljeva potrebno je [23]:

– mjerama ekonomske politike u agraru, napose cijenama i novčanim poticajima stimulirati proizvođače na značajnije uključivanje ove kulture u strukturu sjetve,
– uvoditi i primijeniti suvremenu tehnologiju proizvodnje repice na svim zasijanim površinama (uvođenje hibrida i sortne tehnologije, optimalna ishrana i zaštita usjeva), kako bi se ostvarili realno mogući prosječni prinosi iznad 3,0 t/ha,
– zamijeniti zastarjelu mehanizaciju novim suvremenim strojevima za obradu i pripremu tla, sjetvu i njegu usjeva, napose novih kombajna kojima je moguća brza i pravovremena žetva i kojima se gubici u žetvi smanjuju na minimum,
– kontinuirano educirati proizvođače, napose obiteljska gospodarstva koja nemaju proizvodnih iskustava s ovom kulturom o suvremenim agrotehničkim mjerama.

– 160 000 t (and up to 190 000 t) of soy meal,
– 30 000 t of sunflower meal,
– 10 000 t of oilseed rape meal.

If the existing land resources are taken into consideration our needs for raw oil (and meal) for food would be met by the sowing of 120 000 ha to 130 000 ha with oil bearing plants, i.e., about 12 % of totally cultivable land. Because of their reciprocal and self-incompatibility in the rotation (common diseases) oil bearing plants can be put back on the soil only after 4 to 5 years, which limits their production to a maximum of 230 000 ha p.a.

Further increase of land devoted to oilseed rape for the non-food chain (biodiesel) is possible, apart from a major increase in the land in the existing narrow rotation system, also by recultivation of abandoned and uncultivated land, which would provide newly sown land in a regular rotation of 60 000 to 70 000 ha, that is, a home production of biodiesel fuel of from 60 000 t/year to 70 000 t/ year. The realistic opportunity for increasing the overall production of rape is by increasing average yields to 3,0 t/ha to 3,5 t/ha, which is completely possible given the agroecological and technological conditions. Thus production on the mentioned areas newly sown with rape would increase production to over 30%, that is, it would provide the raw materials for the production of 90 000 t to 100 000 t of biodiesel. In order to attain these goals, it is necessary to:

– incentivise the producers, by economic policy measures in agriculture, particularly with prices and monetary incentives, to bring this crop much more into the structure of their production,
– introduce and applied contemporary technology of the production of rape on all areas sown (introduction of hybrids and variety technology, optimum nutrients and pest control for the crops), so as to ensure the realistically possible average yields of over 3,0 t/ha,
– replace the obsolescent mechanisation with new and contemporary machinery for the tillage of the soil, sowing and crop care, especially with new combine harvesters with which a rapid and correctly-timed harvest is possible, with losses in the harvesting reduced to the minimum,
– continuously educate the producers, particularly small family farmers, who have no production experience with this crop and with contemporary agricultural and technical measures.

5 ZAKLJUČCI

Biodizel je ekološki prihvatljivo alternativno gorivo za dizel motore koje se dobiva transesterifikacijom iz biljnih ulja i životinjskih masti kao obnovljivih resursa. Danas su poznata brojna pozitivna svojstva koja karakteriziraju gorivo iz biljnih ulja [24]:

– biološki ciklus ugljika je zatvoren jer uljane biljke tijekom porasta usvajaju iz zraka ukupni ugljik koji se oslobađa u formi CO_2 pri sagorijevanju goriva,
– bilanca energije goriva iz biljnih ulja je pozitivna, što znači da je Sunčeva energija uskladištena u biljnom ulju značajno veća od one upotrijebljene za njegovu proizvodnju,
– gorivo iz biljnih ulja nedvojbeno manje opterećuje okoliš u odnosu na mineralno dizelsko gorivo jer se njegovim sagorijevanjem oslobađa manje klimadjelotvornih škodljivih tvari (smanjena emisija štetnih ispušnih plinova za preko 50 %, CO_2 – neutralno, ne sadrši sumpor, fosfor i olovo, značajno smanjena količina čađi, smanjena količina nesagorjelih ugljikovodika, CO i krutih čestica). K tomu je značajno manje toksično i ima bolju biorazgradivost u vodi i tlu, te izrazito bolja maziva svojstva.

Kao sirovine za proizvodnju biodizela mogu se upotrijebiti i korištena kuhinjska ulja, ali su ona dostupna u manjim količinama. Glavne sirovine su ulja uljanih kultura iz agrarne proizvodnje, napose ulje uljane repice iz kojega se danas proizvodi preko 85 % ukupne svjetske proizvodnje biodizela.

U Hrvatskoj proizvodnja uljarica i ulja nije dostatna niti za potrebe prehrane stanovništva i stočarstva, zbog njihovog niskog udjela u strukturi sjetve, niskih prosječnih prinosa, nezainteresiranosti prerađivačke industrije, kao i obiteljskih gospodarstava, zbog slabih ekonomskih učinaka u njihovoj proizvodnji. Značajnije povećanje proizvodnje uljarica i za potrebe neprehrambenog lanca (proizvodnju biodizela) moguće je povećanjem površina pod ovim kulturama na preko 200 000 ha, što omogućavaju zemljišni resursi i dopuštaju zahtjevi optimalnog plodoreda, te značajnijim povećanjem njihovih prosječnih prinosa (> 30 %) uvođenjem suvremene tehnologije. Tako bi se osigurale dostatne količine ulja (i sačme) za potrebe prehrane i stočarstva, te sirovina za 90 000 do 100 000 tona biodizela.

5 CONCLUSIONS

Biodiesel is an ecologically acceptable alternative fuel for diesel engines, which is obtained by transesterification from plant oils and animal fats, renewable resources. Today numerous positive properties that characterise fuel from plant oils are known [24]:

– the biological carbon cycle is closed because during their growth oil-bearing plants capture from the air total carbon that is liberated in the form of CO_2 during the combustion of the fuel,
– the net energy balance of fuels from vegetable oils is positive, which means that the solar energy stored in plant oil is considerably larger than that which is needed for its production,
– fuel from vegetable oils has an undeniably much smaller burden on the environment than fossil diesel because its combustion creates fewer climatically harmful substances (reduced emission of harmful exhaust gases by over 50 %, CO_2 – neutral, does not contain sulphur, phosphorous and lead, considerably reduced quantity of soot, reduced quantity of uncombusted hydrocarbons, CO and solid particles). In addition, it is much less toxic and has better biodegradability in water and the soil, and much better lubricating properties.

As raw materials for the production of biodiesel, cooking oils can be used, but these are available only in fairly small quantities. The main raw materials are the oils of oil crops from agricultural production, particularly the oil of oilseed rape, from which over 85 % of world production of biodiesel is derived.

In Croatia, the production of oil bearing plants and oil is not adequate even for the needs of the population and the animal husbandry industry, because they account for a small percentage of crops, of the low average yields, the lack of interest of the processing industry and small family farms, because the low economic effects from their production. Any more significant increase in the production of oil bearing plants for the needs of the non-food chain as well (for the production of biodiesel) can be attained by an increase in the areas devoted to these crops, on over 200 000 ha, which is made feasible by the resources in land and allowed by the requirements of the optimum rotation, and by an important increase in average yields (>30 %) by the introduction of contemporary technology. This would ensure sufficient quantities of oil and meal for the needs of food and animal husbandry, as well as raw materials for 90 000 to 100 000 tons of biodiesel.

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PRVIH POLA STOLJEĆA KOMERCIJALNIH NUKLEARNIH ELEKTRANA

THE FIRST HALF CENTURY OF COMMERCIAL NUCLEAR POWER PLANTS

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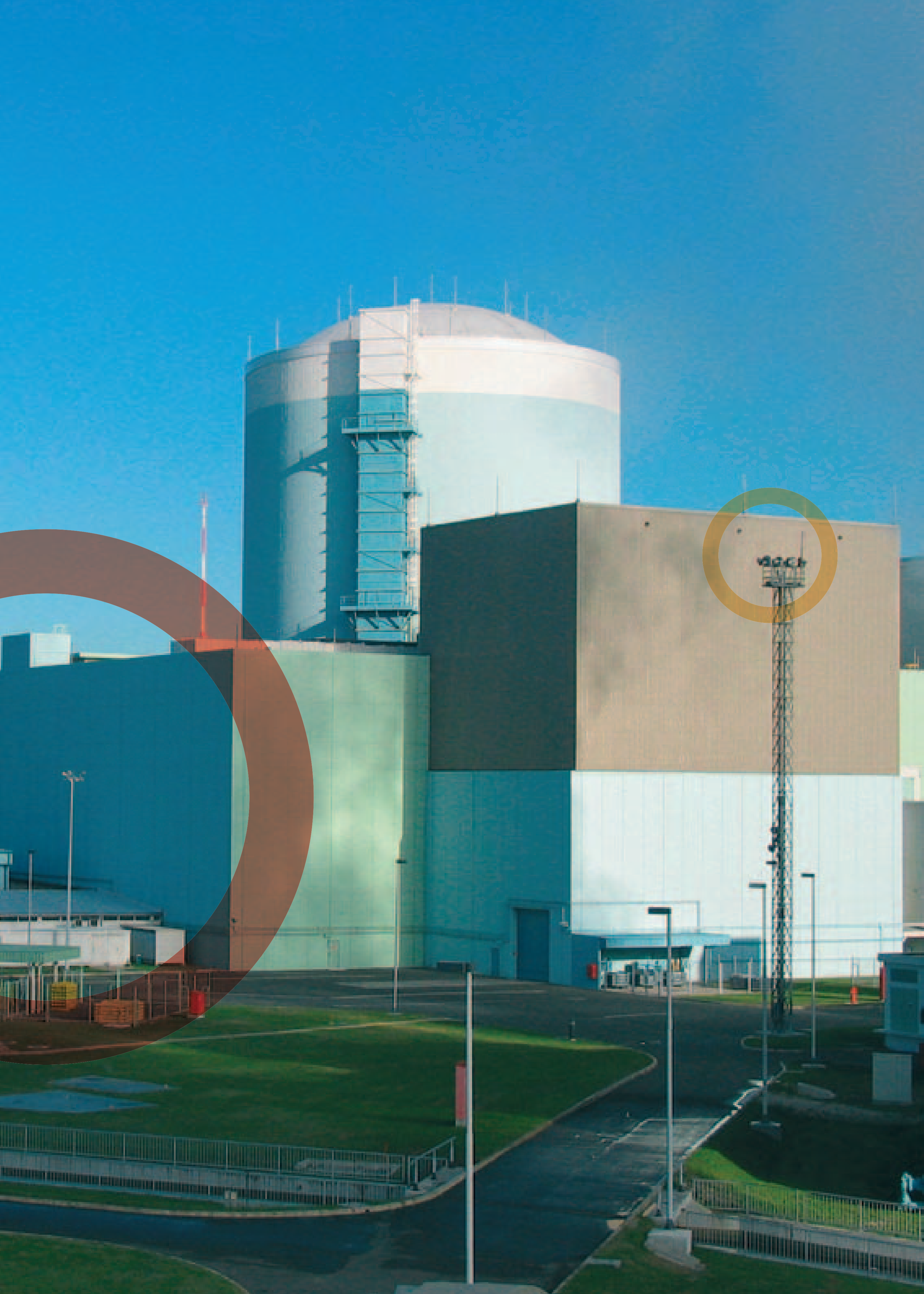
Nakon pet desetljeća postojanja nuklearna energetska industrija je sazrijela, a njen udio u opskrbi električnom energijom na svjetskoj razini je 16 %. Članak daje pregled polustoljetnog razvoja nuklearne tehnologije s naglaskom na miroljubivu primjenu. Okolnosti razvoja i kasnijeg pada korištenja nuklearne energije analiziraju se s više aspekata. Opisuju se karakteristike četiri generacije nuklearnih reaktora, dostatnost rezervi urana kao nuklearnog goriva, problematika zbrinjavanja radioaktivnog otpada te pitanja sigurnosti i ekonomičnosti pogona i proliferacije nuklearnih materijala. Analiziraju se glavne prednosti i nedostatci nuklearne energije u svjetlu najava o značajnom proširenju nuklearnih kapaciteta

After five decades that the nuclear power industry has been in existence, it has matured and its share in the world energy supply is 16 %.The article provides a review of the development of nuclear technology during the past half century, with emphasis upon peaceful applications. The circumstances of the development and subsequent decline in the demand for electricity from nuclear power plants are analyzed from several aspects. The characteristics of the four generations of nuclear reactors, the sufficiency of the uranium reserves and nuclear fuel, the problem of the disposal of radioactive wastes, the safety and cost-effectiveness of nuclear power plants, and the proliferation of nuclear materials are also discussed. The chief advantages and disadvantages of nuclear energy are analyzed in light of statements on the significant expansion of nuclear capacities.

Ključne riječi: nuklearna sigurnost, nuklearne elektrane, nuklearno gorivo, proliferacija, radioaktivni otpad
Key words: nuclear fuel, nuclear power plants, nuclear safety, proliferation, radioactive waste



1 UVOD

Kroz gotovo četiri desetljeća nizala su se razna otkrića vezana uz ionizirajuće zračenje i strukturu tvari, da bi 1939. Otto Hahn i Fritz Strassman u Berlinu proveli eksperiment u kojem su uz pomoć Lise Meitner otkrili fisiju – cijepanje težih jezgri uz oslobađanje velikih količina energije. Temeljem tih istraživanja, tri godine kasnije Enrico Fermi konstruirao je prvi nuklearni reaktor sa samoodržavajućom fisijom. Svijet je ušao u atomsko doba.

Kroz idućih pet i pol desetljeća nuklearna tehnologija doživjela je značajan razvoj i različite primjene. U tom je razdoblju prolazila kroz razdoblja velikih očekivanja, ali i velikih razočaranja. Danas ponovno izgleda da nuklearna tehnologija može ponuditi odgovore na energetske probleme.

U proteklim godinama pokazale su se sve prednosti, ali i svi nedostaci ove tenologije, a o njoj se i danas, kao o rijetko kojoj temi, još uvijek vode brojne, žučne polemike

U ovom će se radu biti dan pregled najvažnijih aspekata razvoja nuklearne industrije i okolnosti u kojima se on zbivao.

1 INTRODUCTION

Over a period of nearly four decades, there were various discoveries connected with ionizing radiation and the structure of matter. In 1939, Otto Hahn and Fritz Strassman, with the help of Lise Meitner, conducted an experiment in Berlin through which they discovered fission – the splitting of heavy nuclei with the liberation of large amounts of energy. Based upon these investigations, three years later Enrico Fermi constructed the first nuclear reactor with self-sustaining fission. The world had entered the Atomic Age.

During the subsequent five and a half decades, nuclear technology underwent significant development and various applications, with great expectations and great disappointments. Today it again appears that nuclear technology can provide answers to energy problems.

During the past years, all the advantages and shortcomings of this technology have become apparent, although polemics on the subject continue.

This article will review the most significant aspects in the development of the nuclear industry and the surrounding circumstances.

2 DRUŠTVENE I POLITIČKE OKOLNOSTI RAZVOJA

Razvoj nuklearne tehnologije od samih početaka pobudio je velik interes, kako znanstvenih, tako i vojnih i političkih krugova. S obzirom na ratno vrijeme u kojem se odvijao, nova su otkrića prvu primjenu dobila u atomskoj bombi. Nažalost, tragedije Hiroshime i Nagasakija već 60 godina prate razvoj miroljubive primjene nuklearne energije.

Razvoj nuklearne energetike i nuklearne industrije u poslijeratnom razdoblju bio je i dalje obilježen vojnom primjenom nuklearne energije. Tako su u poslijeratnom razdoblju mnoge države razvijale nuklearne energetske programe samo kao komplement vojnim programima.

Prekretnicu u korištenju nuklearne energije iz vojnih u energetske svrhe označio je govor tadašnjeg predsjednika SAD-a, D. Eisenhowera, koji je 1953. godine pred Ujedinjenim narodima održao govor Atomi za mir. Tri godine nakon toga prva komercijalna nuklearna elektrana Calder Hall počela je proizvoditi nuklearnu energiju. Privatne tvrtke su uvidjele mogućnosti nove tehnologije te su se počele sve više uključivati u razvoj

2 THE SOCIAL AND POLITICAL CIRCUMSTANCES OF DEVELOPMENT

From the very beginning, the development of nuclear technology aroused great interest among scientific, military and political circles. Since this development occurred during wartime, the new discoveries were initially applied to the atomic bomb. Unfortunately, the tragedies of Hiroshima and Nagasaki have cast a shadow on the development of peaceful applications of nuclear energy for the past 60 years.

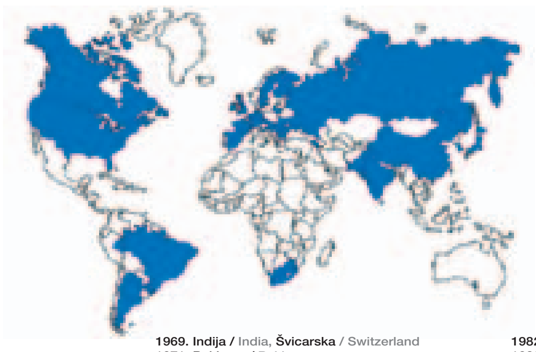
The development of nuclear energetics and the nuclear industry following the Second World War was further characterized by the military applications of nuclear energy. Thus, many countries during the postwar period only developed nuclear energy programs as a complement to their military programs.

The turning point in the use of nuclear energy from military to energy purposes was a speech by United States President Dwight D. Eisenhower in 1953 before the United Nations, in which he spoke about atoms for peace. Three years later, the first commercial nuclear power plant, Calder Hall, began to produce nuclear energy. Private companies saw opportunities in the new technology and began komercijalnih nuklearnih reaktora. Očekivanja od nuklearne industrije bila su velika, a poslijeratno raspoloženje javnosti odražavalo je vjeru u mogućnosti znanosti i novih tehnologija.

Predstavnici nuklearne industrije su, i sami poneseni spektakularnim rastom, mnogo obećavali. Tako je Lewis L. Strauss, predsjedavajući Komisije za atomsku energiju 1954. godine izjavio da je realno očekivati da će naši potomci uživati u električnoj energiji toliko jeftinoj da je se neće isplatiti naplaćivati.

to be increasingly involved in the development of commercial nuclear reactors. The expectations from the nuclear industry were great and the postwar public mood was positive toward the possibilities of science and new technologies.

Representatives of the nuclear industry, themselves carried away by the spectacular growth, promised much. Thus, Lewis L. Strauss, chairman the Atomic Energy Commission, announced in the year 1954 that it was realistic to expect that our descendents would enjoy such inexpensive electricity that it would be "too cheap to meter."



1954. Rusija / Russia
1956. Velika Britanija / UK
1957. SAD / United States
1958. Francuska / France
1961. Njemačka / Germany
1962. Belgija / Belgium, Kanada / Canada
1963. Italija* / Italy, Japan / Japan
1964. Švedska / Sweden
1968. Nizozemska / Netherland, Španjolska / Spain
1969. Indija / India, Švicarska / Switzerland
1971. Pakistan / Pakistan
1972. Slovačka / Slovakia
1973. Kazahstan* / Kazakhstan
1974. Argentina / Argentina, Bugarska / Bulgaria
1975. Finska / Finland
1976. Armenija / Armenia
1977. Koreja / Korea, Ukrajina / Ukraina
1981. Slovenija / Slovenia
1982. Brazil / Brasil, Mađarska / Hungary
1983. Litva / Lithuania
1984. JAR / RSA
1985. Češka / Chech Republic
1989. Meksiko / Mexico
1991. Kina / China
1996. Rumunjska / Romania

*Italija i Kazahstan zatvorili su svoje nuklearne elektrane 1990. i 1999. godine / Italy and Kazakhstan closed their nuslear power plants in 1990 and 1999

Slika 1
Zemlje koje danas imaju komercijalne nuklearne reaktore i vrijeme puštanja u pogon prvih komercijalnih nuklearnih postrojenja [1].
Figure 1
Countries with commercial nuclear reactors today and the years when the first commercial nuclear power plants went on line [1]

S druge strane je pokroviteljstvo države i paralelno razvijanje vojnih programa u značajnom dijelu javnosti produbljivao animozitet prema nuklearnoj energiji. U nadolazećim godinama taj će uteg postati pretežak za nuklearnu energetsku industriju.

Veliki poticaj razvoju nuklearne industrije dala je i naftna kriza 1973. godine (slika 2), te kasnije krize u Iranu koje su uzrokovale skokovite poraste cijene nafte, te natjerale države da energetsku neovisnost postave kao jedan od prioriteta energetske politike.

From the other side, state sponsorship and the parallel development of military programs significantly heightened public animosity toward nuclear energy. In coming years, this burden would become too heavy for the nuclear power industry.

Great incentive to the development of the nuclear power industry was provided by the oil crisis of 1973 (Figure 2), and later the crisis in Iran that caused great increases in oil prices and forced countries to place energy independence among their priorities in energy policy.

Slika 2
Povijesno kretanje cijena nafte [2]
Figure 2
Historical trends in oil prices [2]

U proljeće 1986. godine u ukrajinskoj elektrani Černobilj došlo je do zloglasne nesreće na reaktoru IV. Tridesetak osoba, uglavnom vatrogasci koji su sanirali požar na reaktoru izgubilo je živote neposredno nakon nesreće, čitava okolna naselja s ukupno 350 000 stanovnika su evakuirana i preseljena, a procjenjuje se da je do danas od posljedica te nesreće živote moglo izgubiti do 4 000 ljudi [3]. Taj je događaj bio prekretnica daljnjeg razvoja nuklearne industrije. Za percepciju javnosti na Zapadu nije mnogo značilo uvjeravanje nuklearnih pobornika da u zapadnim elektranama takva nesreća nije moguća, prvenstveno zbog značajnih razlika u dizajnu same elektrane. Černobilska katastrofa postala je gotovo sinonim za nuklearnu energiju. Uz to je zbrinjavanje radioaktivnog otpada nagomilanog iz desetljeća rada elektrana javnost prepoznala kao još uvijek neriješen problem. U to vrijeme nuklearna industrija nije imala spreman uvjerljiv i adekvatan odgovor na pitanja sigurnosti i zbrinjavanja otpada.

Nakon katastrofe u Černobilju nuklearke postaju neprijatelj broj jedan za gotovo sve organizacije zelenih u svijetu. Biti protiv bilo je *in*. To je prisililo vlade zapadnih zemalja da počnu odustajati od daljnjeg razvoja svojih nuklearnih programa, pa čak i napuštati nuklearnu tehnologiju kao izvor električne energije. Tako je Austrija 1978. godine donijela zakon kojim se zabranjuje uporaba nuklearne energije za proizvodnju električne energije i odustala od stavljanja u pogon potpuno dovršene elektrane Zwentendorf. Italija je 1990. godine prije isteka životnog vijeka trajno obustavila rad i posljednjeg od svoja četiri nuklearna reaktora, dok su Njemačka i Švedska odlučile postupno smanjiti broj svojih nuklearnih reaktora.

In the spring of 1986, an accident occurred in Reactor No. 4 at the Ukrainian nuclear power plant in Chernobyl. Approximately thirty persons, mainly firefighters and rescue workers who sanified the fire in the reactor under control, lost their lives directly after the accident. The entire surrounding community of 350 000 inhabitants was evacuated and relocated, and it is estimated that up to 4 000 persons could have lost their lives to date from the consequences of this accident [3]. This event was the turning point in the further development of the nuclear industry. In the perception of the Western public, the assurances of nuclear supporters that such an accident would be impossible in Western nuclear power plants, first of all due to the significant differences in the designs of the power plants themselves, did not matter much. The Chernobyl catastrophe became practically synonymous with nuclear energy. Moreover, the disposal of radioactive wastes that accumulate after decades of nuclear power plant operation has been recognized by public opinion as a problem that remains unsolved. At the time, the nuclear industry did not have a convincing and adequate response prepared to the questions of safety and waste disposal.

Following the Chernobyl catastrophe, nuclear power plants became Public Enemy No. 1 for all the green organizations in the world. To be against nuclear power was *in*. This forced the governments of Western countries to begin to refrain from the further development of their nuclear programs, and even to abandon nuclear technology as a source of electricity. Thus, in 1978 a law was adopted in Austria which prohibited the use of nuclear energy for the production of electricity and prevented the completed Zwentendorf Nuclear Power Plant from going on line. In 1990, Italy terminated the operations of the last of its four nuclear reactors before its working lifetime had expired, while

Prirodni plin postao je najpoželjniji energent budućnosti u mnogim državama. Tako je udio prirodnog plina u periodu od 1992. do 2003. godine u europskoj energetskoj bilanci porastao sa 6 % na 18 %, tj. njegova potrošnja za proizvodnju električne energije povećana je više od 3,5 puta [4].

Efekt staklenika uzrokovan antropogenim emisijama u atmosferu identificiran je kao prioritet u globalnim naporima za očuvanje okoliša i približavanje konceptu održivog razvoja. Obovljivi izvori energije nudili su se kao rješenje, kako za pitanje zaštite okoliša, tako i za pitanje sigurnosti opskrbe. Kao nužnost, prepoznate su i mjere štednje energije i energetske efikasnosti.

Danas, dva desetljeća od Černobilja i pet desetljeća od Calder Halla, situacija se ponovno mijenja. Velik porast potražnje za prirodnim plinom u Europi uzrokovao je probleme u opskrbi i snažan rast njegove cijene, a prošlogodišnje redukcije u isporuci ruskog plina pomogle su mnogim europskim državama spoznati posljedice pretjerane energetske ovisnosti. S obzirom na predviđeni porast potrošnje električne energije, očekuje se da će do 2012. godine u Europi biti potrebno izgraditi najmanje 65 GW novih kapaciteta. Sudeći prema najavama, taj kapacitet će većim dijelom biti plinske elektrane što znači da će godišnji uvoz plina u Europu sa sadašnjih 230 milijardi kubnih metara do 2012. godine morati narasti na najmanje 465 milijardi kubnih metara [4].

Unatoč velikim ulaganjima u obnovljive izvore energije (biomasa, hidroenergija, energija vjetra, Sunčeva energija i geotermalna energija) njihov udio u zadovoljenju ukupnih energetskih potreba je još uvijek marginalan, tek oko 6 % na razini Europske unije, koja je predvodnik u korištenju obnovljivih izvora. Posljedice efekta staklenika prepoznate su kao stvaran i vrlo aktualan problem te izgleda da i zeleni polako prihvaćaju da obnovljivi izvori i energetska efikasnost, iako korisni, ne mogu pružiti rješenje na globalnoj razini, niti ga mogu pružiti dovoljno brzo, naročito s obzirom na golem porast potražnje za energijom koju bilježe ekonomije zemalja u razvoju, posebice Kine i Indije (slika 3).

Germany and Sweden decided to reduce the numbers of their nuclear reactors gradually.

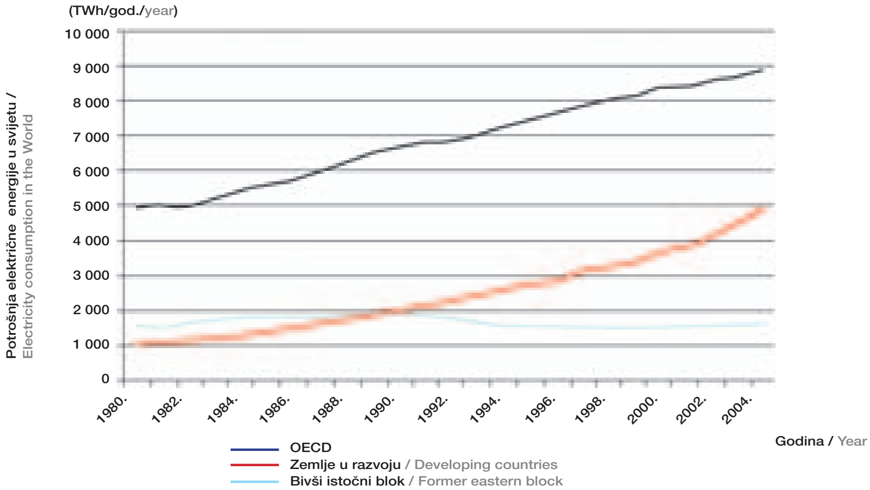
Natural gas became the most desirable energy source of the future in many countries. During the period from 1992 to 2003, the percentage of natural gas in the European energy balance rose from 6 % to 18 %, i.e. its consumption for the production of electricity rose over 3,5 times [4].

The greenhouse effect caused by anthropogenic emissions into the atmosphere was identified as a priority in global efforts for protecting the environment and approaching the concept of sustainable development. Renewable energy sources were offered as solutions for the questions of environmental protection and reliable supply. Energy saving and energy efficiency measures were recognized as necessities.

Today, two decades after Chernobyl and five decades after Calder Hall, the situation is changing again. Tremendous growth in the European demand for natural gas has caused supply problems and considerable price increases. The 2006 cutbacks in the delivery of Russian gas helped many European countries recognize the consequences of excessive energy dependence. Due to expected growth in electricity consumption, it is anticipated that Europe will need at least 65 GW of new capacity by 2012. Judging from announcements, this capacity will be met by gas power plants for the most part, which means that the annual gas imports to Europe, presently 230 billion cubic meters, will have to increase to a minimum of 465 billion cubic meters by 2012 [4].

Despite great investments in renewable energy sources (biomass, hydro, wind, solar and geothermal), their share in meeting the total energy requirements is still marginal, only approximately 6 % at the level of the European Union, which is the leader regarding the question of renewable energy sources. The consequences of the greenhouse effect are recognized as real and very current problems. It appears that the Greens are slowly accepting that renewable sources and energy efficiency, although useful, cannot provide a solution on the global level and cannot provide it quickly enough, especially taking into account the tremendous increase in energy demand that characterizes the economies of developing countries, particularly China and India (Figure 3).

Slika 3
Potrošnja električne energije u svijetu [5]
Figure 3
Electricity consumption in the world [5]



Kao posljedica svega navedenog, podrška nuklearnoj energiji u javnosti ponovno počinje rasti. U takvoj situaciji sve više zemalja ponovno razmatra uporabu nuklearne energije ili je već pokrenulo ambiciozne nuklearne programe. Nuklearna industrija u novim okolnostima gradi imidž tehnologije koja u dostatnim količinama, na ekonomičan i siguran način, može ponuditi alternativu fosilnim gorivima, istodobno ne emitirajući stakleničke plinove. Zahvaljujući polustoljetnom iskustvu, nuklearna industrija naučila se nositi s vlastitim nedostatcima te aktivno raditi na njihovom otklanjanju.

Due to all the above, public support for nuclear energy is beginning to grow. In such a situation, an increasing number of countries are reconsidering the use of nuclear energy or have already inaugurated ambitious nuclear programs. Under these new circumstances, the nuclear industry is building an image of a technology that can offer an alternative to fossil fuels in sufficient quantities and cost effectively, without emitting greenhouse gases. Owing to half a century of experience, the nuclear industry has learned to deal with its shortcomings and is actively working to eliminate them.

3 REZERVE URANA

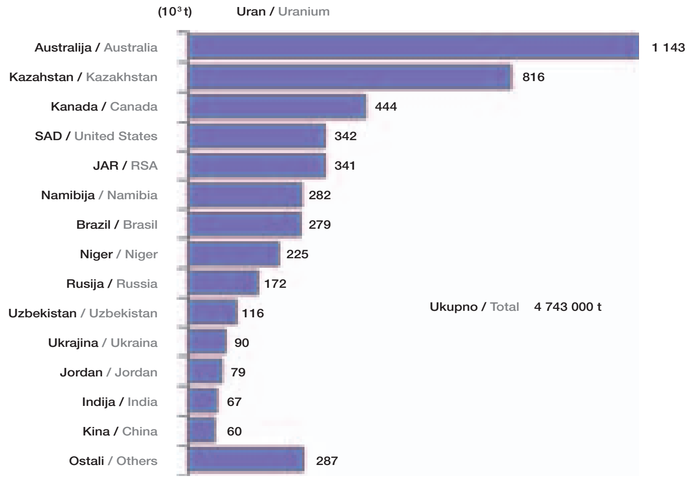
Za razmatranje mogućnosti da nuklearna industrija preuzme značajniju ulogu u opskrbi električnom energijom potrebno je tehnologiju razmotriti i s aspekta resursa, prije svega zaliha goriva.

Svjetske zalihe urana procjenjuju se trenutačno na 18 milijuna tona. Pri toj procjeni kao gornja cijena isplativih rezervi uzeta je cijena od 130 USD/kg prirodnog urana.

3 URANIUM RESERVES

In discussing the possibilities for the nuclear industry to assume a more significant role in the supply of electrical energy, it is necessary to consider the technology from the aspect of resources, particularly fuel reserves.

World uranium reserves are currently estimated at 18 million tons. With this estimate, the top price for cost-effective reserves is considered to be 130 USD/kg of natural uranium.



Slika 4
Potvrđene svjetske zalihe urana, s cijenom 130 USD/kg urana [6]
Figure 4
Confirmed uranium reserves in the world, at the price of 130 USD/kg of uranium [6]

S današnjom potrošnjom urana od 68 000 tona godišnje jednostavnom aritmetikom možemo zaključiti da su potvrđene zalihe urana dostatne za 70 godina rada pod uvjetom da se potrošnja goriva ne povećava (slika 4).

S obzirom da pri sadašnjim cijenama uranova ruda u cijeni električne energije iz nuklearnih elektrana sudjeluje tek sa 2 % do 3 %, nuklearna industrija prilično je tolerantna na cijenu urana. Upravo iz tog se razloga ne poduzimaju značajnija istraživanja novih rezervi. Ukoliko se graničnu cijenu za definiranje dostupnih rezervi urana podigne sa 130 USD/kg na 260 USD/kg urana (što bi cijenu električne energije podiglo tek za približno 3 %), dostupne rezerve urana se povećavaju za faktor 3. Intenziviranje aktivnosti oko istraživanja novih nalazišta, moglo bi povećati dostupne rezerve i za faktor 10. Korištenje tehnologija s gorivim ciklusima sofisticiranijim od danas prevladavajućeg *once through* povećale bi energiju dostupnu iz sadašnjih rezervi za faktor 1,3 (reprocesiranje jednom) do 60 (kombiniranje višestrukog reprocesiranja i brzih oplodnih reaktora), dok se očekuje da će i samo unaprjeđenje sadašnjih lakovodnih reaktora donijeti racionalizaciju u korištenju urana za oko 25 % u bližoj budućnosti. Uz rezerve prirodnog urana moguće je u nuklearnim reaktorima iskoristiti i nuklearni materijal u postojećim nuklearnim bombama (približno 2 000 tona visokoobogaćenog urana i približno 260 tona plutonija), što bi bilo dovoljno za pokrivanje današnje svjetske potrošnje u idućih nekoliko godina.

U slučaju značajnijeg porasta cijene urana, u perspektivi je moguće razmatrati korištenje tzv. nekonvencionalnih rezervi urana; iz fosfatnih naslaga i iz morske vode. Uran iz tih izvora povećava sadašnje rezerve za faktor 4,5 (fosfatne naslage), odnosno čak približno 850 (morska voda).

At today's rate of consumption (68 000 t/year), with simple arithmetic we can conclude that the confirmed uranium reserves are sufficient for 70 years of operation, provided that fuel consumption does not increase (Figure 4).

Since uranium ore accounts for only 2 % to 3 % of the price of electricity generated by nuclear power plants, the nuclear industry is fairly tolerant of the price of uranium. It is for this reason that significant prospecting for new reserves is not underway. If the uppermost price for defining the available uranium reserves were to rise from 130 USD/kg to 260 USD/kg of uranium (which would raise the price of electricity by approximately 3 %), the available uranium reserves would increase by a factor of 3. The intensification of prospecting for new uranium deposits could increase the available reserves by a factor of 10. The use of technologies with more sophisticated fuel cycles than the once-through fuel cycles prevailing today would increase the available energy from the current reserves by a factor of 1,3 (reprocessing once) to 60 (combined multiple reprocessing and fast reactors), while it is anticipated that merely improving the current light-water reactors would provide approximately 25 % rationalization in the use of uranium in the near future. Besides the natural uranium reserves, in nuclear reactors it is also possible to use nuclear material in existing nuclear bombs (approximately 2 000 tons of highly enriched uranium and nearly 260 tons of plutonium), which would be sufficient for covering current world consumption for several years.

In the event of more significant increases in uranium prices, it is also possible to consider using the so-called unconventional uranium reserves, from phosphate deposits and seawater. Uranium from phosphate deposits would increase the current reserves by a factor of 4,5 and from seawater by a factor of 850.

Današnji način korištenja urana može se smatrati s aspekta tog resursa prilično neracionalan, te je evidentno da postoje razne mogućnosti kojima je energiju sadržanu u uranu moguće iskoristiti na višestruko efikasniji način. Ukoliko će se neke od navedenih opcija implementirati zajedno, dostupna energija iz urana povećat će se i mnogostruko više.

Slijedom navedenog moguće je zaključiti da rezerve urana nisu ograničavajući faktor za razvoj nuklearne industrije. Također nije zanemariva niti činjenica da su svjetske rezerve urana ravnomjernije raspoređene od primjerice nafte i plina, te da se dobar dio tih rezervi nalazi u politički stabilnim zemljama.

Osim goriva, kratkoročni ograničavajući faktori su resursi same industrije. Naime, nakon gotovo dva desetljeća stagnacije i rezanja troškova, nuklearna industrija prilično je smanjila svoje kapacitete, kako u pogledu proizvodnje, tako i u pogledu ljudskih resursa. Najavljivani rast nuklearne industrije, bez sumnje će biti potrebno poduprijeti i stvaranjem novih kapaciteta, kako industrijskih tako i ljudskih.

4 TEHNOLOŠKI RAZVOJ

4.1 Generacija I.

Današnji nuklearni reaktori uglavnom su reaktori takozvane Generacije II. i III. dok su svi reaktori prve generacije umirovljeni [7].

Prvu samoodržavajuću nuklearnu reakciju ostvario je Enrico Fermi sa suradnicima koncem 1942. godine na Sveučilištu u Chicagu. Električna energija iz nuklearnog reaktora po prvi put je proizvedena koncem 1951. godine iz američkog eksperimentalnog reaktora EBR-1, a prva nuklearna elektrana za proizvodnju električne energije započela je s radom 27. lipnja 1954. godine u Obninsku u Rusiji.

Mnogi reaktori Generacije I. bili su, poput reaktora Fermi 1, jedinstveni i nisu se više gradili za razliku od reaktora Generacije II. koji su se gradili u serijama i koji su, iako individualno dizajnirani, koristili iste dizajnerske principe. Neki reaktori prve genercije poput Magnox reaktora, uz manje izmjene, evoluirali su u drugu generaciju nuklearnih reaktora koja se počela graditi od sredine 60-ih godina prošlog stoljeća.

Today's manner of using uranium resources could be called irrational. It is evident that there are various possibilities whereby the energy contained in uranium can be harnessed in a manner that is many times more efficient. Insofar as some of the cited options will be implemented together, the available energy from uranium will increase many more times.

Consequently, it is possible to conclude that the uranium reserves are not a limiting factor for the development of the nuclear power industry. Furthermore, the fact should not be ignored that the world uranium reserves are more evenly distributed than, for example, oil and gas, and that a good portion of these reserves are located in politically stable countries.

In addition to fuels, the resources of the industry itself are short-term limiting factors. After nearly two decades of stagnation and cutting costs, the nuclear industry has reduced its capacities somewhat, in terms of production and human resources. The heralded growth of the nuclear industry will undoubtedly have to be supported by new capacities, both industrial and human.

4 TECHNOLOGICAL DEVELOPMENT

4.1 Generation I

Today's nuclear reactors are generally reactors of the so-called Generations II and III, while all the Generation I reactors have been retired [7].

The first self-sustaining nuclear reaction was achieved by Enrico Fermi and his associates in late 1942 at the University of Chicago. Electricity from a nuclear reactor was first produced in late 1951 from the American experimental reactor EBR-1, and the first nuclear power plant for the production of electricity began operations on June 27, 1954 in Obninsk, Russia.

Many Generation I reactors, such as the Fermi 1 reactor, were unique and are no longer being constructed, unlike Generation II reactors which were built in series and which, although designed individually, share the same designing principles. Some Generation I reactors, such as the Magnox reactor, evolved with minor changes into the Generation II nuclear reactors that were first constructed in the mid 1960s.

4.2 Generacija II.

Nuklearni reaktori druge generacije razvili su se iz svojih prethodnika i gradili su se čitavih 30 godina, do sredine 90-ih godina. Promjene u dizajnu bile su značajne, no ipak ne u cijelosti revolucionarne.

Tipični predstavnici ove najduže epohe u razvoju nuklearne energetike, koja je doživjela svoj procvat početkom 70-ih godina ali i strmoglavi pad narudžbi 80-tih godina, su tlakovodni reaktori (PWR – Pressurised Water Reactor), ključajući reaktori (BWR – Boiling Water Reactor) i napredni plinom hlađeni reaktori (AGR – Advanced Gas Reactors).

Tlakovodni reaktori PWR (Pressurized Water Reactor)

PWR reaktori najrašireniji su tip nuklearnih reaktora u svijetu, njih više od 230 koristi se za proizvodnju električne energije, a nekoliko stotina za pogon nuklearnih podmornica za što su izvorno i bili dizajnirani. Za hlađenje i za moderaciju neutrona koriste vodu pod visokim tlakom, a kao gorivo se obično koristi nekoliko postotaka obogaćen uran-235. Jedina hrvatsko-slovenska nuklearka Krško također je PWR tipa. Slična serija tlakovodnihn reaktora pod nazivom VVER (Vodo-vodnoj energetičeskij reaktor) građena je u bivšem Sovjetskom Savezu i državama Varšavskog bloka. Prvi reaktori ovog tipa razvijeni su prije 1970. godine, dok je noviji dizajn snage 1 000 MW razvijen 1975. godine. Osim što je vrlo sličan PWR-u prošao je i sličan razvojni put, budući da je prvotno razvijan za korištenje u ruskim nuklearnim podmornicama i ratnim brodovima. Kao i u PWR-u, gorivo je malo obogaćeni uranov dioksid UO_2, a moderator i hladioc je obična voda. Danas je u pogonu oko 50 reaktora ovog tipa.

Ključajući reaktori BWR (Boiling Water Reactor)

BWR reaktor vrsta je lakovodnih reaktora koju je razvio General Electric sredinom 50-ih. Ključajuća voda u reaktorskoj jezgri je radni medij koji se koristi za odvođenje topline s nuklearnog goriva i za usporavanje neutrona kako bi se povećala vjerojatnost nuklearne fisije. Zbog svoje robusnosti i relativno jednostavne izvedbe ovi reaktori se nisu razvijali za pogon podmornica, nego isključivo za proizvodnju jeftine električne energije. Za razliku od PWR-a, para proizvedena u reaktoru ide izravno do turbine. Danas je u pogonu više od 80 BWR reaktora.

CANDU (Cada Deuterium Uranium)

CANDU reaktor razvijen je u kasnim 50-im i ranim 60-im godinama u Kanadi. Riječ je o tlakovodnom reaktoru hlađenom teškom vodom. Gorivo je smješteno u tlačne cijevi, okružene teškom vodom

4.2 Generation II

Generation II nuclear reactors developed from their predecessors and were built for a full 30 years, until the mid 1990s. Changes in design were significant but not entirely revolutionary.

Typical representatives of the longest epoch in the development of nuclear energy, that flourished during the 1970s but experienced a steep drop in orders in the 1980s, are the Pressurized Water Reactor – PWR, Boiling Water Reactor – BWR, and Advanced Gas Reactor – AGR.

Pressurized Water Reactor (PWR)

PWR reactors are the most widespread type of nuclear reactors in the world. Over 230 of them are in use for electricity production and several hundred for the powering of nuclear submarines, for which they were originally designed. Water under high pressure is used for cooling and the moderation of neutrons, and uranium-235 enriched by several percentage points is generally used for fuel. The only Croatian-Slovenian nuclear power plant, Krško, is also of the PWR type. A similar series of pressurized water reactors known as Water-Cooled Water-Modulated Energy Reactors (WWER or VVER) was built in the former Soviet Union and the countries of the Warsaw block. The first reactors of this type were developed prior to the year 1970, while the new design with 1 000 MW of power was developed in 1975. Besides being very similar to the PWR, it followed a similar developmental path, since it was initially developed for use in Russian nuclear submarines and warships. As with the PWR, the fuel is slightly enriched uranium dioxide, and the moderator and coolant are ordinary water. Today, approximately 50 reactors of this type are in operation.

Boiling Water Reactor (BWR)

A BWR is a type of light-water reactor developed by General Electric in the mid 1950s. Boiling water in the reactor core is the working medium that is used to conduct heat away from the nuclear fuel and reduce the kinetic energy of neutrons in order to increase the probability of nuclear fission. Due to their bulk and relatively simple construction, these reactors were not developed to power submarines but exclusively for the production of low-cost electricity. Unlike PWRs, the steam produced in the reactor goes directly to the turbine. Today, over 80 BWRs are in operation.

Cada Deuterium Uranium Reactor (CANDU)

The CANDU reactor was developed in the late 1950s and early 1960s in Canada. This is a pressurized reactor cooled with heavy water. The fuel is contained in pressure tubes surrounded by heavy water at low pressure. Due to its superior pod niskim pritiskom. Teška voda zbog boljih moderacijskih svojstava omogućuje korištenje prirodnog urana za gorivo. Danas je u pogonu oko 40 CANDU reaktora, uglavnom u Canadi i Indiji.

Napredni plinom hlađeni reaktor AGR (Advanced Gas Reactor)

AGR reaktori predstavnici su druge generacije britanskih plinom hlađenih reaktora nastalih razvojem Magnox reaktora. AGR koriste grafit kao neutronski moderator i ugljični dioksid za hlađenje goriva. Za razliku od svojih prethodnika, ovi reaktori radi većeg iskorištenja koriste više temperature hladioca. Također kao gorivo koriste obogaćeni uran čime je smanjena potreba za učestalim zamjenama goriva. Danas je u pogonu sedam AGR reaktora. Snage su im 555 MW ili 625 MW. Svi reaktori nalaze se u Velikoj Britaniji.

Kipući reaktor kanalnog tipa RBMK (Reaktor baljšoj mašćnosti Kanaljnij)

RBMK je danas zastarjeli tip grafitnih reaktora hlađenih vodom. Ozloglašeni predstavnik ove generacije nuklearnh reaktora je Černobilj. Kako je VVER reaktor bio tehnološki puno zahtjevniji, bivši Sovjetski Savez se više zalagao za gradnju RBMK reaktora. Osim povoljnih ekonomskih okolnosti, RBMK je mogao koristiti prirodni uran kao gorivo, koje se moglo mijenjati tijekom pogona, dakle bez zaustave i reaktor je proizvodio plutonij za vojne svrhe. Danas je u pogonu još desetak RBMK reaktora i to isključivo u Rusiji.

4.3 Generacija III.

Reaktori ove generacije razvijeni su (i još se razvijaju) poboljšanjem dizajna reaktora iz prethodne generacije. Posebno je poboljšana tehnologija izrade nuklearnog goriva te sigurnosni sustavi.

Prvi reaktor ove generacije u pogonu je od 1996. godine u Japanu. Tipovi reaktora Generacije III. su EPR, AP 1000, ABWR i System 80+.

Europski tlakovodni reaktor EPR (European Pressurized Reactor)

Ovaj reaktor razvija francusko-njemački konzorcij Areva/Siemens. Reaktor može koristiti 5 % obogaćeni uran ili MOX gorivo (miješani oksid urana i plutonija). Dizajn reaktora je napredan u prvom redu zbog povećane sigurnosti (dodano nekoliko pasivnih sigurnosnih sustava), ali i zbog velike izlazne snage (1 600 MW).

U tijeku je gradnja prvog reaktora ove vrste u Finskoj (Olkiluoto 3). Međutim, zbog određenih problema u gradnji, datum puštanja elektrane u pogon pomaknut je za više od 18 mjeseci, tako

moderating properties, heavy water permits the use of natural uranium for fuel. Approximately 40 CANDU reactors are in operation today, mainly in Canada and India.

Advanced Gas Reactor (AGR)

AGRs are representatives of the second generation of British gas-cooled reactors that came about with the development of Maxnox reactors. AGRs use graphite as the neutron moderator and carbon dioxide for cooling the fuel. Unlike their predecessors, these reactors use high temperature coolants for greater efficiency. Furthermore, they use enriched uranium as fuel, thereby reducing the need for frequent fuel replacement. There are seven AGR reactors in operation today, with power ratings of 555 MW or 625 MW. All these reactors are located in Great Britain.

High Power Channel Type Reactor (Reaktor Bolshoy Moshchnosti Kanalniy – RBMK)

The RBMK is now an obsolete type of graphite-moderated water-cooled reactor. The infamous representative of this generation of nuclear reactors was located at Chernobyl. Since the WWER was technologically more demanding, the former Soviet Union invested more in the building of RBMK reactors. Besides economic considerations, the RBMK was able to use natural uranium as fuel, which could be changed during operation, i.e. without shutting down, and the reactor produced plutonium for military purposes. There are still RBMKs in operation today, exclusively in Russia.

4.3 Generation III

Reactors of this generation were developed (and continue to be developed) by improving the design of reactors from the previous generation, particularly the fuel technologies and safety systems.

The first reactor of this generation has been in operation in Japan since 1996. The types of Generation III reactors are the European Pressurized Reactor – EPR, the Advanced Passive 1000 – AP 1000, the Advanced Boiling Water Reactor – ABWR and System 80+.

European Pressurized Reactor (EPR)

This reactor was developed by the French-German consortium of Areva/Siemens. The reactor can use 5% enriched uranium oxide or MOX (mixed uranium plutonium oxide) fuel. The reactor design is advanced, first of all due to increased safety (several passive safety systems have been added), but also due to the high electrical power output (1 600 MW).

The construction of the first reactor of this type is in progress in Finland (Olkiluoto 3). However, due da se prvi kilovatsati očekuju tek početkom 2011. godine. Vrijednost projekta procijenjena je na oko 3 milijarde eura.

AP1000

AP 1000 napredni je reaktor snage oko 1100 MW koji kao i EPR koristi napredne pasivne sigurnosne sustave. AP1000 ima znatno manje ventila, manje cjevovoda, manje kabela, manje pumpi, manje sustava za hlađenje, ventilaciju i zagrijavanje te 45 % manji volumen reaktorske zgrade u odnosu na konvencionalne PWR elektrane. Navedene redukcije vode velikim uštedama u troškovima izgradnje, ali i u trajanju izgradnje (3 godine). Dizajn kojeg razvija Westinghouse službeno je odobren koncem 2005. godine i tijekom 2007. i 2008. godine očekuju se narudžbe za gradnju 10 reaktora [8].

Napredni ključajući reaktor ABWR (Advanced Boiling Water Reactor)

ABWR napredni je dizajn ključajućeg reaktora kojeg razvija General Electric. Glavno poboljšanje u odnosu na postojeće BWR reaktore je smještaj recirkulacijske pumpe i cjevovoda unutar reaktorske tlačne posude, čime je reducirana mogućnost curenja hladioca. U slučaju gubitka hladioca odgovor elektrane je u cijelosti automatiziran budući da čak 72 sata nije potrebna nikakva reakcija operatera. Tri reaktora ove vrste trenutačno su u pogonu u Japanu, a nekoliko ih je u izgradnji (Japan) ili se planira njihova gradnja (Japan, SAD).

Napredni tlakovodni reaktor System 80+

Ovaj reaktorski dizajn razvija ABB Combustion Engineering. Snaga reaktora iznosi 1 300 MW, a jedna od njegovih posebnosti je korištenje plutonijevog goriva, što ga čini zanimljivim u smislu korištenja zaliha nuklearnih materijala iz atomskih bombi. Ovaj tip reaktora razvijen je iz sličnog reaktora PWR reaktora System 80 koji je već u pogonu u nekoliko nuklearnih elektrana u SAD-u i Koreji.

4.4 Generacija III+

Reaktori koji, iako dijelom revolucionarni, ne zadovoljavaju kriterije reaktora Generacije IV. nazivaju se reaktori III+ generacije. Najrazvijeniji prototipovi iz ove generacije su kipući reaktor s pojednostavljenom ekonomijom (ESBWR – Economic Simpified Boiling Water Reactor) i Pebble bed modular reactor (PBMR).

to certain construction problems, the date that this power plant will go on line has been postponed for over 18 months, so that the first kilowatt hours are not expected until early 2011. This project has been estimated to cost approximately 3 billion euros.

Advanced Passive 1000 (AP 1000)

The AP 1000 is an advanced reactor designed to generate approximately 1 100 MW, which like the EPR uses advanced passive safety systems. The AP 1000 has significantly fewer valves, less piping, less cable, fewer pumps, smaller HVAC (heating, ventilation and air conditioning) and 45 % less building volume than a conventional PWR plant. These reductions lead to great savings in construction costs and time (3 years). The design developed by Westinghouse was officially approved in late 2005. Orders are anticipated in 2007 and 2008 for the construction of ten reactors [8].

Advanced Boiling Water Reactor (ABWR)

The ABWR is an advanced boiling water reactor developed by General Electric. The chief improvement in comparison to existing BWRs is the containment of the recirculation pumps and piping inside the reactor pressure vessel, which reduces the possibility of coolant leakage. In the event of a Loss of Coolant Accident (LOCA), plant response has been fully automated and no operator action is required for 72 hours. Three reactors of this type are already in operation in Japan, several are under construction in Japan, or are planned in Japan and the United States.

System 80+ Advanced Pressurized Water Reactor (System 80+ APWR)

This reactor design was developed by ABB Combustion Engineering. The reactor generates 1 300 MW. One of its advantages is the use of plutonium fuel, making it interesting in the sense of being a useful means for the disposal of Weapon Graded Plutonium from dismantled nuclear warheads. This reactor type was developed from a similar System 80 PWR that is already in operation at several nuclear power plants in the United States and Korea.

4.4 Generation III+

Reactors which, although somewhat revolutionary, do not meet the criteria of Generation IV reactors are known as Generation III+ reactors. The most advanced prototypes from this generation are the Economic Simplified Boiling Water Reactor – ESBWR and the Pebble Bed Modular Reactor – PBMR.

ESBWR

Razvoj ESBWR-a se temelji na usavršenom plinom hlađenom reaktoru (ABWR – Advanced Boiling Water Reactor). I ovaj reaktor je dizajnirao General Electric i temelji se na tehnologiji kipućih reaktora.

Reaktor je pasivno siguran, što znači da za njegovu zaustavu u slučaju nekog izvanrednog događaja koji bi u konačnici mogao rezultirati taljenjem jezgre nije potrebna posebna reakcija operatera niti bilo kojeg elektronskog uređaja. Pasivna sigurnost je kod ovog reaktora temeljena na dva sigurnosna sustava: prva komponenta su izolacijski kondenzatori ili izmjenjivači topline koji preuzimaju paru iz reaktora ili zaštitne posude (containmenta), kondenziraju je, prenose toplinu u bazen s vodom te vraćaju vodu ponovno u reaktor, dok se drugi sustav temelji na gravitaciji. Sustav automatski potapa reaktor vodom iz zasebnog bazena iznad reaktora ukoliko dođe do pada razine vode u reaktoru.

Reaktor se hladi prirodnom cirkulacijom hladioca, nema posebnih pumpi za cirkulaciju niti cjevovoda. Jezgra je zbog toga kraća od tradicionalnih BWR reaktora. Ispod reaktora smješten je sustav cjevovoda koji omogućuje hlađenje jezgre tijekom ozbiljne nesreće.

Vjerojatnost istjecanja radioaktivne materije u atmosferu je nekoliko redova veličine niža nego kod konvencionalnih reaktora, a očekivani trošak izgradnje je čak 60 % do 70 % niži nego kod lakovodnih reaktora. Predviđena električna snaga takvog reaktora je 1 550 MW.

PBMR (Pebble Bed Modular Reaktor)

Ovaj reaktor jedan je od naprednih reaktorskih dizajna sa značajno većom iskoristivošću i višom sigurnosnom razinom. Reaktor umjesto vode koristi grafit kao moderator te neki poluinertni plin (helij, dušik ili ugljični dioksid) kao hladioc koji dostiže vrlo visoke temperature i izravno ulazi u plinsku turbinu. Na taj način uspješno se uklanja čitav niz međusustava (npr. parogeneratori) i podiže iskoristivost na približno 50 %. Gorivo se izrađuje u obliku kuglica (pebble = oblutak) s jezgrom od obogaćenog urana i grafitnim plaštem. Reaktor također posjeduje pasivnu sigurnost, a dodatna mu je prednost što se gorivo može mijenjati tijekom pogona. Ovaj reaktorski dizajn inicijalno je razvijao njemački Siemens, a danas na njegovom razvoju radi Westinghouse, Južnoafrička Republika i Kina. Tijekom 2007. godine u Južnoafričkoj Republici planira se početi s gradnjom probnog reaktora koji bi trebao biti gotov do 2011. godine, a 2013. godine trebala bi započeti komercijalna gradnja.

Economic Simplified Boiling Water Reactor (ESBWR)

The development of the ESBWR was based upon improvements made in the gas-cooled Advanced Boiling Water Reactor – ABWR. This reactor was also designed by General Electric and is based upon the technology of boiling water reactors.

The reactor is a passively safe design, which means that in the event of some exceptional occurence that could result in the meltdown of the core, no special reaction is required from the operator or any electronic equipment. The passive safety of this reactor is based upon two safety systems. The first components are isolation condensers, which are heat exchangers that take the steam from the reactor vessel or the containment, condense it, transfer the heat to a water pool and return the water into the reactor. The second system is the Gravity Driven Cooling System (GDCS), which automatically floods the reactor with water from separate pool above the vessel in the event that a low water level is detected in the reactor.

The reactor is cooled by the natural circulation of the coolant. There are no special pumps for circulation or piping. Therefore, the core is shorter than in conventional BWRs. Below the reactor is a piping system that allows for the cooling of the core in the event of a very severe accident.

The probability of the release of radioactive material into the atmosphere is several orders of magnitude lower than for conventional reactors, and the estimated building cost is 60 –70 % lower than for other light-water reactors. The anticipated power rating of such a reactor is 1 550 MW.

Pebble Bed Modular Reactor (PBMR)

This reactor is one of the advanced reactor designs with significantly higher efficiency and safety. Instead of water, it uses graphite as the moderator and an inert or semi-inert gas (helium, nitrogen or carbon dioxide) as the coolant, which reaches very high temperatures and enters the gas turbine directly. In this manner, it eliminates an entire series of intermediary systems, such as the steam generator, and increases transfer efficiency to approximately 50 %. The fuel is manufactured in a pebble shape, with a core of enriched uranium and graphite covering. The reactor also has passive safety. An additional advantage is that the fuel can be changed during operation. This reactor design was initially developed by the German firm of Siemens. Westinghouse, the Republic of South Africa and China are currently working on its further development. During 2007, the beginning of the construction of a demonstration reactor is planned in the Republic of South Africa, which should be completed by 2011, and commercial construction should start in the year 2013.

4.5 Generacija IV.

Reaktori Generacije IV. skup su novih i naprednih tehničkih rješenja koja su trenutačno u razvojnoj fazi. Generalno, za te se reaktore ne očekuje da će biti raspoloživi za komercijalnu proizvodnju prije 2030. godine. Istraživanja o ovoj najnovijoj generaciji nuklearnih reaktora započeo je Međunarodni forum reaktora IV. generacije (Generation IV. International Forum). Primarni ciljevi Foruma su poboljšanje nuklearne sigurnosti, smanjenje mogućnosti proliferacije, smanjenje nuklearnog otpada i smanjenje troškova gradnje i kasnijeg pogona takvih elektrana.

Treba napomenuti da je za ostvarenje takvih ciljeva nužno osmisliti i nove alate za ekonomsku procjenu opravdanosti gradnje reaktora IV. generacije, budući da se njihove karakteristike bitno razlikuju od postojećih reaktora II. i III. generacije.

Početno je razmatran veliki broj raznih reaktorskih dizajna, no njihov broj je ipak reduciran kako bi se bilo moguće fokusirati na najperspektivnije tehnologije. Danas se najviše govori o četiri predstavnika termalnih reaktora i isto toliko brzih oplodnih reaktora.

Visokotemperaturni reaktor VHTR (Very High Temperature Reactor)

VHTR koncept temelji se na helijem hlađenoj jezgri s grafitom kao moderatorom i uranovom gorivnom ciklusu. U reaktoru će se moći dostići temperatura od 1 000 °C. Jezgra može biti u obliku prizme ili kuglica. U oba slučaja uran je uložen u grafit. Za VHTR također se podrazumijeva pasivna sigurnost.

Superkritični vodom hlađeni reaktor SCWR (Supercritical Water Cooled Reactor)

Superkritični vodom hlađeni reaktor je koncept koji koristi superkritičnu vodu kao radni medij. SCWR je u svojoj osnovi lakovodni reaktor koji radi na puno višem tlaku i temperaturi od klasičnih PWR-a i BWR-a. Njegove osnovne prednosti su značajno veći stupanj toplinskog iskorištenja (45 %) u odnosu na 33 % iskoristivosti klasičnih lakovodnih reaktora te znatno tehnološko pojednostavljenje elektrane. Ovaj reaktor predstavlja svojevrsnu kombinaciju PWR i BWR reaktora s glavnim ciljem proizvodnje jeftine električne energije. Na njegovom razvoju rade 32 organizacije iz 13 zemalja.

Reaktor hlađen rastaljenom soli MSR (Molten Salt Reactor)

Kao što mu ime govori, hladioc ovog naprednog reaktorskog dizajna je rastaljena sol. Do sada je predstavljeno više dizajna za ovaj tip reaktora, a napravljeno je i nekoliko prototipova. Ranija rješenja oslanjala su se na nuklearno gorivo

4.5 Generation IV

Generation IV reactors are a group of new and advanced technical solutions that are currently in the developmental stage. It is generally not expected that these reactors will be available for commercial construction before the year 2030. Research on this newest generation of nuclear reactors was begun by the Generation IV International Forum (GIF). The primary goals of the forum are to improve nuclear safety, reduce the possibilities for proliferation, minimize nuclear waste and lower the cost of building and running such plants.

It should be mentioned that for achieving such goals, it is necessary to devise new tools for the economic assessment of the justification for building Generation IV reactors, since their characteristics differ significantly from those of the current Generation II and III reactors.

Initially, a large number of various reactor designs were considered. Their number was eventually reduced in order to focus on the most promising technologies. Today, the most discussed are four representatives of thermal reactors and the same number of fast reactors.

Very High Temperature Reactor (VHTR)

The VHTR concept is based upon a helium-cooled core with graphite as the moderator and a uranium-fueled cycle. It will be possible to reach a temperature of 1 000 °C inside the reactor. The core can be of either a prismatic block or pebble bed form. In both cases, the uranium is imbedded in graphite. The VHTR also implies passive safety.

Supercritical Water Cooled Reactor (SCWR)

The SCWR is a water cooled reactor concept that uses supercritical water as the working fluid. The SCWR is basically a light-water reactor that operates at higher pressures and temperatures than classical PWRs and BWRs. Its basic advantages are a significantly higher thermal efficiency (45 %) in comparison to 33 % efficiency for current light-water reactors and significant technological simplification of the plant. This reactor represents a type of a combination of PWR and BWR reactors, with the main goal of producing low-cost electricity. Thirty-two organizations from 13 countries are working on its development.

Molten Salt Reactor (MSR)

As the name implies, the coolant for this advanced reactor design is molten salt. Until now, many designs have been presented for this type of reactor and several prototypes have been built. Earlier solutions relied upon nuclear fuel dissolved in molten fluoride salt as uranium tetrafluoride. Criticality was reached with the flowing of the otopljeno u rastaljenim solima flora tvoreći uranov tetraflorid. Kritičnost se dosiže dolaskom medija u grafitnu jezgru koja ujedno služi kao moderator. Neki današnji koncepti više se oslanjaju na gorivo disperzirano unutar grafitne matrice s rastaljenom soli čime se osigurava hlađanje pri visokoj temperaturi i niskom tlaku.

Međunarodni inovativan i sigurni reaktor IRIS (International Reactor Innovative and Secure)

IRIS je modularni lakovodni reaktor srednje električne snage (najmanje 335 MW) na čijem razvoju radi Westinghouse zajedno s velikim brojem međunarodnih ustanova među kojima se nalazi i Fakultet elektrotehnike i računarstva iz Zagreba [9]. Dizajn reaktora ima naglašenu otpornost na proliferaciju i udovoljava naprednim sigurnosnim kriterijima koji se postavljaju pred reaktore Generacije IV. Najvažnija poboljšanja su inherentna sigurnost ostvarena na način da su sve glavne komponente smještene unutar zajedničke posude i dodatno, većina sigurnosnih sustava zasniva se na djelovanju prirodnih sila kao što su gravitacija ili prirodna cirkulacija.

Plinom hlađeni brzi reaktor GFR (Gas Cooled Fast Reactor)

Plinom hlađeni brzi reaktor koristi brze neutrone u zatvorenom nuklearnom gorivnom ciklusu za puno efikasnije iskorištenje energetskog potencijala nuklearnog goriva. Stoga je udio cijene goriva u cijeni električne energije kod ovih reaktora značajno reduciran. Reaktor je hlađen helijem, a izlazna mu je temperatura 850 °C.

Brzi reaktori hlađen natrijem SFR (Sodium Cooled Fast Reactor)

SFR predstavlja nadogradnju dva postojeća projekta: LMFBR (Brzi reaktor hlađen tekućim metalima) i IFR (Integralni brzi reaktor).

Cilj projekta je povećati efikasnost korištenja urana kroz oplodnju plutonija te omogućavanje transformacije takozvanih transuranskih izotopa koji još stoljećima svojim ionizirajućim zračenjem opterećuju lokaciju na kojoj se skladište. U reaktoru se nalazi nemoderirana jezgra u kojoj se događa fisija s brzim neutronima. Višak neutrona pruža mogućnost da se transuranski izotopi transformiraju u druge izotope s kraćim vremenima poluraspada ili u nuklearno gorivo.

SFR je hlađen tekućim natrijem, a za gorivo koristi metalnu leguru urana i plutonija. Gorivo je oklopljeno čeličnim košuljicama dok je zazor između košuljice i goriva ispunjen tekućim natrijem.

medium into the graphite core, which also served as the moderator. Some current concepts rely more on fuel dispersed in a graphite matrix, with the molten salt assuring cooling at a high temperature and low pressure.

International Reactor Innovative and Secure (IRIS)

The IRIS is a modulated light-water reactor of medium power rating, a minimum of 335 MW, being developed by Westinghouse together with a large number of international institutions, including the Faculty of Electrical Engineering and Computing in Zagreb [9]. The reactor design has marked proliferation resistance and meets the safety criteria for Generation IV reactors. The most important improvements are passive safety achieved in a manner that the chief components are located inside a common vessel. In addition, the majority of the safety systems are based upon the activity of natural forces such as gravitation or natural circulation.

Gas Cooled Fast Reactor (GFR)

The GFR uses fast neutrons in a closed nuclear fuel cycle to enhance the utilization of the energy potential of nuclear fuel. Therefore, the percentage of the fuel cost in the price of electricity generated by this reactor is significantly reduced. The reactor is cooled with helium and has an outlet temperature of 850 °C.

Sodium Cooled Fast Reactor (SFR)

The SFR is based upon two existing projects, the Liquid Metal Fast Breeder Reactor (LMFBR) and the Integrated Fast Reactor (IFR).

The goal of the project is to increase the efficiency of uranium utilization through breeding plutonium and allow the transformation of the transuranic isotopes that continue to emit ionizing radiation for centuries, creating storage problems. In the reactor is an unmoderated core where fast neutron fission occurs. The excess of neutrons provides for the transuranic isotopes to be transformed into other isotopes with shorter half-lives or into nuclear fuel.

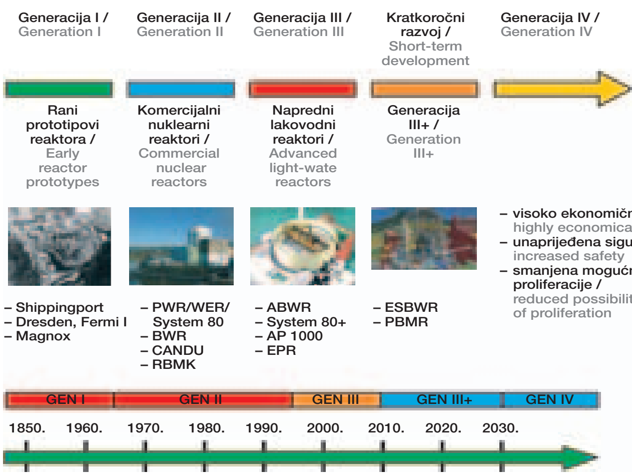
The SFR is cooled by liquid sodium and uses a metallic alloy of uranium and plutonium for fuel. The fuel is contained in steel cladding while the space between the fuel and the cladding is filled with liquid sodium.

Olovom hlađen brzi reaktor LFR (Lead Cooled Fast Reactor)

LFR se odlikuje zatvorenim gorivnim ciklusom s tekućim olovom kao hladiocem. Pogodan je za elektrane različitih snaga, od baterije snage 50 MW do 150 MW s vrlo dugim intervalom izmjene goriva, preko modularnih sistema snage 300 MW do 400 MW pa do velikih kompaktnih blokova od 1 200 MW. Gorivo je bazirano na fertilnom uranu i transuranskim elementima. Reaktor je hlađen prirodnom predajom topline vanjskom hladiocu koji se nalazi na temperaturi od 550 °C. Visoke temperature također omogućuju proizvodnju vodika termokemijskim procesima. Nekoliko ovih reaktora bilo je korišteno za pogon ruskih podmornica, no zbog problema sa skrućivanjem hladioca ovaj reaktorski dizajn više se ne primjenjuje u te svrhe.

Lead Cooled Fast Reactor (LFR)

The LFR is characterized by a closed fuel cycle with liquid lead as the coolant. It is suitable for power plants of various power ratings, from a battery of 50 MW to 150 MW, and features a very long refueling interval, a modular system rated at 300 MW to 400 MW, and large compact blocks of 1 200 MW. The fuel is based on fertile uranium and transuranic elements. The reactor is cooled by natural heat transfer with an outlet coolant at a temperature of 550 °C. The high temperatures also allow the production of hydrogen by thermochemical processes. Several of these reactors were used for powering Russian submarines but due to problems with the hardening of the coolant, this reactor design is no longer used for this purpose.



Slika 5
Razvoj nuklearnih reaktora

Figure 5
The development of nuclear reactors

5 EKONOMSKI ASPEKTI

U poslijeratnom razdoblju nuklearne elektrane razvijale su direktno države, ili su njihov razvoj i izgradnju snažno podržavale.

Elektroprivrede su u tom razdoblju bile u direktnom vlasništvu države ili pod njenom snažnom kontrolom, a tržište električne energije bilo je monopolističko. Planiranje razvoja elektroenergetskog sustava bilo je centralizirano i dugoročno. Projekti izgradnje novih nuklearnih elektrana bili su izloženi niskom regulatornom riziku, imali su pristup relativno jeftinom kapitalu, a rizik na povrat investicije bio je nizak, s obzirom da su svi troškovi prenošeni na kupce električne energije. Snažan gospodarski uzlet nakon rata za sobom je nosio i značajno povećanje konzuma energije. Te su okolnosti u 1970-tim i 1980-tim godinama pogodovale značajnom rastu nuklearne industrije.

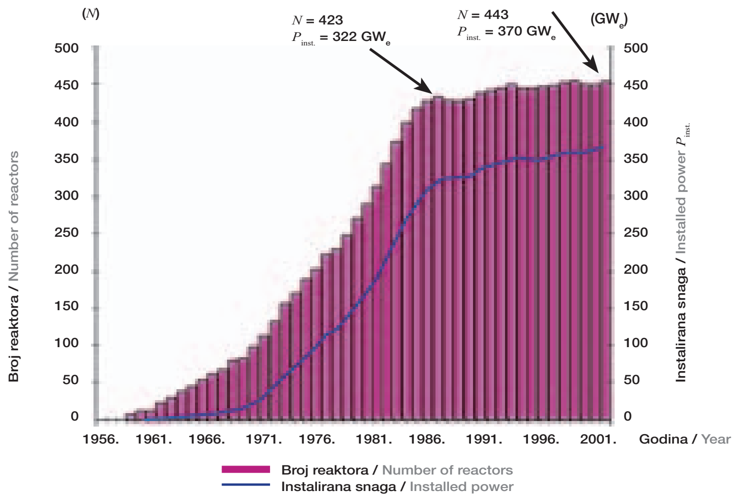
5 ECONOMIC ASPECTS

After the Second World War, nuclear power plants were developed directly by governments or their development and construction received strong government support.

During this period, electrical supply companies were under direct state ownership or under their powerful control, and the electricity market was monopolistic. The planning of the development of the electricity system was centralized and long range. The projects for the construction of new nuclear power plants had low regulatory risk, access to relatively inexpensive capital, and low risk for investment return, since all the costs were transferred to the electricity consumer. The tremendous economic growth after the war led to a significant increase in energy consumption. During the 1970s and 1980s, these circumstances favored the significant growth of the nuclear industry.

Porast instalirane snage reaktora u periodu od 1965. do 1975. godine rastao je po prosječnoj godišnjoj stopi od preko 30 %, dok je u periodu 1965. do 1985. godine prosječni godišnji rast industrije bio preko 20 % (slika 6).

The growth in the installed power of reactors during the period from 1965 to 1975 increased at an average annual rate of over 30 %, while during the period from 1965 to 1985 the average industrial growth rate was over 20 % (Figure 6).



Slika 6
Instalirani nuklearni kapaciteti krajem 2006. u svijetu [1].
Figure 6
Installed nuclear capacities in the world at the end of 2006 [1]

Iako je u sedamdesetim i prvoj polovini osamdesetih nuklearna industrija bilježila snažnu ekspanziju, mnogi pokazatelji su u mnogome ukazivali na dječje bolesti. Izgradnju su često obilježavala prekoračenja budžeta i rokova, dok je pogon reaktora bio obilježen velikim brojem ispada i relativno niskom raspoloživosti postrojenja. Uz to je u SAD-u došlo do nesreće na elektrani Otok tri milje (TMI). Iako nije ispuštena veća količina radioaktivnosti u okoliš i niti jedan pojedinac nije nastradao, taj je događaj značajno utjecao na percepciju javnosti o nesigurnosti nuklearnih elektrana. S aspekta nuklearne industrije, taj je događaj ukazao na nekoliko činjenica: zaštine mjere nuklearnih reaktora od ispuštanja radioaktivnosti u okoliš te zaštite pojedinaca dobro su odradile svoju namjenu, te su posljedice po ljude i okoliš praktički bile zanemarive. S druge strane, ekonomske štete od nuklearne nesreće, prvenstveno za vlasnika postrojenja su značajno veće od očekivanja; čišćenje postrojenja je skup i dugotrajan proces, a izgubljena proizvodnja golema. To je natjeralo nuklearnu industriju da uloži dodatne napore u poboljšanje sigurnosti nuklearnih elektrana, kako radi percepcije javnosti, tako i zbog ekonomskih razloga.

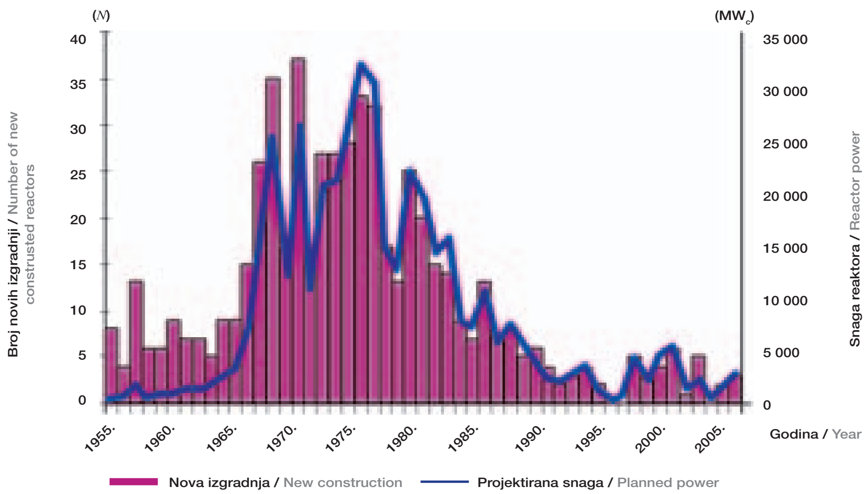
Već spomenuta katastrofa u Černobilju 1986. godine, iako na sasvim drugom konceptu reaktora od zapadnih, snažno je uzdrmala nuklearnu industriju. Naftne krize iz sedamdesetih i ranih osamdesetih bile su prošlost i cijena nafte ponovno je bila niska.

Although the nuclear industry recorded powerful expansion during the 1970s and first half of the 1980s, it was not without growing pains. There were frequent budget overruns and unmet construction deadlines. Reactor plants were characterized by frequent outages and relatively low plant availability. Moreover, the Three Mile Island accident occurred in the United States. Although large quantities of radioactivity were not released into the environment and not a single person was injured, this event had a powerful negative impact on public perception regarding the safety of nuclear power plants. From the aspect of the nuclear industry, this event demonstrated several facts: the safety measures at nuclear reactors to prevent the discharge of radioactivity into the environment and protect persons had performed their intended purpose well, and the consequences to persons and the environment were practically negligible. On the other side, the economic repercussions from the nuclear accident, first of all to the owner of the plant, were far greater than expected. The cleaning of the plant is an expensive and long process, and production losses are enormous. This forced the nuclear industry to invest additional efforts into improving the safety of nuclear power plants, due to both public perceptions and economic considerations.

The previously mentioned catastrophe in Chernobyl in 1986, although based on a reactor with a completely different concept than those in the West, powerfully shook the nuclear industry. The oil crisis from the 1970s and early 1980s had passed and the price of oil was once again low.

Kao posljedica svega navedenog, krajem 1980-tih godina značajno pada broj novih narudžbi, a nuklearna industrija bilježi stagnaciju (slika 7). Nakon dva desetljeća intenzivog rasta, udio nuklearne energije počeo se stabilizirati na 16 % do 17 % u globalnoj proizvodnji električne energije.

As a consequence of everything that has been cited, in the late 1980s there was a significant decrease in the number of new orders, and the nuclear industry recorded stagnation (Figure 7). After two decades of intense growth, the share of nuclear energy began to stabilize at 16 – 17 % of global electricity production.



Slika 7
Broj pokrenutih novih izgradnji, brojčano i po snazi reaktora [1].
Figure 7
Newly constructed reactors, according to numbers and projected power ratings [1]

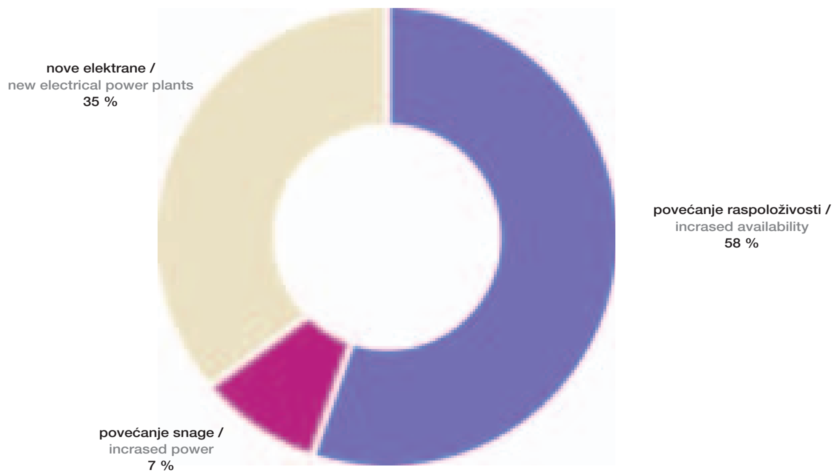
Nuklearna industrija okrenula se poboljšanjima performansi postojećih reaktora, prije svega povećanju njihove raspoloživosti i pouzdanosti, te povećanju snage postojećih reaktora. Uz to su ulagani značajni napori u snižavanje troškova pogona.

Porast proizvodnje električne energije u nuklearnim elektranama od devedesetih na dalje, tek je u manjoj mjeri posljedica puštanja u pogon novih reaktora, a većim dijelom je posljedica povećanja raspoloživosti postojećih elektrana (slike 8 i 9). U periodu od 1990. do 2004. godine godišnja proizvodnja električne energije iz nuklearnih elektrana porasla je s 1 901 TWh na 2 619 TWh, tj 37 %, dok je izgrađenih novih kapaciteta bilo tek 6,7 % više.

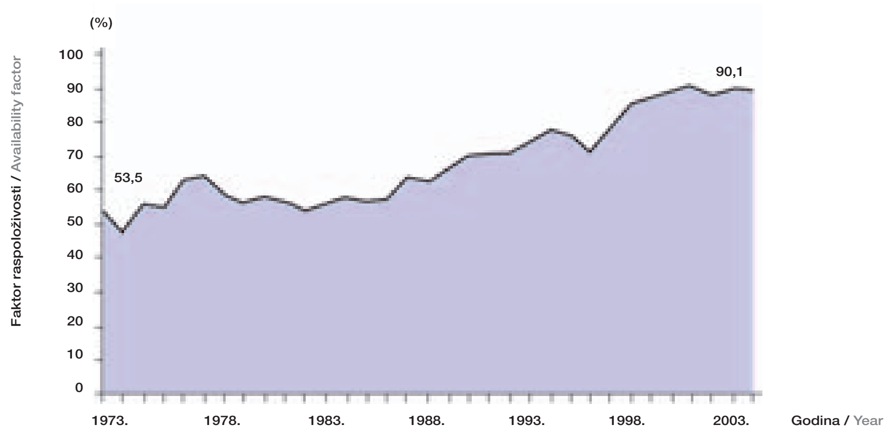
The nuclear industry turned to improving the performance of existing reactors, first of all to increasing their availability, reliability and power ratings. Significant efforts were also invested in reducing plant costs.

The increase in the production of electricity in nuclear power plants since the 1990s is only to a lesser extent a consequence of placing new plants into operation, and to a greater extent a consequence of increasing the availability of the existing plants (Figures 8 and 9). During the period from 1990 to 2004, the annual production of electricity from nuclear power plants rose from 1 901 TWh to 2 619 TWh, i.e. 37 %, while there were only 6,7 % more new plants constructed.

Slika 8
Uzrok povećanja proizvodnje nuklearnih elektrana u svijetu od 1990. – 2004. [10]
Figure 8
Factors increasing production from nuclear power plants in the world, 1990 – 2004 [10]

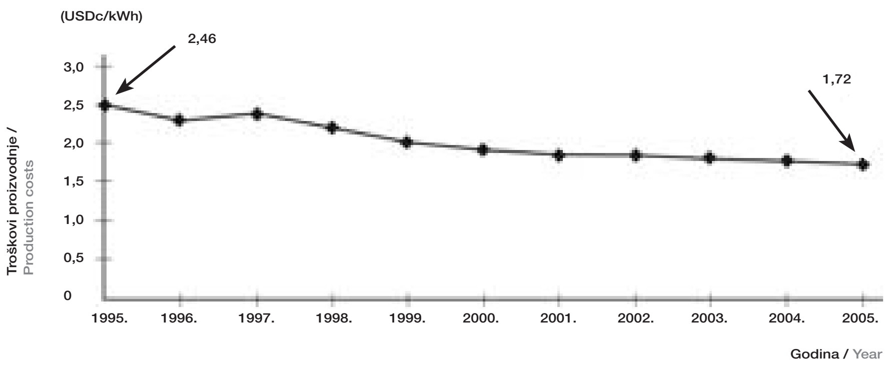


Slika 9
Faktor raspoloživosti američkih nuklearnih elektrana [6]
Figure 9
The availability factor of American nuclear power plants [6]



Povećanje raspoloživosti pogona omogućilo je značajno veću proizvodnju iz postojećih elektrana. U kombinaciji sa sustavnim snižavanjem troškova pogona i održavanja, nuklearna industrija je unatoč snažnom porastu cijene urana uspjela značajno sniziti troškove proizvodnje kWh električne energije (slika 10).

Increased plant availability permitted significantly greater production from existing power plants. Together with the systematic reduction in plant costs and maintenance, despite the considerable increase in the price of uranium, the nuclear industry succeeded in significantly lowering the production costs of a kWh of electrical energy (Figure 10).



Slika 10
Troškovi proizvodnje nuklearnog kWh u SAD-u [6]
Figure 10
Production costs for a nuclear kWh in the United States [6]

U devedesetima je energetika počela prolaziti kroz neke fundamentalne promjene. Glavni razlozi su: liberalizacija tržišta, privatizacija elektroprivrednih kompanija, problemi sigurnosti opskrbe te efekt staklenika.

Konsolidacija same nuklearne industrije, kao i navedeni eksterni faktori ponovo su učinili nuklearnu industriju atraktivnom investitorima i korisnicima električne energije.

Ekonomske prednosti nuklearne industrije nedvojbene su kod već izgrađenih reaktora. Već izgrađeni reaktori, naročito oni već otplaćeni, tj. oni koji imaju samo operativne troškove su prilično profitabilni i danas proizvode gotovo najjeftiniju struju na tržištu. Kod novih reaktora je sitacija nešto drugačija, a s obzirom na to da u Zapadnoj Europi već gotovo 20 godina nije započela gradnja niti jednog novog reaktora, nalaze studija teško je verificirati. Smjer u kojem ide razvoj nuklearne industrije ide k sve većim jedinicama kako bi se u što većoj mjeri ostvarile koristi od ekonomije veličine. Taj smjer međutim nosi i mnoge nedostatke: velik investicijski rizik, veliki i komplicirani projekti, relativno mali broj novoizgrađenih reaktora te mala mogućnost za standardizaciju, spora krivulja učenja i dugo vrijeme izgradnje. U tablici 1 predstavljeni su rezultati nekolicine recentnijih studija o troškovima proizvodnje električne energije iz nuklearnih elektrana. Rezultati su prilično različiti zbog različitosti ulaznih pretpostavki, što također dobro oslikava rizike koje nosi nuklearni projekt.

In the 1990s, energetics began to experience several fundamental changes. The main reasons were the liberalization of the markets, the privatization of electric companies, problems in the dependability of the supply and the greenhouse effect.

The consolidation of the nuclear industry itself, as well as the previously mentioned external factors, once again made the nuclear industry attractive to investors and electricity consumers.

The economic advantages of the nuclear industry are undoubtedly greater in the case of reactors that have already been built. Such reactors, especially those which have been paid for, i.e. those which have only operative costs, are fairly profitable and produce what is nearly the least expensive electricity on the market today. With new reactors, the situation is somewhat different, taking into account that for the past 20 years construction has not begun on single new reactor in Europe, so that study findings are difficult to verify. The direction in which the development of the nuclear industry is going is toward increasingly larger units, in order to achieve the maximum benefits from the economy of size. However, this direction also includes many shortcomings: high investment risk, large and complicated projects, the relatively small number of newly built reactors, little possibility for standardization, the slow learning curve and long construction time. In Table 1, the results of several recent studies on the costs of producing energy from nuclear power plants are presented. The results are fairly diverse due to the diversity of the input parameters, and also illustrate the risks of nuclear projects.

Tablica 1 – Usporedba procijenjenih troškova nuklearne električne energije [11]
Table 1 – Comparison of the estimated costs of nuclear electricity [11]

Izdavač / Publisher	Naziv Studije / Study Title	Izdana / Published	Trošak proizvodnje / Production Costs (EUR/MWh)
Lappeenranta University of Technology	Finnish 5th Reactor Economic Analysis	2002.	24
UK Performance and Innovation Unit	The Economics of Nuclear Power	2002.	34 – 56
Massachusetts Institute of Technology	The Future of Nuclear Power	2003.	55 – 65
The Royal Academy of Engineers	The Costs of Generating Electricity	2004.	34
University of Chicago	The Economic Future of Nuclear Power	2004.	43 – 58
Canadian Energy Research Institute	Levelised Unit Electricity Cost Comparison of Alternative Technologies for Base load Generation in Ontario	2004.	49
IEA/NEA	Projected Costs of Generating Electricity: 2005 Update	2005.	18 – 56

Konkurentnost nuklearnih elektrana u odnosu na elektrane na fosilna goriva različita je u pojedinim zemljama, te načelne ocjene nisu jednoznačne. U komparaciji alternativa potrebno je također imati na umu stalan i u posljednje vrijeme izražen trend porasta cijena fosilnih goriva, te tendenciju da se kWh iz elektrana na fosilna goriva optereti i naknadom za ispuštanje stakleničkih plinova. Iako su dugoročna predviđanja nezahvalna, s današnjim trendovima nuklearne elektrane su dugoročno vrlo atraktivan izbor.

Istodobno treba imati na umu da će neke od promjena koje se odvijaju u energetici postaviti i nove izazove pred nuklearnu industriju. Privatizacija i liberalizacija će prije svega pred investitore postaviti značajno veće rizike na povrat investicije. Uz napore koje ulaže industrija da nuklearne elektrane učini što atraktivnijom opcijom ulagačima, bez sumnje će i države morati prilagoditi pristup, prije svega u smislu licenciranja i regulatorne nesigurnosti.

The competitiveness of nuclear power plants in comparison to fossil fuel power plants is different in individual countries, and the principle assessments are not unambiguous. In comparison to alternatives, it is also necessary to bear in mind the recent marked trend of rising fossil fuel prices and the tendency for an extra charge to be levied on kWh from fossil fuel power plants for greenhouse gas emissions. Although long-term projections are unrewarding, with the current trends nuclear power plants are a very attractive long-term choice.

At the same time, it is necessary to bear in mind that some of the changes that are occurring in energetics will also pose new challenges to the nuclear industry. Privatization and liberalization will pose a significantly greater risk to investors in terms of returns on their investments. Besides the efforts by industry to make nuclear power plants an attractive option to investors, governments will undoubtedly have to adapt their approach, particularly regarding the questions of licensing and regulatory uncertainties.

6 OTPAD

Tipična nuklearna elektrana s tlakovodnim reaktorom električne snage 1 000 MW koja u jednoj godini proizvede oko 7,5 TWh električne energije, pri tome proizvede 200 – 350 m³ nisko i srednjeradioaktivnog otpada, oko 25 tona, odnosno oko 20 m³ visokoradioaktivnog otpada te oko 25 tona istrošenog goriva. Nisko i srednjeradioaktivni otpad čine zaštitna odjeća radnika, alati, krpe, istrošeni filteri, istrošene ionske smole i slično.

Doktrina zbrinjavanja otpada u nuklearnoj industriji je koncentrirati i izolirati, za razliku od doktrine, koja se primjenjuje u npr. termoelektranama na fosilna goriva raspršI i razrijedi.

Odlagališta radioaktivnog otpada se dizajniraju tako da se raznim inžinjerskim strukturama sprječava kontakt radioaktivnih materijala i okoline za vrijeme dok mogu predstavljati opasnost za okolinu.

Danas su u svijetu poznate i u primjeni mnoge metode obrade i zbrinjavanja i odlaganja nisko i srednjeradioaktivnog otpada, dok su metode za trajno i konačno zbrinjavanje visokoradioaktivnog otpada još uvijek u fazi ispitivanja (Yucca Mountain u SAD i ONKALO u Finskoj).

6.1 Zbrinjavanje nisko i srednjeradioaktivnog otpada

Nisko i srednjeradioaktivni otpad uobičajeno se zbrinjavaju u plitkim (površinskim ili pripovršinskim) ili dubokim odlagalištima. U tu svrhu se konstruiraju višestruke inženjerske barijere koje će osigurati višegodišnju izoliranost skladišta radi onemogućavanja kontakta radioaktivnih nuklida sa životnom sredinom, posebice podzemnim vodama.

Uobičajena tehnologija podrazumijeva ulaganje bačava s otpadom u armiranobetonske posude te ispunjavanje međuprostora betonom ili sličnim materijalom. Tako dobiveni blokovi odlažu se u betonirane tunele obložene nepropusnom glinom.

Kako je sprječavanje kontakta radionuklida s podzemnim i površinskim vodama jedan od najvažnijih zadataka, često se i čitavo skladište oblaže slojem vodonepropusnog materijala te se također ugrađuje i sustav kontrole drenaže vode koja bi eventualno prodrla u odlagalište.

Duboko odlaganje temelji se na identičnim osnovnim principima izolacije od okoline kao i plitko. Takva se odlagališta grade u stabilnim geološkim formacijama na dubinama od više desetaka do više stotina metara ispod površine

6 WASTES

A typical nuclear power plant with a pressurized water reactor and a power rating of 1 000 MW that produces approximately 7.5 TWh of electricity annually also produces 200 – 350 m³ of low-level and medium-level radioactive wastes, approximately 25 tons or 20 m³ of high-level radioactive wastes, and approximately 25 tons of spent fuel. Low-level and medium-level radioactive waste consists of protective workers' clothing, tools, rags, spent filters, spent ionic resins etc.

The doctrine for the disposal of wastes in the nuclear industry is concentrate and isolate, unlike the doctrine applied, for example, to fossil fuel thermoelectric power plants, which is disperse and dilute.

Repositories for radioactive wastes are designed with various engineering structures in order to prevent contact between radioactive materials and the environment for the period of time that they can pose a hazard to the environment.

Today, many methods are known and applied in the world for processing and disposing of low-level and medium-level radioactive wastes, while methods for the permanent and final disposal of high-level radioactive wastes are still in the investigative phase (Yucca Mountain in the United States and ONKALO in Finland).

6.1 The Disposal of Low-Level and Medium-Level Radioactive Wastes

Low-level and medium-level radioactive wastes are usually disposed of in shallow (surface or near surface) or deep repositories. For this purpose, multiple engineering barriers are constructed that will assure many years of isolation, in order to prevent contact between radioactive nuclides and the environment, particularly with underground waters.

The customary technology means the storage of barrels containing wastes in reinforced concrete vessels and filling the spaces with concrete or a similar material. Such blocks are then stored in concrete repository tunnels that are covered with impermeable clay.

Since the prevention of contact between radionuclides and underground and surfaces waters is one of the most important tasks, the entire repository is often coated with a layer of water-impermeable material and a system of controlled drainage water is installed that could eventually penetrate into the repository.

Deep repositories are constructed according the identical basic principles of isolation from the environment as are shallow repositories. Such repositories are built in stable geological formations at depths of zemlje. Stabilne geološke formacije i duboko zakapanje pružaju dodatnu sigurnost da će radionuklidi ostati izolirani od okoline dok god za nju predstavljaju opasnost.

Nisko i srednjeradioaktivni otpad sadrži radioizotope koji gube radiotoksičnost u vremenskom periodu od nekoliko godina pa do najviše nekoliko stotina godina. Osiguravanje izolacije u tom relativno kratkom vremenu ne predstavlja problem, te se smatra da današnja odlagališta tog otpada uspješno rješavaju taj problem. Mnoge države imaju odlagališta za srednje i nisko radioaktivni otpad koja normalno rade već dulji niz godina.

6.2 Zbrinjavanje istrošenog goriva

Za razliku od nisko i srednjeradioaktivnog otpada, istrošeno gorivo zadržava svoju radiotoksičnost i više od 100 000 godina, te trajno zbrinjavanje tog otpada predstavlja značajno veći izazov. Istrošeno gorivo po izlasku iz reaktora sadrži samo oko 3 % fisijskih produkata, tj. pravog otpada. Reprocesiranjem se fisijski produkti izdvajaju i nakon toga ustakljuju te tako odlažu kao visokokoncentrirani visokoradioaktivni otpad. Alternativa tome je direktno odlaganje, tj. gorivi elementi se odlažu u posebno konstruirane spremnike i takvi odlažu u duboka geološka odlagališta.

Prednost reprocesiranja leži u tom što se značajno smanjuje volumen otpada za odlaganje, te u tome što se najveći dio istrošenog goriva može ponovno koristiti u gorivom ciklusu nuklearnih reaktora. Nedostatci su u danas visokoj cijeni procesa te u opasnosti od proliferacije plutonija izdvojenog reprocesiranjem. Tablica 2 prikazuje prihvaćene strategije u raznim državama u svijetu.

tens to hundreds of meters below the surface of the earth. Stable geological formations and deep burial provide additional assurance that the radionuclides will remain isolated from the environment as long as they represent a hazard.

Low-level and medium-level wastes contain radioisotopes that lose their radiotoxicity within a period of from several years to a maximum of several hundred years. The problem of insuring their isolation for this relatively short time is considered to have been successfully solved by today's repositories. Many countries have repositories for low-level and medium-level radioactive wastes that have operated normally for many years.

6.2 The Disposal of Spent Fuel

Unlike low-level and medium-level radioactive wastes, spent fuel retains its radiotoxicity for over 100 000 years, and the permanent disposal of this waste represents a considerably greater challenge. Upon leaving the reactor, spent fuel contains only 3 % fission products, i.e. genuine waste. Through reprocessing, the fission products are separated and afterward placed in glass and disposed of as highly concentrated high-level radioactive waste. An alternative to this is direct disposal, i.e. the fuel elements are placed in specially constructed vessels and then placed in deep geological repositories.

The advantages of reprocessing lie in the significant reduction in the volume of waste for disposal and that most of the spent fuel can be reused in the fuel cycle of nuclear reactors. The shortcomings are in the high cost of the process and the danger of the proliferation of plutonium separated by reprocessing. Table 2 shows the accepted strategies in the regimes of various countries throughout the world.

Tablica 2 – Pregled strategija postupanja s istrošenim gorivom [6]
Table 2 – Strategies for dealing with spent nuclear fuel [6]

Država / Country	Direktno odlaganje / Direct disposal	Reprocesiranje / Reprocessing
Belgija / Belgium	✓	✓
Kanada / Canada		
Kina / China	✓	✓
Finska / Finland		
Francuska / France		✓
Njemačka / Germany		✓
Indija / India		✓
Japan / Japan		✓
Rusija / Russia	✓	✓
Južna Koreja / South Korea	✓	
Španjolska / Spain	✓	
Švedska / Sweden		
Švicarska / Switzerland		✓
Velika Britanija / Great Britain	✓	✓
SAD / United States		

S obzirom da još uvijek niti jedno trajno odlagalište visokoradioaktivnog otpada nije u pogonu, visokoradioaktivni otpad se trenutno skladišti u privremenim odlagalištima. Primjenjuju se tehnologije mokrog i suhog skaldištenja. Mokro skaldištenje se odvija u bazenima za istrošeno gorivo u sklopu nuklearnih elektrana ili u za tu svrhu posebno izgrađenim centralnim objektima, dok je suho odlaganje obavlja u dizajniranim suhim spremnicima casks.

Pri skladištenju visokoradioaktivnog otpada, osim izolacije radionuklida od okoline potrebno je osigurati stalno i efikasno hlađenje istrošenog goriva koje emitira toplinu još dosta godina po vađenju iz reaktora.

Troškove zbrinjavanja otpada nije moguće odrediti s potpunom sigurnošću s obzirom da još ne postoje konkretna iskustva s trajnim odlaganjem visokoradioaktivnog otpada, ali se u većini analiza i studija procjenjuje da troškovi zbrinjavanja otpada, uključujući razgradnju nuklearne elektrane, sudjeluju u ukupnoj cijeni električne energije iz nuklearnih elektrana s oko 10 %.

U prijašnjim desetljećima je pitanje trajnog rješavanja pitanja visokoradioativnog otpada bilo zanemarivano, te odgađano za budućnost. Danas sve više država uviđa da je to pitanje nužno riješiti što prije kako bi se omogućilo i opravdalo daljnje korištenje nuklearne energije.

Since not a single permanent repository for high-level radioactive waste is in operation, high-level radioactive waste is currently stored in temporary repositories. The technologies of wet and dry storage are used. Wet storage means placing the spent fuel in pools within the grounds of the nuclear power plants or specially constructed central objects for this purpose, while dry storage involves placing the spent fuel in specially designed dry storage casks.

In the storage of high-level radioactive waste, in addition to the isolation of the radionuclides from the environment, it is necessary to provide constant and efficient cooling of the spent fuel, which emits heat for many years after being removed from the reactor.

It is not possible to determine the costs for the disposal of wastes with complete certainty because there is no concrete experience with the permanent storage of high-level radioactive wastes, but in the majority of analyses and studies it is estimated that the costs of waste disposal, including the decommissioning of nuclear power plants, comprise approximately 10 % of the total price of electricity from nuclear power plants.

In past decades, the question of the permanent solution to the problem of high-level radioactive waste received little attention and was postponed for the future. Today, an increasing number of countries realize that it is necessary to resolve this question as soon as possible in order to facilitate and justify the continued use of nuclear energy.

7 SIGURNOST

Primarna pažnja javnosti i investitora usmjerena je na rizik od udesa na nuklearnom reaktoru s oslobađanjem radioaktivnosti u okoliš. Zbog specifičnog rizika sigurnost je od početaka bila odlučujući kriterij kod izgradnje nuklearnih elektrana, rezultirajući u konzervativnim tehničkim i termodinamičkim parametrima goriva i rashladnog sustava. Zbog niske cijene urana učinak na ekonomiju bio je malen, ali je konzervativnost u projektiranju imala nepovoljan učinak na investicijske troškove.

Opsežna probabilistička studija nuklearne sigurnosti WASH-1400 [12] objavljena 1974. godine omogućila je uočavanje komponenata koje u većoj mjeri doprinose riziku i time racionalniju primjenu kozervativnog projektiranja. Veličina koja se koristi za kvantitativno izražavanje sigurnosti reaktora je vjerojatnost talenja reaktorske jezgre VTJ ili CMP (Core Melting Probability). Takav događaj počinje s nekim inicijalnim kvarom, razvija se pretpostavkom slijeda drugih kvarova koji mogu konačno dovesti do izostanka hlađenja jezgre. Semi-empiričkom probabilističkom metodom računaju se doprinosi svih inicirajućih događaja da bi njihov zbroj dao ukupnu vjerojatnost taljenja jezgre reaktora. Analizom učestalosti inicirajućih kvarova za razdoblje od 1969. do 1974. godine došlo se do godišnje vjerojatnosti taljenja jezgre od 10^{-4} do 10^{-3}, bliže višoj vrijednosti [13]. Jedno topljenje na reaktoru elektrane Otok Tri Milje (bez Černobilja kao reaktora irelevantnog za zapadnu reaktorsku tehnologiju) u 10 000 reaktor-godina pogona do 2005. godine potvrđuje procjenu.

Brojna poboljšanja sigurnosti na lakovodnim reaktorima PWR i BWR tipa u pogonu, primijenjena nakon udesa na elektrani Otok Tri Milje smanjila su vjerojatnosti taljenja jezgre za 6 odnosno 8 puta [14]. Analiza inicirajućih događaja u razdoblju od 1980. do 1982. godine dala je vjerojatnost taljenja jezgre oko 1,5 x 10^{-4} i zatim 10^{-4} za sredinu 80-tih godina. No, već projekti novih reaktora izvedeni u 80-tim godinama mogli su ugraditi rezultate sigurnosnih studija i analiza i postići veliko smanjenje vjerojatnosti taljenja jezgre.

Tako je izračunata vjerojatnost taljenja jezrge reaktora Sizewell B, koji je u pogonu od 1995. godine, smanjena na 1,1 x 10^{-6}. Slične, gotovo sto puta manje vrijednosti nego u 80-tim godinama imaju i drugi novi projekti kao američki AP600 ili finski PWR reaktor Olkiluoto 3 u gradnji. Zaštitna zgrada oko reaktora (bez koje je bio Černobiljski reaktor) smanjuje vjerojatnost širenja radioaktivnosti u okoliš na oko 3 x 10^{-9}, pa i manje.

7 SAFETY

The primary attention of the public and investors is focused on the risk from an accident at a nuclear reactor with the release of radioactivity into the environment. Due to this specific risk, safety was the deciding criterion from the beginning in the construction of nuclear power plants, resulting in a conservative technique and thermodynamic parameters for fuel and the cooling system. Due to the low price of uranium, the impact on the economy was slight. Nevertheless, conservatism in designing had an unfavorable impact on investment costs.

An exhaustive probability study on nuclear safety, WASH-1400 [12], published in the year 1974, made it possible to identify the components that largely contribute to the risk and apply conservative design practices rationally. The value that is used for the quantitative expression of the safety of a reactor is the Core Melting Probability (CMP). Such an event begins with an initial equipment problem and develops with the assumption of a sequence of other problems which can ultimately lead to loss of core cooling. Using the semi-empirical probabilistic method, the contributions of all the initiating events are computed, the sum of which yields the total value of the Core Melting Probability of a reactor. Thorough analysis of the frequency of initiated equipment problems for the period from 1969 to 1974 yielded annual Core Melting Probabilities of from 10^{-4} to 10^{-3}, closer to the higher value [13]. One core melting in a reactor at Three Mile Island (not counting Chernobyl because this reactor is irrelevant for Western reactor technology) out of 10 000 cumulative reactor years up to the year 2005 confirms this estimate.

Numerous security improvements on light-water reactors of the PWR and BWR types in operation, which were applied after the accident at Three Mile Island, have reduced Core Melting Probability by 6 or 8 times [14]. Analysis of the initiating events during the period from 1980 to 1982 yielded a CMP of approximately 1,5 x 10^{-4} and then 10^{-4} for the mid 1980s. However, the projects for new reactors constructed during the 1980s were already able to incorporate the results of the safety studies and analyses, and achieved even greater reduction of the CMP.

Thus, the calculated Core Melting Probability of the Sizewell B reactor, which has been in operation since 1995, was reduced to 1,1 x 10^{-6}. Similarly, other new projects such as the American AP 600 and the Finnish PWR Olkiluoto 3 under construction have nearly one hundred times lower probabilities than those built during the 1980s. A protective building around a reactor (which the

S tisuću reaktora u pogonu jedno talenje jezgre moglo bi se očekivati u tisuću godina, a kada bi se dogodilo, vjerojatnost širenja radioaktivnosti u okoliš bila bi manja od jedan posto zahvaljujući zaštitnoj zgradi. To je izuzetan stupanj sigurnosti prihvatljiv i za najgušće naseljena područja.

Rad na unaprjeđenju nuklearne sigurnosti svejedno se i dalje nastavlja u okvirima medjunarodnih projekata INPRO, reaktora Generacije IV. i drugim, ali prioritet nije daljnje smanjenje vjerojatnosti taljenja jezgre. Smanjena vjerojatnost u većoj mjeri će se ostvariti inherentnim fizikalnim karakteristikama i zakonitostima, a manje višestrukošću sigurnosnih sustava, što vodi u visoke investicijske troškove.

8 PROLIFERACIJA

Za razliku od tehničkih i ekonomskih pitanja koja se postavljaju kad se raspravlja o budućnosti nuklearne energetike i koja se rješavaju istraživanjem i razvojem, problem nuklearne proliferacije, tj. širenja nuklearnog oružja primarno je politički i treba biti razriješen političkim metodama. No, to ne umanjuje utjecaj na budućnost nuklearne energije. Nije sporno da se tehnologija za miroljubivo korištenje nuklearne energije može upotrijebiti za dobivanje nuklearnog eksploziva, iako početne i priznate nuklearne sile SAD, SSSR, Velika Britanija, Francuska i Kina nisu išle tim putem, jer je prva primjena nuklearne energije bila vojna. U Međunarodnoj studiji gorivnih ciklusa (International Fuel Cycle Evaluation, INFCE, 1978 –1980) prerada goriva i obogaćenje urana izdvojene su kao operacije ciklusa goriva osjetljive s obzirom na proliferaciju.

Prije 30 godina američki predsjednik Jimmy Carter zabranio je preradu istrošenog goriva u SAD, ali ta tehnička mjera zamišljena da spriječi proliferaciju izdvajanjem plutonija nije imala odziva u zemljama manje bogatima uranom od SAD. Osim pet nominalnih nuklearnih sila, medju kojima je Ruska Federacija u tom smislu sljednik SSSR-a, još dvanaest zemalja posjeduje instalacije za obogaćenje ili preradu goriva (Argentina, Belgija, Brazil, Indija, Italija, Izrael, Japan, Južna Afrika, Nizozemska, Njemačka, Pakistan, Sjeverna Koreja). Četiri od njih danas su prepoznate kao zemlje u posjedu nuklearnog oružja. U jednom periodu to je vrijedilo i za Južnu Afriku. Irački pokušaj proizvodnje plutonija završio je 1981. godine kada su izraelske zračne snage uništile irački reaktor Osiraq. Ozbiljna zabrinutost izazvana je gradnjom instalacija za obogaćenje

Chernobyl reactor lacked) reduces the probability of spreading radioactivity into the environment to approximately a value of 3×10^{-9}, or even lower. With a thousand reactors in operation, one core melting can be anticipated in a thousand years, and when it would occur, the probability of the spread of radioactivity into the environment would be less than one percent, owing to the protective building. This exceptional degree of safety is even acceptable for the most densely populated areas.

Nonetheless, work on improving nuclear safety continues within the framework of international projects such as the International Project on Innovative Nuclear Reactors and Fuel Cycles, INPRO, Generation IV reactors etc. However, the priority is not further reduction in CMP. Lower probability will be achieved to a greater extent through the inherent physical characteristics and laws, and to a lesser extent through multiple safety systems, which lead to high investment costs.

8 PROLIFERATION

Unlike technical and economic questions that are posed when the future of nuclear energy is discussed and are solved by research and development, the problem of nuclear proliferation, i.e. the spread of nuclear weapons, is primarily political and should be solved by political methods. However, this does not diminish the impact on the future of nuclear energy. It is indisputable that the technology for the peaceful use of nuclear energy can be used for obtaining a nuclear explosive, although the original and recognized nuclear powers, i.e. the United States, Soviet Union, Great Britain, France and China, did not take this path, because the first applications of nuclear energy were military. In the International Fuel Cycle Evaluation, INFCE, 1978 – 1980, the processing of fuel and enrichment of uranium were singled out as proliferation sensitive fuel cycles operations.

Thirty years ago, the American president Jimmy Carter prohibited the processing of spent nuclear fuel in the United States. However, this technical measure, conceived to prevent nuclear proliferation from the separation of plutonium, was not implemented in countries less rich in uranium than the United States. Except for the five nominal nuclear powers, among whom the Russian Federation is in this sense the heir to the former Soviet Union, another twelve countries possess installations for the enrichment or processing of nuclear fuel (Argentina, Belgium, Brazil, India, Italy, Israel, Japan, South Africa, the Netherlands, Germany, Pakistan and North Korea). Four of them are already recognized as countries that urana u Iranu, bez obzira na deklaracije da se radi samo o energetskom programu.

Ako se promatra budućnost u kojoj bi nuklearna energija dala bitan doprinos zamjeni fosilnih goriva u svim sektorima potrošnje, onda to znači višestruko veći broj reaktora, s nizom novih nuklearnih zemalja. Nastavljajući s praksom nacionalnih instalacija za preradu goriva i obogaćenjem urana to znači i povećanu opasnost nuklearne proliferacije, kao i ilegalnog prometa nuklearnim materijalima.

Pitanje dugoročne budućnosti nuklearne energije moglo bi se formulirati kao pitanje može li se gradnja nacionalnih instalacija za obogaćenje urana i preradu istrošenog goriva zamjeniti rješenjem otpornijim na proliferaciju, nekim oblikom međunarodnog servisa za opskrbu nuklearnim gorivom. Premda se u današnjoj međunarodnoj situaciji s otvorenim konfliktima na Bliskom Istoku, Dalekom Istoku, te izmedju Indije i Pakistana, napuštanje nacionalnih instalacija izgleda nedostižnom iluzijom. Optimizam se ipak može izvoditi iz toga što je alternativa gotovo sigurno klizanje u proliferaciju, nuklearni terorizam i katastrofu nuklearnog sukoba.

8.1 Ugovor o neširenju nuklearnog oružja – pokušaj kontrole nuklearne proliferacije

Najraniji pokušaj da se osigura od zloupotrebe nuklearne tehnologije bio je američki prijedlog u Ujedinjenim Narodima 1946. dok su eksplozije nad Hiroshimom i Nagasakijem još bile u svježem sjećanju. Prema tome prijedlogu, poznatom kao Lilienthal-Baruchov prijedlog, osnovala bi se agencija u okviru Ujedinjenih Naroda, International Atomic Development Agency, IADA, koja bi u svojim instalacijama obavljala najveći dio aktivnosti ciklusa goriva. No, Sovjetski Savez je tada već radio na svojoj atomskoj bombi (aktivirana 1949. godine) i suprostavio se prijedlogu.

Umjesto da svijet krene zajedničkim putem prema miroljubivom korištenju nuklearne energije, započela je trka u nuklearnom naoružanju. Ona je trajala sve do raspada Sovjetskog Saveza 1990. s time što je količina nuklearnog oružja dosegla brojke od više desetaka tisuća atomskih glava na svakoj strani, dovoljno za višestruko uništenje planeta.

Sredinom 80-tih godina u zraku su trajno bili bombarderi s nuklearnim oružjem, a desetine nuklearnih brodova i podmornica bile su razmještene na strateškim pozicijama, spremne za neposrednu akciju. Uz izvjesnu dozu sreće čovječanstvo je preživjelo taj nevjerojatan period.

possess nuclear weapons. At one period, this also applied to South Africa. Iraqi attempts to produce plutonium ended in 1981, when Israeli aerial forces destroyed the Iraqi reactor Osiraq. The construction of installations for the enrichment of uranium in Iran has aroused serious concern, despite a declaration that this merely involves the energy program.

If a future is considered in which nuclear energy would provide a significant contribution to the replacement of fossil fuels in all sectors of consumption, this would mean many times more reactors and a series of new nuclear countries. Continuing with the practice of national installations for the processing of spent nuclear fuel and uranium enrichment also signifies an increased threat of nuclear proliferation, as well as the illegal traffic of nuclear materials.

The question about the long-term future of nuclear energy could be formulated as the question of whether the construction of national installations for the enrichment of uranium and the processing of spent nuclear fuel can be replaced by a solution providing greater resistance to proliferation, some form of international service for the supply of nuclear fuel. Although in the current situation with open conflicts in the Near East, Far East, and between India and Pakistan, the abandonment of national installations appears to be a pipe dream. Optimism is possible because the alternative is nearly certain proliferation, nuclear terrorism and catastrophic nuclear conflict.

8.1 The Treaty on the Non-Proliferation of Nuclear Weapons – An Attempt to Control Nuclear Proliferation

The earliest attempt to insure against the abuse of nuclear technology was the American proposal at the United Nations in 1946, while the explosions in Hiroshima and Nagasaki were still fresh in memory. According to this proposal, known as the Lilienthal-Baruch Plan, an agency would be established within the framework of the United Nations, the International Atomic Development Agency, IADA, which would conduct most of the activity of the fuel cycle in its own installations. However, the Soviet Union was already working on its own atomic bomb, activated in the year 1949, and opposed this proposal.

Instead of the world embarking on a common path toward the peaceful use of nuclear energy, the nuclear arms race began. It lasted until the dissolution of the former Soviet Union in 1990, when there were many tens of thousands of atomic warheads on each side, enough to destroy the planet many times over.

Medjutim, ta situacija kao pozadina bitna je za razumijevanje kontrole širenja nuklearnog oružja. Do 1990. godine dvije nadmoćne nuklearne super sile kontrolirale su svaka svoj blok, dok je grupa nesvrstanih zemalja inzistirala na nuklearnom razoružanju.

U toj općoj atmosferi 1970. godine stupio je na snagu Ugovor o neširenju nuklearnog oružja, Non-Proliferation Treaty (NPT). NPT je ugovor izmedju grupe zemalja u posjedu nuklearnog oružja i zemalja koje ne posjeduju nuklearno oružje, ali žele iskorištavati nuklearnu energiju u miroljubive svrhe. Te zemlje obvezuju se ugovorom, (članak III.), isključivo na miroljubivu uporabu i prihvat međunarodnih kontrola od strane Međunarodne agencije za atomsku energiju MAAE (IAEA Safeguards). Nuklearne sile pak obvezuju se na stvarne korake prema nuklearnom razoružanju i na pomoć u usvajanju nuklearne tehnologije (članak IV.). Uravnotežene obveze dviju strana Ugovora rezultirale su u tome da je Ugovor o neširenju nuklearnog oružja postao jedan od najšire prihvaćenih međunarodih ugovora, sa 189 država potpisnica do konca 2006. godine.

Ugovor predviđa reviziju stanja primjene svakih pet godina. No, kako se iza 1970. godine utrka u nuklearnom naoružanju još samo intenzivirala, petogodišnje revizijske konferencije bile su mjesto sve oštrije kritike nenuklearnih članica prema nuklearnim silama. Čevrta revizijska konferencija 1990. godina bila je u nešto povoljnijoj atmosferi nakon sporazuma o uklanjanju nuklearnog oružja srednjeg dometa (Intermediate Nuclear Force Treaty) 1987. godine. U pozitivnijoj klimi nakon prestanka hladnog rata potpisani su izmedju SAD i Sovjetskog Saveza ugovori o smanjenju strateškog nuklearnog oružja, START I, 1991. godine, s redukcijom od polaznih 13 000 i 10 000 atomskih glava na oko 8 000 za svaku stranu. START II potpisan je 1993. godine i predviđa daljnju redukciju na 3 000 do 3 500 atomskih glava za svaku stranu.

Nakon raspada Sovjetskog Saveza najvećim dijelom je povučeno taktičko oružje malih snaga i malog dosega koje je izgubilo svoje mjesto u novim strateškim odnosima.

U toj povoljnijoj klimi na Petoj revizijskoj NPT konferenciji održanoj 1995. godine dogovoreno je produženje ugovora na neodređeno vrijeme. Nakon toga, pogoršanje opet nastupa kad je postalo vidljivo da bez obzira na ugovore START I i START II ipak ne dolazi do značajne redukcije strateškog oružja najveće snage. Također nije stupio na snagu ugovor o obustavi svih nuklearnih

During the mid 1980s, there were constantly bombers carrying nuclear weapons in the air, and dozens of nuclear ships and submarines were stationed at strategic positions, ready for direct combat. Humankind survived this incredible period with a certain amount of luck. However, this situation is the essential background for understanding the control of the proliferation of nuclear weapons. Until 1990, the two nuclear superpowers each controlled their own blocks, while the group of nonaligned countries was insisting upon nuclear disarmament.

Amidst this general atmosphere, in 1970 the Non-Proliferation Treaty, NPT, went into effect. The NPT is a contract among a group of countries that possess nuclear weapons and countries that do not possess nuclear weapons but want to use nuclear energy for peaceful purposes. These countries are obligated by Article III of the Treaty to use nuclear energy exclusively for peaceful purposes and accept international control by the International Atomic Energy Agency (IAEA Safeguards). The nuclear powers are obligated to take actual steps toward nuclear disarmament and contribute “to the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear-weapon States” (Article IV). The balanced obligations of the two parties to the Treaty resulted in it becoming one of the most widely accepted international treaties, with 189 countries having signed it by the end of the year 2006.

The Treaty provides for a review of its operation every five years. However, since the nuclear arms race only intensified after 1970, the Review and Extension Conferences held every five years were places of increasingly sharp criticism of the nuclear powers by the non-nuclear members. The Fourth Review and Extension Conference, held in the year 1990, took place in a somewhat more favorable atmosphere following the Intermediate-Range Nuclear Forces Treaty of 1987, on the elimination of intermediate-range weapons. In the positive climate following the end of the Cold War, treaties were signed between the United States and the Soviet Union on the reduction of strategic nuclear weapons, START I, 1991, with reduction from the initial 13 000 and 10 000 atomic warheads on each side to approximately 8 000 on each side. START II, signed in 1993, called for further reductions of 3 000 – 3 500 atomic warheads on each side.

After the dissolution of the Soviet Union, for the most part tactical weapons of low power and range that had lost their places in the new strategic relationship were withdrawn.

testova (Comprehensive Test Ban Treaty, CTBT) potpisan1996.

Na Šestoj revizijskoj NPT konferenciji 2000. godine nuklearne sile svjesne svojih neispunjenih obveza deklariraju svoju predanost procesu nuklearnog razoružanja (unequivocal commitment). No, u idućih pet godina do sljedeće, posljednje Sedme revizijske NPT konferencije 2005. godine nije bilo napretka niti u redukciji naoružanja niti u stupanju na snagu zabrane testova (CTBT), kao ni Ugovora o zabrani proizvodnje materijala za nuklearno oružje, Fissile Materials Cut of Treaty, FMCT, pa je ova konferencija završila bez dogovora i zaključaka, u neizvjesnosti, s pesimističkim predviđanjima glede budućnosti.

Tu su relevantna upozorenja Direktora MAAE dr. Muhameda ElBaradeia iz kolovoza 2006. godine [15] prilikom desete godišnjice potpisa Ugovora o zabrani nuklearnih testova CTBT koji još uvijek nije stupio na snagu, iako ga je potpisalo 170 zemalja, a ratificiralo 135, pa dakle odražava želju većine zemalja. Dr. ElBaradei ističe da je NPT utemeljen na dva stupa, prvi stup je kontrola proliferacije prema članku III. Ugovora. Tu je MAEE načinila mnogo, od 1970. godine razvijena je kontrolna operativa i regulativa, ugovore o kontroli ratificiralo je 162 potpisnice NPT-a, a njih 78 i kasnije formulirane (od 1997. godine) Dodatne protokole kojima se osigurava viši stupanj sigurnosti od proliferacije. Drugi stup Ugovora o neširenju nuklearnog oružja je članak VI, obveza nuklearne petorke da učine stvarne korake prema uklanjanju nuklearnog oružja. Dr. ElBaradei navodi da u 2006. godini još uvijek postoji oko 27 000 atomskih glava. No, nije samo problem što nije došlo do bitnog napretka u uklanjanju nuklearnog oružja. Ni deset godina nakon potpisa na snagu nije stupio Ugovori o zabrani nuklearnih pokusa CTBT, a za zabranu proizvodnje materijala za nuklearno oružje, FMCT još nema suglasnosti za početak pregovora. Ta su dva ugovora bitna za zaustavljanje daljnjeg razvoja i proizvodnje nuklearnog oružja. Izostaje potvrda nuklearnih sila da one doista imaju namjeru ispuniti svoju obvezu prema NPT i odreći se nuklearnog oružja. U takovoj situaciji dr. ElBaradei naslućuje mogućnost erozije NPT- a, smatrajući da se međunarodni sustav kontrole proliferacije nalazi na opasnoj prekretnici.

8.2 Multilateralni pristupi

Zadržavanjem velikog dijela strateškog nuklearnog arsenala dviju nuklearnih supersila gotovo dvadeset godina po završetku hadnog rata, nuklearno oružje pretvoreno je u svojevrsni statusni simbol i prepoznato kao poluga svjetske dominacije. Ono postaje atraktivno ili izaziva obrambenu reakciju, a

In this favorable climate, at the Fifth NPT Review and Extension Conference, held in the year 1995, the extension of the Non-Proliferation Treaty for an indefinite period of time was agreed upon. After this, the situation worsened when it became evident that despite START I and START II, there was not going to be any significant reduction in the strategic weapons of the superpowers. Furthermore, the Comprehensive Test Ban Treaty, CTBT, which was signed in the year 1996, did not go into effect.

At the Sixth NPT Review and Extension Conference, held in the year 2000, the nuclear powers, aware of their unfulfilled obligations, declared their unequivocal commitment to the nuclear disarmament process. However, during the subsequent five years until the Seventh NPT Review and Extension Conference in 2005, there was no progress in the reduction of armaments, the going into effect of the Comprehensive Test Ban Treaty (CTBT) or the going into effect of the Fissile Material Cut-Off Treaty, FMCT, to ban the production of fissile material that can be used for nuclear weapons. Thus, the Seventh NPT Review and Extension Conference ended without consensus or conclusions, in uncertainty, amidst pessimistic forecasts for the future.

Relevant warnings were made by the General Director of the International Atomic Energy Agency (IAEA), Dr. Mohamed ElBaradei, in August 2006 [15] on the occasion of the tenth anniversary of the Comprehensive Test Ban Treaty opening for signature, which still has not gone into force although it has been signed by 170 countries and ratified by 135, thereby expressing the desire of the majority of countries. Dr. ElBaradei points out that the Nuclear Non-Proliferation Treaty had two "legs," the first of which was non-proliferation according to Article III of the Treaty. The IAEA had done much in this regard, having established a system of verification in 1970. An arms control treaty was ratified by 162 signers of the Non-Proliferation Treaty, and 78 of them ratified the subsequently formulated (1997) Additional Protocol, which assures a higher degree of protection from proliferation. The other "leg" of the Nuclear Non-Proliferation Treaty is Article VI, a commitment by the five countries with nuclear weapons to take actual steps towards nuclear disarmament. Dr. ElBaradei notes that in the year 2006, there were still 27 000 nuclear warheads in existence. However, the problem was not only that there had been no significant progress in the elimination of nuclear weapons. Even ten years after the Comprehensive Test Ban Treaty had been opened for signature, it had not gone into effect, and for the Fissile Material Cut-Off Treaty, FMCT, there was still no agreement on a mandate to start negotiating. These two treaties are essential to halt the continued development and production of nuclear weapons. What is missing is u svakom slučaju stimulira proliferaciju. Nuklearne sile koje se ne razoružavaju, niti su spremne odreći se daljnjeg razvoja nuklearnog oružja nisu u poziciji, ni moralno ni legalno, pozivati se na NPT u nastojanju da zaustave nuklearne razvoje u nenuklearnim zemljama. Pokušava se stoga novim pristupom gdje se pojedinim zemljama nude ugovori za opskrbu nuklearnim gorivom, ukoliko odustanu od vlastitih instalacija za obogaćenje urana.

Zemlja koja dobavlja gorivo pri tom nema obveze vlastitog razoružanja, a zemlja primalac odriče se prava koje je imala po članku IV. ugovora NPT. Za razliku od sustava NPT koji je imao gotovo univerzalan prihvat svojom ravnotežom obveza dviju strana, u tzv. Multilateralnom sustavu nuklearne zemlje nemaju obveze razoružanja. Vrlo je mala šansa da takav sustav bude univerzalno prihvaćen poput NPT-a. Nije nemoguće da će takav sustav dobave goriva biti pogodan nekim zemljama, ali ga sigurno neće prihvatiti one zemlje koje kao i postojeće nuklearne sile žele posjedovati taj statusni simbol. Multilateralne pristupe analizirala je i MAAE [16]. Međutim, jedno univerzalno prihvaćanje odricanja od nacionalnih instalacija za obogaćenje urana i preradu goriva zamislivo je samo ako bi se sve postojeće instalacije, dakle i one u nuklearnim zemljama, izuzele iz nacionalnog upravljanja i došle pod jurisdikciju i nadzor međunarodne organizacije poput MAAE, drugim riječima ako bi se vratili na nešto slično početnom pokušaju iz 1946. godine. No, dok je internacionalizacija gorivnog ciklusa dugoročnija budućnost, koraci nuklearnih zemalja potpisnica NPT u pravom smjeru bili bi oni kojim bi one pokazale namjeru ispunjavanja svojih obveza po članku VI, a to su prihvat zabrane testova, tj. ugovora CTBT i zabrane proizvodnje materijala za nuklearno oružje (FMCT).

confirmation from the nuclear powers that they truly intend to fulfill their obligations toward the Nuclear Non-Proliferation Treaty and relinquish their nuclear weapons. In such a situation, Dr. ElBaradei senses possible erosion of the NPT, in that the international system of the control of nonproliferation could be at a dangerous turning point.

8.2 Multilateral Approaches

The two nuclear superpowers, by retaining a large portion of their strategic nuclear arsenal for nearly twenty years after the end of the Cold War, have transformed nuclear weapons into a type of status symbol that is recognized as a lever of world domination. Nuclear weapons are becoming attractive or provoke a defensive reaction, and in any case stimulate proliferation. The nuclear powers are not disarming, are not ready to relinquish the further development of weapons, and are not in a moral or legal position to invoke the NPT in their attempts to stop nuclear development in non-nuclear countries. They are, therefore, attempting a new approach, whereby they offer individual countries contracts for the supply of nuclear fuel if they relinquish their own installations for uranium enrichment.

Accordingly, the country that supplies nuclear fuel is not required to disarm, and the recipient country relinquishes the rights which it had pursuant to Article IV of the Nuclear Non-Proliferation Treaty. Unlike the system of the NPT, which had almost universal acceptance with its balanced obligations between the two sides, the nuclear countries are not obligated to disarm in the so-called multilateral system. There is very little chance that such a system would be universally accepted, as was the NPT. It is not impossible that such a system for the supply of nuclear fuel will be favorable for some countries, but it certainly will not be accepted by those countries which, like the existing nuclear powers, want to possess this status symbol. Multilateral approaches have also been analyzed by the IAEA [16]. However, the universal acceptance of the relinquishment of national installations for uranium enrichment and processing spent nuclear fuel is only conceivable if all the installations, including those in the nuclear countries, are removed from national administration and come under the jurisdiction and supervision of an international organization such as the IAEA, i.e. if they were to return to something similar to the attempt begun in the year 1946. However, while the internationalization of the fuel cycle is still in the distant future, it would be a step in the right direction by the nuclear countries that are signers of the NPT to demonstrate their intentions to fulfill their obligations pursuant to Article VI, by accepting the test ban, i.e. the Comprehensive Test Ban Treaty, and by prohibiting the production of materials for nuclear weapons according to the Fissile Material Cut-Off Treaty.

9 ZAKLJUČAK

Nakon pet desetljeća postojanja nuklearna energetska industrija je sazrijela, a njen udio u opskrbi električnom energijom na svjetskoj razini je 16 %. Trendovi u planiranju energetike ponovo ju čine atraktivnom opcijom, te mnogi predviđaju daljnji rast sadašnjeg udjela u opskrbi. Zalihe urana dostatne su da omoguće razvoj čak i u najoptimističnijem scenariju. Tehnološki razvoj i akumulirano iskustvo učinili su današnje reaktore pogonski pouzdanim i ekonomičnim, a sigurnost je dosegla vrlo visok nivo. Proizvodnja velikih količina električne energije bez emisija stakleničkih plinova svakako je jedan od glavnih aduta nuklearne tehnologije.

Unatoč značajnom napretku, najavljena nuklearna renesansa sa sobom nosi i značajne izazove za nuklearnu industriju. Prije svega sadašnji dobri pokazatelji sigurnosti, pouzdanosti i ekonomičnosti pogona reaktora moraju se nastaviti i u budućnosti. Liberalizacija tržišta električnom energijom mijenja preference investitora i čini ih više osjetljivim na rizike. Zbog toga će nuklearna industrija morati uložiti značajne napore za snižavanje troškova i skraćivanje rokova izgradnje nuklearnih elektrana. Iako je pitanje zbrinjavanja nisko i srednje radioaktivnog otpada riješeno, potrebno je uložiti dodatne napore kako bi se ponudio adekvatan odgovor i na pitanje zbrinjavanja visokoradioaktivnog otpada. Značajno širenje nuklearne energije nesumnjivo će povećati i opasnost od proliferacije nuklearnih materijala, te je i u tom aspektu potrebno uložiti značajne napore. Očekuje se da će reaktori naprednog dizajna (AP1000, EPR, ABWR) s karakteristikama pasivne sigurnosti, sniženim investicijskim i pogonskim troškovima pružiti odgovore na većinu navedenih problema.

Nuklearna tehnologija, kao i svaka druga uostalom, ima određene predosti i nedostatke. Današnje okolnosti ponovno favoriziraju prednosti, te su sve glasniji glasovi da se na nuklearnu tehnologiju mora računati kao bitnu sastavnicu energetskog miksa budućnosti.

9 CONCLUSION

After five decades that the nuclear power industry has been in existence, it has matured and its share in the world energy supply is 16 %. Trends in energy planning once again make it an attractive option and many predict the continued growth of its share in the total electricity supply. Uranium reserves are sufficient to permit development, even in the most optimistic scenario. Technological development and accumulated experience have made today's reactor plants reliable and economical. A very high level of safety has been achieved. The production of large quantities of electrical energy without the emission of greenhouse gases is certainly one of the most attractive attributes of nuclear technology.

Despite significant advancement, the heralded nuclear renaissance also implies challenges for the nuclear industry. First of all, today's good safety indices and reliability, together with the cost effectiveness of reactor plants, must also continue in the future. The liberalization of the electricity market changes the preferences of investors and makes them more vulnerable to risks. Therefore, the nuclear industry must invest considerable efforts in reducing costs and shortening the time required for the construction of nuclear power plants. Although the question of the disposal of low-level and medium-level radioactive wastes has been solved, it is necessary to invest additional efforts in order to provide an adequate response to the question of the disposal of high-level radioactive wastes. The significant spread of nuclear energy will undoubtedly increase the threat of the proliferation of nuclear materials, and it is also necessary to invest considerable efforts in this aspect. It is anticipated that reactors of advanced design (AP 1000, EPR and ABWR), characterized by passive safety, reduced investment costs and reduced operational costs, will provide responses to the majority of the problems presented.

Nuclear technology, like any other technology, has certain advantages and disadvantages. Today's circumstances once again favor the advantages, and it is increasingly apparent that it is necessary to count on nuclear technology as an essential component of the energy mix of the future.

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OPTIMALNA RC ZAŠTITA TIRISTORA
OPTIMAL RC PROTECTION OF THYRISTORS

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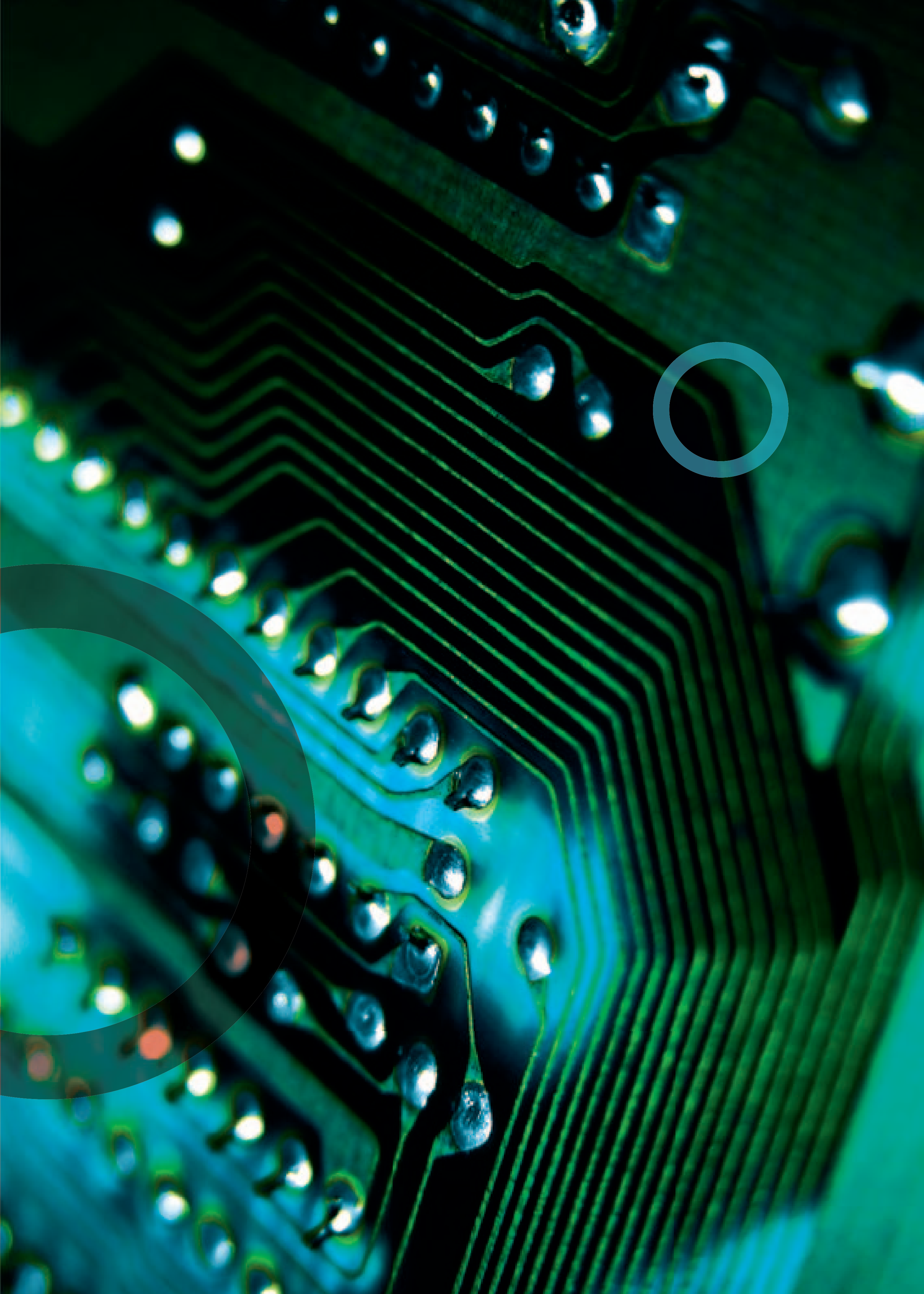
Tiristori su osjetljivi na brzinu porasta anodnog napona, prenapona oporavka i brzinu porasta struje. Zbog toga se tiristori zaštićuju dodatnim sklopovima. Ponekad zaštitni sklop projektiran za prigušenje jednog prijelaznog procesa neće biti optimalan za prigušenje drugog procesa pa je nužno nekakvo kompromisno rješenje. U radu se analiziraju optimalni uvjeti rada zaštite tiristora, s tim da su u obzir uzeti parametri tiristora, koji su karakteristični za period uklapanja i isklapanja. Analiza je provedena u normiranom obliku, što analizi daje općenitost.

Thyristors are susceptible to the increase rate of anode voltage, recovery overvoltage and current increase rate. They are therefore protected by means of supplementary circuits. Sometimes a protection circuit that has been designed to attenuate a certain transient process is not optimal for the attenuation of some other process, therefore a compromise solution is needed. In this paper, the optimal operating conditions of the thyristor protection are analyzed, where the thyristor parameters that are characteristic for the turn-on and turn-off period have been taken into consideration. The analysis has been performed in a normized form, which assures its general applicability.

Ključne riječi: frekvencija, napon, RC zaštita, regulacija, tiristor
Key words: frequency, RC protection, regulation, thyristor, voltage



1 UVOD

Tiristori imaju vrlo široku primjenu na području regulacije u elektrotehnici. Sustavi uzbude sinkronih generatora realizirani su promjenom statičke uzbude, tj. primjenom tiristora, čime se postiže: visoka pogonska preciznost, pouzdanost, potrebna snaga uzbude, te regulacija napona generatora. Također je vrlo velika primjena tiristora u regulaciji brzine vrtnje elektromotora. Posebno je pogodna primjena za velike sporohodne motore, te regulaciju grupnih elektromotornih pogona, gdje su prisutni teški pogonski uvjeti.

Isto tako je važna primjena tiristora u raznim regulatorima-pretvaračima, namijenjenim za industrijske potrebe, kao što je npr. indukcijsko grijanje i taljenje metala u svrhu daljnje obrade, te praktički svugdje gdje se zahtijeva regulacija napona i frekvencije u vrlo širokom rasponu.

Ograničenje brzine porasta napona [1] i ograničenje prenapona oporavka tiristora [2] postiže se pomoću RC sklopa koji se dodaje paralelno tiristoru, a ograničenje brzine porasta struje [3] i [4] postiže se dodavanjem induktiviteta u seriju s tiristorom. Na taj način se postiže tzv. RC zaštita i L zaštita. Na tu temu napisano je mnogo radova. S obzirom na način nadomještanja tiristora u periodu oporavka barijere svi ti radovi o zaštiti mogu se podijeliti u dvije grupe. U prvoj grupi radova tiristor se tretira kao idealna sklopka [5], a u drugoj grupi tiristor se nadomješta sa strujnim izvorom, čija struja eksponencijalno pada [6]. U radovima [1], [2], [3], [4], [7], [8] i [9] pri analizi navedenih pojava, tiristor je nadomješten paralelnim RC sklopom, ali bez zaštitnog RC sklopa, dok je u radu [3] pri analizi RC zaštite tiristor nadomješten nelinearnim otporom. U ovom radu analizira se naponska i strujna zaštita tiristora, pri čemu je tiristor nadomješten paralelnim RC sklopom.

1 INTRODUCTION

Thyristors are widely applied for regulation purposes in electrical engineering. Excitation systems of synchronous generators are realized by variation of static excitation, i.e. by application of thyristors, which assures: high operating preciseness, reliability, the required excitation power and regulation of the generator voltage. Thyristors are much applied in particular to regulate the rotation speed of an electric motor. They are particularly suitable for large, low speed motors and for regulation of electrical motor drives, where operating conditions are hard.

Also, the application of thyristors is important in various regulators-converters that are used for industrial purposes, e.g. induction heating and melting of metal for further processing, and indeed wherever a wide range regulation of voltage and frequency is required.

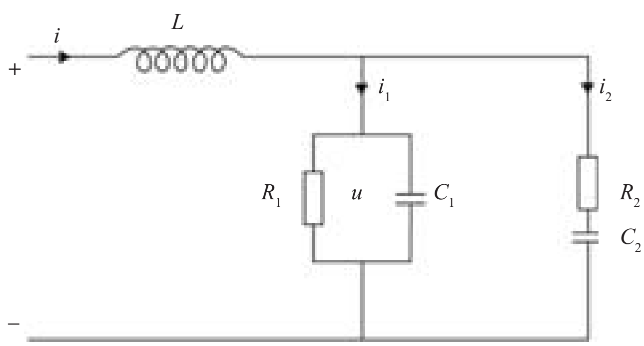
Limitation of the voltage increase rate [1] and of the thyristor recovery overvoltage [2] is achieved by an RC circuit which is added parallel to the thyristor, while limitation of the current increase rate [3] and [4] is performed by adding the inductance serially to the thyristor. In this way, the so called RC protection and L protection are realized. Many papers have been written on this topic. With regard to substitution of the thyristors in a barrier recovery period, all these papers can be grouped into two groups. In the first group, the thyristor is considered an ideal switch [5] and in the second group where the thyristor is replaced with a current source whose current decreases exponentially [6]. In the papers [1], [2], [3], [4], [7], [8] and [9] for analysis of the phenomena mentioned, the thyristor was replaced with a parallel RC circuit, but without a protective RC circuit, while in the paper [3], for analysis of RC protection, the thyristor was replaced with a nonlinear resistance. In this paper, voltage and current protection of the thyristor are analyzed, where the thyristor is replaced with a parallel RC circuit.

2 NADOMJESNA SHEMA I OSNOVNE RELACIJE

Dimenzije tiristora rastu s dopuštenom snagom pa se u nekim režimima rada ne mogu zanemariti parametri tiristora. U ovom se radu tiristor nadomješta paralenim R_1, C_1 linearnim elementima (slika 1) dok se paralelni zaštitni krug R_2, C_2 smatra bezinduktivnim, a u serijskom zaštitnom krugu s induktivitetom L se zanemaruje otpor R, koji je obično malog iznosa u odnosu na otpor tiristora R_1.

2 EQUIVALENT SCHEME AND BASIC RELATIONS

The dimensions of thyristors increase with the increase of the power allowed, and therefore the thyristor parameters in certain operating regimes cannot be disregarded. In this paper, the thyristor is replaced with linear elements R_1, C_1 (Figure 1), the parallel protective circuit R_2, C_2 is considered non-inductive and in a serial protection circuit of inductance L, the resistance R, which is usually low in comparison with the thyristor resistance, R_1, is disregarded.



Slika 1
Nadomjesna shema tiristora i elemenata zaštite
Figure 1
Equivalent scheme of the thyristor and protective elements

Početni uvjeti za analizu brzine porasta napona su $i(0) = 0$ i $u_{C_1}(0) = u(0) = 0$, dok je za analizu prenapona oporavka uzeto da je početni uvjet $i(0) = I_{2M}$ (maksimalna inverzna struja), a napon na kapacitetu je $u(0) = U < E$ [2].

Analizu je pogodno provesti u normiranom obliku, radi poopćenja rezultata pa se kao prvo definira bezdimenziono vrijeme $\tau = \omega t$. Kružna frekvencija ω naknadno će biti određena. Nadomjesna shema (slika 1) može se opisati sljedećim jednadžbama:

Initial conditions for analysis of the voltage increase rate are $i(0) = 0$ and $u_{C_1}(0) = u(0) = 0$, while for analysis of the recovery overvoltage it has been taken that the initial condition is $i(0) = I_{2M}$ (maximal inverse current) and voltage at the capacitance is $u(0) = U < E$ [2].

The analysis must be performed in a normized form, for generalization of results, therefore non-dimensional time $\tau = \omega t$ is initially defined. Circular frequency ω will be determined later. An equivalent scheme (Figure 1) can be described by the following equations:

$$\omega L \frac{\mathrm{d}\,i}{\mathrm{d}\,\tau} + u = E, \qquad (1)$$

$$i = i_1 + i_2, \qquad (2)$$

$$i_1 = \frac{u}{R_1} + \omega C_1 \frac{\mathrm{d}\,u}{\mathrm{d}\,\tau}, \tag{3}$$

$$u = R_2 i_2 + \frac{1}{\omega C_2} \int i_2 \,\mathrm{d}\,\tau, \tag{4}$$

gdje je:

E – istosmjerni napon,
u – napon na tiristoru.

Primjenom Laplaceove transformacije na relacije (1) do (4) dobiva se da je normirani napon na tiristoru:

where:

E – direct voltage,
u – voltage at thyristor.

If the Laplace transformation is applied to the relation (1) to (4), the following normized voltage is obtained at the thyristor:

$$\frac{U}{E} = \frac{b_3 p^3 + b_2 p^2 + b_1 p + 1}{p(a_3 p^3 + a_2 p^2 + a_1 p + 1)}, \tag{5}$$

gdje je:

where:

$$a_1 = \omega \left(\frac{L}{R_1} + R_2 C_2 \right), \tag{5a}$$

$$b_1 = \omega \left(\frac{L i(0)}{E} + R_2 C_2 \right), \tag{5b}$$

$$a_2 = \omega^2 L C_1 \left(1 + \frac{C_1}{C_2} + \frac{R_1 C_1}{R_2 C_2} \right), \tag{5c}$$

$$b_2 = \omega^2 \left(\frac{L i(0)}{E} R_2 C_2 + L C_1 \frac{u(0)}{E} \right), \tag{5d}$$

$$a_3 = \omega^3 L C_1 R_2 C_2, \tag{5e}$$

$$b_3 = \omega^3 L C_1 R_2 C_2 \frac{u(0)}{E}. \tag{5f}$$

Za definiranje nepoznate frekvencije ω pogodno je odabrati da član a_3 karakteristične jednadžbe (5) bude jednak jedinici (a_3 = 1) pa slijedi:

For defining the unknown frequency ω it is suitable to establish that the value of the member a_3 of the characteristic equation is equal to one (a_3 = 1), from which follows:

$$\omega^3 = \frac{1}{LC_1R_2C_2}. \tag{6}$$

Zbog pojednostavljenja i poopćavanja proračuna uvode se sljedeće supstitucije:

For simplification and generalization of the calculation, the following substitutions are introduced:

$$\omega_0 = \frac{1}{\sqrt{LC_1}}, \tag{7}$$

$$\rho = \sqrt{\frac{L}{C_1}}, \tag{8}$$

$$\delta = \frac{\rho}{R_1}, \tag{9}$$

$$\alpha = \frac{\omega_0 L i(0)}{E} \tag{10}$$

– faktor početne struje / initial current factor,

$$\beta = \frac{u(0)}{E} \tag{11}$$

– faktor početnog napona / initial voltage factor,

a umjesto nepoznatih elemenata R_2 i C_2 sljedeći normirani parametri:

and, instead of the unknown elements R_2 and C_2, the following normized parameters are introduced:

$$\lambda_1 = \frac{R_2}{\rho}, \tag{12}$$

$$\lambda_2 = \frac{C_2}{C_1}. \tag{13}$$

Karakteristična jednadžba može se prikazati na sljedeći način:

The characteristic equation can be presented as follows:

$$p^3 + a_2 p^2 + a_1 p + 1 = (p + p_0)(p^2 + 2\zeta\,\omega_n p + \omega_n^2) = 0, \tag{14}$$

gdje je:

ζ – relativno prigušenje, a
ω_n – relativna kružna frekvencija.

Usporedbom koeficijenata relacije (14) slijedi da je:

where:

ζ – relative attenuation,
ω_n – relative circular frequency.

From comparison of the coefficients in the relation (14) it follows:

$$p_0 = \frac{1}{\omega_n^2}, \tag{15}$$

$$a_1 = \omega_n^2 + \frac{2\zeta}{\omega_n}, \tag{16}$$

$$a_2 = \frac{1}{\omega_n^2} + 2\zeta\omega_n. \tag{17}$$

Relativno prigušenje ζ i relativna kružna frekvencija ω_n ne mogu se jednostavno izraziti u ovisnosti o koeficijentima a_1 i a_2. Radi daljnjeg pojednostavljenja proračuna uvode se sljedeće supstitucije:

Relative attenuation ζ and relative circular frequency ω_n cannot be unambiguously expressed in dependence on the coefficients a_1 and a_2. For further simplification of the calculation, the following substitutions are introduced:

$$\lambda = \sqrt[3]{\lambda_1 \lambda_2}, \tag{18}$$

$$z = \frac{\lambda}{\omega_n}, \tag{19}$$

$$x = \omega_n \tau. \tag{20}$$

Uzimajući u obzir dane supstitucije i izraze a_1 i a_2, jednadžbe (5), (15), (16) i (17), dobiju se sljedeće dvije jednadžbe:

If the substitutions and expressions a_1 and a_2, the equations (5), (15), (16) and (17), are taken into consideration, the following two equations are obtained:

$$\frac{\delta}{z\omega_n^3} + z^2 = \frac{2\zeta}{\omega_n^3} + 1, \tag{21}$$

$$\frac{1+\lambda_2}{z^2\omega_n^3}+\delta z=2\zeta+\frac{1}{\omega_n^3}. \qquad (22)$$

Iz jednadžbi (21) i (22) dobije se da je:

From the equations (21) and (22) it is obtained as follows:

$$\omega_n^3=\frac{2\zeta z-\delta}{z\left(z^2-1\right)}, \qquad (23)$$

$$\lambda_2=\frac{(2\zeta-\delta z)(2\zeta z-\delta)}{z^2-1}z+z^2-1. \qquad (24)$$

Danim supstitucijama nije izgubljeno ni jedno rješenje, a postiglo se da je relativna kružna frekvencija ω_n izražena eksplicitno u ovisnosti o samo dvije varijable ζ i z. Koeficijenti b_1, b_2 i b_3 u relaciji (5) mogu se također izraziti u ovisnosti o ζ i z na sljedeći način:

None of the solutions has been lost due to the substitutions, whereas the relative circular frequency ω_n is explicitly expressed in dependence of only two variables, ζ and z. The coefficients b_1, b_2 and b_3 in the equation (5) can be also expressed in dependence of ζ and z as follows:

$$\frac{b_1}{\omega_n^2}=\frac{\alpha}{z\omega_n^3}+z^2, \qquad (25)$$

$$\frac{b_2}{\omega_n}=\alpha z+\frac{\beta}{z^2\omega_n^3}, \qquad (26)$$

$$b_3=\beta. \qquad (27)$$

Na taj način parametri jednadžbe (5) ovise o dvije varijable ζ i z i tri faktora α, β i δ.

The parameters of the equation (5) depend at the end on two variables ζ and z and on three factors α, β and δ.

3 ODREĐIVANJE PRVOG MAKSIMUMA NAPONA

Za određivanje prenapona oporavka kao i brzine porasta na tiristoru potrebno je odrediti prvi maksimum napona na tiristoru. Taj napon ovisi o faktorima α, β i δ i varijablama ζ i z, koje ovise o parametrima λ_1 i λ_2. Iz karakteristične jednadžbe (14) proizlazi da postoje četiri karakteristična slučaja. Za svaki slučaj se razmatra oblik napona $u(\tau)$.

1) Slučaj ($\zeta < 1$)

Izraz za normirani napon na tiristoru ima sljedeći oblik:

3 DETERMINING OF THE FIRST VOLTAGE MAXIMUM

In order to determine the recovery overvoltage and increase rate at the thyristor, the first voltage maximum at the thyristor must be determined. This voltage depends on factors α, β and δ and variables ζ and z, which depend on the parameters λ_1 and λ_2. It is to be concluded, based on the characteristic equation (14), that there are four characteristic cases. For each case, the voltage form $u(\tau)$ is considered.

1) Case ($\zeta < 1$)

The equation for the normized voltage on the thyristor is as follows:

$$\frac{u}{E} = 1 + A e^{-x\omega_n^3} + e^{-\zeta x}\left[A_1 \sin mx + A_2 \cos mx\right]. \quad (28)$$

Izrazi za konstante A, A_1 i A_2 su vrlo složeni pa ovdje nisu navedeni. Prvi maksimum se može približno odrediti iz drugog dijela jednadžbe (28), a numeričkim postupkom se može točno odrediti taj maksimum.

2) Slučaj ($\zeta = 1$)

Traženi normirani napon ima oblik:

The expressions for the constants A, A_1 and A_2 are very complex, and therefore they are not presented here. The first maximum can be approximately determined from the second part of the equation (28), this maximum can be exactly determined by means of a numerical method.

2) Case ($\zeta = 1$)

The subject normized voltage has the following form:

$$\frac{u}{E} = 1 + A e^{-x\omega_n^{-3}} + e^{-x}\left[A_1 x + A_2\right]. \quad (29)$$

čiji se prvi maksimum može približno odrediti iz drugog dijela jednadžbe, a točno numeričkim postupkom.

3) Slučaj ($\zeta = \omega_n = 1$)

Traženi normirani napon je oblika:

whose first maximum can be approximately determined from the second part of the equation, this maximum can be exactly determined by means of a numerical method.

3) Case ($\zeta = \omega_n = 1$)

The subject normized voltage has the following form:

$$\frac{u}{E} = 1 + e^{-\tau} + e^{-x}\left[\frac{A_1 \tau^2}{2} + A_2 \tau + A_3\right]. \quad (30)$$

Prvi maksimum se može točno odrediti iz relacije (30).

4) Slučaj ($\zeta > 1$)

The first maximum can be exactly determined from the equation (30).

4) Case ($\zeta>1$)

Traženi normirani napon je:

The subject normized voltage is:

$$\frac{u}{E} = 1 + A\,\mathrm{e}^{-x\omega_0^{-1}} + A_1\,\mathrm{e}^{s_1 x} + A_2\,\mathrm{e}^{s_2 x}, \tag{31}$$

gdje je:

where:

$$s_1 = \zeta - \sqrt{\zeta^2 - 1}, \tag{31a}$$

$$s_2 = \zeta + \sqrt{\zeta^2 + 1}. \tag{31b}$$

Prvi maksimum se može približno odrediti iz drugog dijela relacije (31), a točnu vrijednost numeričkim putem. Navedene konstante A, A_1 i A_2 za pojedine slučajeve dane su u [9], kao i odgovarajući numerički postupak za određivanje prvog maksimuma.

The first maximum can be approximately determined from the second part of the equation (31), the exact value can be determined by means of a numerical method. The mentioned constants A, A_1 and A_2 for particular cases are given in [9], as well as a numerical method for determining the first maximum.

4 DIJAGRAMI MAKSIMALNOG NAPONA I ODGOVARAJUĆEG VREMENA PORASTA NAPONA

4 DIAGRAMS OF MAXIMAL VOLTAGE AND RELATED VOLTAGE INCREASE TIME

Pri određivanju zaštite tiristora, prvo se definira strujna zaštita s induktivitetom L, a zatim se definira naponska zaštita preko R_2 i C_2. Ta naponska zaštita ne smije dopustiti prekoračenje graničnog prenapona oporavka i granične brzine porasta napona na tiristoru. Postoji veliki broj parova R_2 i C_2 koji zadovoljavaju samo jednu vrijednost, a manji broj i drugu naponsku vrijednost. Za praktičnu primjenu potrebno je odrediti sljedeće normirane funkcije:

– Normirani prenapon (prvi maksimum):

In determining the protection of the thyristor, the current protection with an inductance L must be determined first, afterwards the voltage protection is defined using R_2 and C_2. The voltage protection will prevent the thyristor critical recovery voltage and critical voltage increase rate being exceeded. There are numerous pairs of values R_2 and C_2 that fulfil one value only, while fewer of them fulfil another value as well. The following normized functions will be determined for practical application:

– Normized overvoltage (the first maximum):

$$M_n = \frac{U_m}{E} = f(\alpha, \beta, \delta, \zeta, z). \tag{32}$$

– Normirano vrijeme porasta prvog maksimuma:

– Normized increase time of the first maximum:

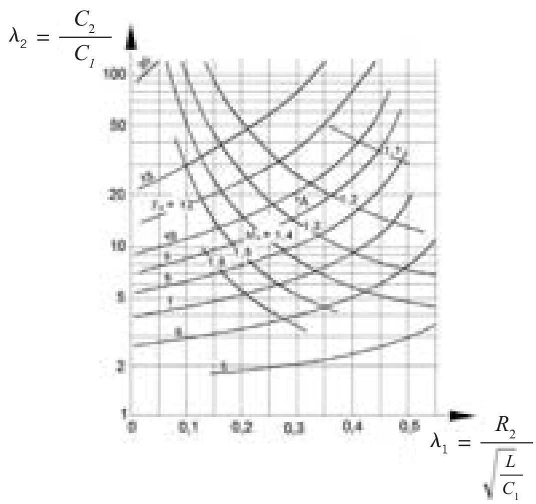
$$T_n = \omega_0 t_1 = z x_1 = g(\alpha, \beta, \delta, \zeta, z). \tag{33}$$

Obje definirane funkcije ovise o faktorima α, β i δ i varijablama ζ i z, koje ovise o parametrima λ_1 i λ_2. Treba odrediti takav par λ_1 i λ_2 koji uz zadane faktore α, β i δ zadovoljavaju normirane vrijednosti M_n i T_n. Tako se npr. funkcija f za razne vrijednosti M_n može prikazati u ravnini λ_1 i λ_2 kao familija krivulja. Na isti način može se prikazati i g funkcija. Na osnovu toga nacrtano je niz familija krivulja M_n i T_n u ovisnosti o parametrima λ_1 i λ_2 te različitim faktorima α, β i δ. Na slici 2 prikazane su familije krivulja M_n i T_n za $\delta = 0{,}01$, $\alpha = \beta = 0$.

Both defined functions depend on the factors α, β and δ and on the variables ζ and z, which depend on the parameters λ_1 and λ_2. The pair of values λ_1 and λ_2 must be so determined that along with the specified factors α, β and δ they meet the normized values M_n and T_n. For example, the function f for various values M_n can be presented in the plane λ_1 and λ_2 as a family of curves. The function g can be presented the same way. Based on this, a group of curves M_n and T_n has been plotted, dependent on the parameters λ_1 and λ_2 and on various factors α, β and δ. The family of curves M_n and T_n for $\delta = 0{,}01$, $\alpha = \beta = 0$ is presented in Figure 2.

Slika 2
Normirani dijagrami prenapona oporavka M_n i vremena T_n za ($\delta = 0{,}01$; $\alpha = \beta = 0$)

Figure 2
Normized diagrams of the recovery overvoltage M_n and time T_n for ($\delta = 0{,}01$; $\alpha = \beta = 0$)



5 IZBOR TIRISTORA I RC ZAŠTITE

5.1 Izbor tiristora i osnovni podaci

Izbor tiristora vezan je uz dobro poznavanje dinamike rada sklopa. Pri tome je potrebno uzeti u obzir niz navedenih specifičnih osobina tiristora kao što su: nominalna i dozvoljena vrijednost napona i struje, struja pridržavanja, vrijeme uključenja i odmaranja, $\mathrm{d}u/\mathrm{d}t$, $\mathrm{d}i/\mathrm{d}t$ itd.

Obično se poteškoće javljaju kod projektiranja pretvarača s višim frekvencijama. Povećanje radne frekvencije ograničeno je sljedećim faktorima: kritičnim vrijednostima brzine porasta direktnog napona ($\mathrm{d}u/\mathrm{d}t$) i struje uključenja ($\mathrm{d}i/\mathrm{d}t$), vremenom komutacije (uključenja i odmaranja) i gubitcima snage u tiristoru.

Opteretivost tiristora u značajnoj mjeri ovisi o frekvenciji. Pri povišenim frekvencijama rastu komutacijski gubici, osobito gubici uključenja tiristora. Za pouzdan rad tiristora nužno je uskladiti gubitke u periodu komutacije s gubi-

5 SELECTION OF THYRISTOR AND RC PROTECTION

5.1 Selection of thyristor and basic data

The selection of the thyristor demands a thorough knowledge of the circuit operating dynamics. Many of the specified thyristor properties need to be taken into consideration here: nominal and allowed current and voltage, holding current, turn-on time and resting time, $\mathrm{d}u/\mathrm{d}t$, $\mathrm{d}i/\mathrm{d}t$ etc.

Difficulties usually occur when converters of higher frequencies are designed. Increase of operating frequency is limited by the following values: critical values of the direct voltage increase rate ($\mathrm{d}u/\mathrm{d}t$) and of the turn-on current increase rate ($\mathrm{d}i/\mathrm{d}t$), commutation time (turn-on and resting) and power losses in the thyristor.

The loadability of the thyristor depends on frequency to a significant degree. At higher frequencies commutation losses increase, particularly turn-on losses of the thyristor. For reliable operation of the thyristor, losses in the commutation period must cima u periodu vođenja da ne dođe do većih temperaturnih oscilacija, zbog čega brže dolazi do umora materijala tiristora. Pojava umora, uvjetovana različitim temperaturnim koeficijentom širenja sastavnih dijelova tiristora, dovodi do uništenja tiristora nakon određenog broja ciklusa zagrijavanja i hlađenja. Pri tome svemu značajnu ulogu ima brzina porasta struje uključenja ($\mathrm{d}i/\mathrm{d}t$). Pravilnim izborom zaštite tiristora mogu se znatno smanjiti komutacijski gubici uključenja.

Svi navedeni parametri tiristora neće istodobno biti jednako kritični, a to ovisi o režimu rada. U tu svrhu izgrađeni su razni tipovi tiristora koji odgovaraju zahtjevima pojedinih vrsta pretvarača.

Tiristor 501PBQ110 proizvod IR izabran je za prikaz proračuna RC zaštite. Ne ulazeći u kompletnu analizu rada određenog pretvarača, treba odrediti RC zaštitu tiristora za sljedeće uvjete rada:

$$\frac{\mathrm{d}u}{\mathrm{d}t} = 300 \frac{V}{\mu s},$$

$$\frac{\mathrm{d}i}{\mathrm{d}t} = 25 \frac{A}{\mu s},$$

$I_T = 250\mathrm{A}$ – istosmjerna struja provođenja tiristora,

$E = 600\mathrm{V}$ – istosmjerno.

Iz danih podataka lako se izračuna potrebni induktivitet $L = E/(\mathrm{d}i/\mathrm{d}t) = 24\ \mu\mathrm{H}$.

Vrijednosti otpora R_1 i C_1 nije moguće jednoznačno odrediti jer se u nekim slučajevima, kao npr. kod serijskog spajanja tiristora, tiristoru dodaje paralelno otpor, a u kapacitet C_1 treba uključiti i parazitni kapacitet spojnih vodova. Iz dimenzija tiristora procijenjeno je da je R_1, u oba smjera oko 50 Ω, a odgovarajući kapacitet C_1 oko 1nF.

5.2 Proračun RC zaštite za $\mathrm{d}u/\mathrm{d}t$

Brzina skupljanja kritičnog napona u bazama ovisi i o obliku anodnog napona. Kritična ili granična vrijednost $\mathrm{d}u/\mathrm{d}t$ je ona vrijednost kod koje je tiristor još sposoban da blokira napon određene amplitude linearnog porasta. Ta se vrijednost određuje eksperimentalno. U realnim uvjetima valni oblik napona razlikuje se od ispitnog napona pa je potrebno utvrditi funkcionalnu vezu između eksperimentalno utvrđene kritične vrijednosti

be aligned with losses in the conducting period, in order to prevent significant temperature oscillations that speed up fatigue of the thyristor material. The fatigue, caused by different thermal expansion coefficients of the thyristor components, will after a certain number of warming-up and cooling-down cycles destroy the thyristor. In this, the turn-on current increase rate ($\mathrm{d}i/\mathrm{d}t$) plays an important role. Proper selection of the thyristor protection can contribute to a significant decrease of the commutation turn-on losses.

All the thyristor parameters mentioned will not be equally critical at the same time, it depends on the operating regime. For this purpose, many various types of thyristors meeting the demands of particular types of converters have been designed and produced.

The thyristor 501PBQ110 product IR has been selected for calculation of the RC protection. Without performing an overall analysis of operation for a certain converter, RC protection of the thyristor must be determined for the following operating conditions:

$$\frac{\mathrm{d}u}{\mathrm{d}t} = 300 \frac{V}{\mu s},$$

$$\frac{\mathrm{d}i}{\mathrm{d}t} = 25 \frac{A}{\mu s},$$

$I_T = 250\mathrm{A}$ – direct conducting current of the thyristor

$E = 600\mathrm{V}$ – direct.

From the above data, the inductance $L = E/(\mathrm{d}i/\mathrm{d}t) = 24\ \mu\mathrm{H}$ is calculated.

The resistance values of R_1 and C_1 cannot be unambiguously determined, as in certain cases, e.g. when the thyristors are serially connected, the resistance is added in parallel to the thyristor and a parasitic capacitance of the connecting lines must be included in the capacitance C_1. From the thyristor dimensions, it is estimated that R_1, in both directions is about 50 Ω, the referring capacitance C_1 is approximately 1nF.

5.2 Calcuation of RC protection for $\mathrm{d}u/\mathrm{d}t$

The collection rate of the critical voltage in bases depends on the anode voltage form. A critical or boundary value $\mathrm{d}u/\mathrm{d}t$ is the value at which the thyristor is still capable of blocking the voltage of the specific linear increase amplitude. This value

$\mathrm{d}u/\mathrm{d}t$ i $\mathrm{d}u/\mathrm{d}t$ kod stvarnog valnog oblika. Kritična vrijednost $\mathrm{d}u/\mathrm{d}t$ može se definirati kao:

is experimentally determined. In real conditions, the voltage waveform differs from the test voltage, therefore functional relationship between the experimentally determined critical value $\mathrm{d}u/\mathrm{d}t$ and $\mathrm{d}u/\mathrm{d}t$ under the realistic waveform shall be found out. The critical value $\mathrm{d}u/\mathrm{d}t$ can be defined as follows:

$$\left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{\mathrm{kr}} = k\frac{U_{\mathrm{m}}}{t_1}\,, \qquad (34)$$

gdje je:

U_{m} – vršna vrijednost rastućeg napona,
t – vrijeme kroz koje se postigne taj maksimalni napon,
k – faktor korekcije.

Neki proizvođači ispituju brzinu porasta s eksponencijalnom funkcijom. Kritična brzina porasta napona definira se nagibom pravca koji prolazi kroz točku čija je vrijednost 0,632 U_{m}. Može se smatrati da nakon tri vremenske konstante τ eksponencijalna funkcija poprimi maksimalnu vrijednost pa je u ovom slučaju k_1 = 1,9.

U slučaju sinusnog ispitnog napona uzima se da je nagib određen pravcem koji prolazi kroz 0,5 U_{m} pa je u tom slučaju k_2 = 1,5. Takva definicija najbliža je slučaju linearnog porasta napona jer postoji neznatno odstupanje.

Prilikom priključenja tiristorskog sklopa (slika 1) na napon E, napon na tiristoru raste od neke početne vrijednosti $u(0)$ do prvog maksimuma U_{m} tokom vremena t_1. Na osnovi toga može se odrediti normirana brzina porasta napona na tiristoru:

where:

U_{m} – peak value of the increasing voltage,
t – time for obtaining the maximal voltage,
k – correction factor.

Some manufacturers test the increase rate with an exponential function. The critical voltage increase rate is defined by the slope of the line passing through the point whose value is 0,632 U_{m}. It can be considered that after the three time constants τ the exponential function reaches the maximal value, therefore k_1 = 1,9.

In the case of the sine testing voltage, it is considered that the slope is determined by a line passing through 0,5 U_{m}, therefore k_2 = 1,5. This definition is closest to the linear increase of voltage, as the deviation is insignificant.

When the thyristor circuit (Figure 1) is connected to the voltage E, the voltage at the thyristor increases from the initial value $u(0)$ to the first maximum U_{m} during the time t_1. Based on this, the normized voltage increase rate at the thyristor is:

$$\left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{\mathrm{n}} = \frac{1}{k\omega_0 E}\,\frac{\mathrm{d}u}{\mathrm{d}t} = \frac{M_{\mathrm{n}}}{T_{\mathrm{n}}} \qquad (35)$$

Tako npr., ako je R_1 = 4,9 kΩ i C_1 = 10 nF slijedi iz jednadžbi (7), (8) i (9) da je δ = 0,01, a početni napon i struja su nula, pa je $\alpha = \beta = 0$. Odgovarajuća familija krivulja T_{n} i M_{n} za navedene podatke prikazana je na slici 2. Uz dane podatke za E i $\mathrm{d}u/\mathrm{d}t$ i k = 1,9 dobije se da je normirani napon $(\mathrm{d}u/\mathrm{d}t\,)_{\mathrm{n}}$ = 0,129.

Ako se izabere da je normirani prenapon M_{n} = 1,26 dobije se normirano vrijeme porasta T_{n} = 9,77 s. Na slici 2 to je točka A iz čega proizlazi da je optimalna RC zaštita određena s R_2 = 14,7 Ω i C_2 = 0,185 μF.

For example, if R_1 = 4,9 kΩ and C_1 = 10 nF, from equation (7), (8) and (9) it follows that δ = 0,01, while the initial voltage and current are equal to zero, therefore $\alpha = \beta = 0$. The referring curve family T_{n} and M_{n} for the specified data is presented on Figure 2. With the given values for E and $\mathrm{d}u/\mathrm{d}t$ and k = 1,9, the normized voltage $(\mathrm{d}u/\mathrm{d}t)_{\mathrm{n}}$ = 0,129 is obtained.

If the normized overvoltage M_{n} = 1,26 is selected, the normized increase time T_{n} = 9,77 s is obtained. In Figure 2 it is the point A, which implies that the optimal RC protection is defined by R_2 = 14,7 Ω and C_2 = 0,185 μF.

Na temelju numeričke analize u [9] došlo se do zaključka da na izbor elemenata RC zaštite ne utječe otpor $R_1 \geq 4{,}9$ kΩ, dok je utjecaj kapaciteta C_1 očit.Treba imati na umu da kapacitet inverzno polarizirane barijere opada s porastom napona.

Proizvođač za promatrani tiristor daje sljedeće vrijednosti za RC zaštitu: R_2 = 15 Ω, C_2 = 0,2 μF, dok prema [5] slijedi da je: R_2 = 11,8 Ω i C_2 = 0,175 μF. Treba istaći da je dobra podudarnost rezultata provedene analize i rezultata dobivenih iz [5] samo u području najmanje osjetljivosti na parazitni kapacitet C_1, koji nije uzet u obzir u [5].

5.3 Prenapon u inverznom režimu rada tiristora

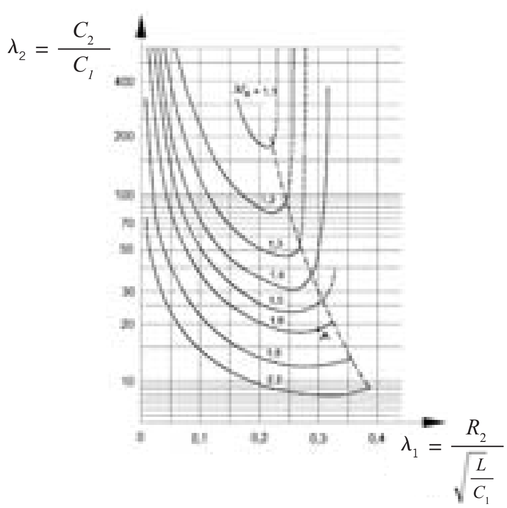
Analiza u inverznom režimu rada provedena je na istoj shemi (slika 1). Budući da oscilacije u inverznom režimu rada započnu u trenutku kada inverzna struja dosegne svoj maksimum I_{RM} [1], za navedeni tiristor ta struja je I_{RM} = 55 A, tako da faktor početne struje α u ovom slučaju nije jednak nuli. U [9] je numerički prikazano da faktor početne struje α ima dominantan utjecaj na iznos prenapona, dok je faktor početnog napona β zanemariv, jer se dobivaju gotovo iste vrijednosti za β = 0 i β = 1. Također je pokazano da otpor $R_1 \geq 4{,}9$ kΩ nema utjecaja, dok kapacitet C_1 znatno utječe jer s porastom kapaciteta C_1 raste inverzni prenapon. Zbog toga radnu točku treba izabrati tako da je RC zaštita što manje osjetljiva na promjena kapaciteta C_1.

Based on the results of the numerical analysis in [9] it has been concluded that the resistance $R_1 \geq 4{,}9$ kΩ does not affect the selection of elements of RC protection, whereas the influence of the capacitance C_1 is evident. It must be taken into consideration that the capacitance of the inversely polarized barrier decreases with the increase of voltage.

For the observed thyristor, the manufacturer gives the following values for RC protection: R_2 = 15 Ω, C_2 = 0,2 μF, while in accordance with [5] the values are as follows: R_2 = 11,8 Ω and C_2 = 0,175 μF. It is to be emphasized that the compliance of the results of the performed analysis and the results obtained from [5] is good only in the range where susceptibility to the parasitic capacitance C_1, which has not been taken into account in [5], is lowest.

5.3 Overvoltage in the thyristor inverse operating regime

The analysis in an inverse operating regime was performed in line with the same scheme (Figure 1). As the oscillations in an inverse operating regime start at the moment when the inverse current reaches its maximum value I_{RM} [1], the current value for the subject thyristor is I_{RM} = 55 A, therefore the initial current factor α in this case is not equal to zero. In [9] it is numerically presented that the initial current factor α has a predominant influence on the overvoltage value, whereas the initial voltage factor β is negligible, as almost the same values are obtained for β = 0 and β = 1. It is also shown that the resistance $R_1 \geq 4{,}9$ kΩ has no influence, whereas the influence of capacitance C_1 is significant, as an increase of the capacitance C_1 affects an increase of the inverse overvoltage. Therefore the operating point needs to be chosen so that RC protection is susceptible to a change of the capacitance C_1 as little as possible.



Slika 3
Normirani dijagram inverznog prenapona M_n (δ = 0,01, α = 4,49 i β = 0)

Figure 3
Normized diagram of the inverse overvoltage M_n (δ = 0,01, α = 4,49 and β = 0)

Na slici 3 dana je familija krivulja normiranog prenapona M_n za sljedeće faktore δ = 0,01, α = 4,49 i β = 0. Za već izabrane parametre zaštite slijedi da je u ovom slučaju normirani prenapon M_n = 1,6 (točka A), dok je za izabrani tiristor dopuštena vrijednost M_n = 2. Pomoću metode dane u [1] dobije se za dati prenapon da je R_2 = 13,2 Ω, C_2 = 0,2 µF. Treba istaći da je ta analiza provedena pod pretpostavkom da struja oporavka trenutno pada na nulu, a da napon prepolarizacije ima skok, što ne odgovara stvarnosti.

6 ZAKLJUČAK

Posebno je važna primjena zaštite tiristora pri pretvaranju istosmjerne struje u izmjeničnu, visoke frekvencije i velike snage, npr. kod pretvarača za indukcijsko grijanje, vjetroelektrane i dr.

Prigušenje prenapona oporavka i brzine porasta napona na tiristoru postiže se RC zaštitom, a ograničenje brzine porasta struje ograničuje se induktivitetom. U radu je pokazano da izbor zaštite tiristora ovisi i o parametrima tiristora. Posebno je ukazano da na optimalni izbor RC zaštite u znatnoj mjeri utječe kapacitet inverzno polarizirane barijere kao i paralelni parazitni kapacitet spojnih vodova. To se može izbjeći tako da se bira radna točka u kojoj je osjetljivost na promjenu parazitnih kapaciteta zanemariva. Numerički postupak je složen, ali se može napraviti niz dijagrama za karakteristične faktore α, β i δ čime se postupak izbora optimalnih parametara RC zaštite pojednostavljuje.

The curve family of the normized overvoltage M_n for the following factors δ = 0,01, α = 4,49 i β = 0 is provided on Figure 3. For the selected parameters of protection, the normized overvoltage in this case is M_n = 1,6 (point A), whereas the allowed value for the chosen thyristor is M_n = 2. Using the method provided in [1], for the given overvoltage, the following values are obtained R_2 = 13,2 Ω, C_2 = 0,2 µF. It is to emphasize that this analysis has been performed under the assumption that the recovery current falls to zero momentarily, whereas there is a jump of the repolarization voltage, which is not in accordance with the actual situation.

6 CONCLUSION

Application of thyristor protection is particularly important for conversion of direct current into alternating current, for high frequencies and high powers, e.g. for the induction heating converters, wind power plants, etc.

Attenuation of the recovery voltage and of the voltage increase rate at the thyristor is achieved by RC protection, whereas the current increase rate is limited by inductance. It is presented in the paper that the thyristor parameters affect the selection of the thyristor protection. It is particularly emphasized that capacitance of the inversely polarized barrier, as well as parasitic capacitance of the connecting lines, have a significant impact on optimal selection of RC protection. It can be avoided by selection of the operating point where sensitivity to change of the parasitic capacities is negligible. The numerical procedure is complex, but referring diagrams for characteristic factors α, β and δ can be made, which significantly simplifies the selection procedure for the optimal parameters of RC protection.

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OPTIČKI NAPONSKI PRETVARAČI
OPTICAL VOLTAGE TRANSDUCERS

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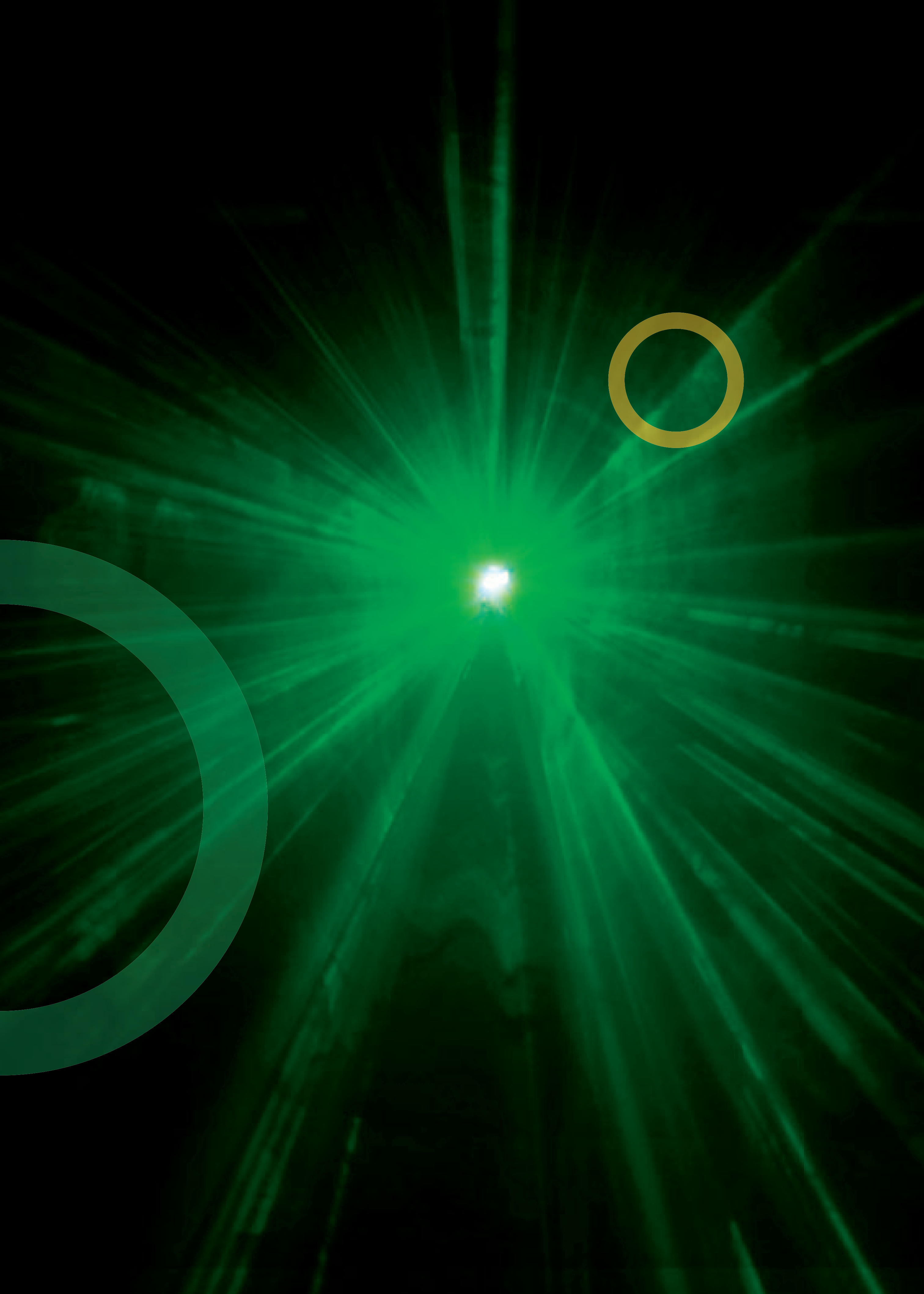
U članku su opisana osnovna načela rada optičkih pretvarača za mjerenje visokog napona. Pockels je primijetio da je nastajanje razlike indeksa loma u nekim kristalima proporcionalno narinutom električnom polju. Glavni dijelovi osjetila zasnovanih na Pockelsovom učinku su: polarizator, Pockelsov kristal i analizator. To su pasivni elementi, u koje se svjetlost dovodi i odvodi optičkim nitima iz elektroničkog uređaja koji se nalazi na potencijalu zemlje. Polarizirana svjetlost koja titra u dvije međusobno okomite ravnine prolazi kroz kristal različitim brzinama, a pod djelovanjem električnog polja brzine se mijenjaju, a to se detektira u elektroničkom sklopu. Prema ulazu svjetlosti u odnosu na narinuto električno polje razlikuje se uzdužni i poprečni učinak.

The paper presents basic operating principles of optical transducers for the measurement of high voltage. It was observed by Pockels that the change in refractive indexes in certain crystals is proportional to the applied electric field. The main parts of the sensor based on Pockels effect are: polarizer, Pockels crystal and analyzer. These are passive elements to and from which the light is taken by means of optical fibers from an electronic device at the earth potential. The polarized light that vibrates in two mutually perpendicular planes passes through the crystal at different speeds that change under the influence of the electric field, which is detected by an electronic circuit. The longitudinal and transverse effect are distinguished with respect to the applied electrical field.

Ključne riječi: optički naponski pretvarači, Pockelsov učinak
Key words: optical voltage transducers, Pockels effect



1 UVOD

Visoki napon se može mjeriti korištenjem elektrooptičkih učinaka, i to Pockelsovog ili Kerrovog učinka. Pockels je primijetio da je nastajanje razlike indeksa loma u nekim kristalima proporcionalno narinutom električnom polju. Polarizirana svjetlost koja prolazi kroz kristal, a titra u dvije različite ravnine, pod djelovanjem električnog polja različito mijenja brzinu širenja. Linearna ovisnost promjene indeksa loma o jakosti električnog polja naziva se Pockelsov, a kvadratna ovisnost Kerrov učinak. Elektrooptičke učinke pokazuju mnogi kristali, tekućine i plinovi. Različite tvari imaju i različitu, ali stalnu ovisnost promjene indeka loma o električnom polju. Za elektrooptičke pretvarače koriste se kristali velike Pockelsove ili Kerrove konstante, određenog rasporeda kristalografskih osi.

Električno polje i svjetlosna zraka moraju ulaziti u kristal u strogo određenim pravcima. Zbog toga se koriste kristali s međusobno okomitim osima, i to oni iz kubične ili tetragonske kristalne građe. Prema ulazu svjetlosti u odnosu na narinuto električno polje razlikuje se uzdužni i poprečni učinak. Kod uzdužnog Pockelsovog učinka svjetlosna zraka, mjereno električno polje i optička os kristala su u istom pravcu. Poprečni Pockelsov učinak ima svjetlosnu zraku u smjeru optičke osi kristala, a mjereno električno polje je okomito. Na uzdužnom Pockelsovom učinku se zasnivaju pretvarači za mjerenje punog visokog napona, dok izvedbe s poprečnim Pockelsovim učinkom redovito koriste kapacitivno djelilo napona, to jest mjere niski napon.

1 INTRODUCTION

High voltage can be measured using electrooptical effects, i.e. the Pockels or Kerr effect. It was observed by Pockels that the change in refractive indexes in certain crystals is proportional to the applied electric field. The polarized light, which passes through the crystal and vibrates in two different planes, under the influence of the electric field effects has different changes of the propagation rate. The linear dependence between the change of the refractive index and the intensity of the electric field is recognized as the Pockels effect, while the square dependence is recognized as the Kerr effect. Numerous crystals, liquids and gases demonstrate electrooptical effects. Different substances exhibit different, but constant, relationships between the change of refractive index and electric field. For electrooptical transducers, crystals with specifically arranged crystallographic axes which have a high Pockels or Kerr constant are used.

The electric field and light ray have to intersect the crystal in strictly determined directions. For this reason, crystals of cubic or tetragonal structure with mutually perpendicular axes are used. The longitudinal and transverse effect are distinguished with respect to the applied electrical field. In the longitudinal Pockels effect, the light ray, measured electrical field and optical axis of the crystal are all in same direction. In the transverse Pockels effect, the light ray is in the direction of the crystal optical axis; the measured electrical field is perpendicular to it. Transducers for measuring the full high voltage are based on the longitudinal Pockels effect, while the configurations based on the transverse Pockels effect usually use a capacitive voltage divider, i.e. measure low voltage.

2 OPTIČKI NAPONSKI PRETVARAČ S UZDUŽNIM POCKELSOVIM UČINKOM

Širenje svjetlosti u vakuumu odvija se najvećom brzinom i u svim smjerovima jednako. U kristalima brzina svjetlosti, odnosno indeks loma ovise o smjeru njenog širenja i ravnini titranja. Indeks loma svjetlosti, n, definiran je kao odnos brzine svjetlosti u vakuumu, c, i brzine u nekoj tvari, v:

2 OPTICAL VOLTAGE TRANSDUCER WITH LONGITUDINAL POCKELS EFFECT

In a vacuum, light propagates at the highest speed, equally in all directions. In crystals, the speed of light, i.e. the refraction index, depends on the direction of propagation and the vibration plane. The index of light refraction index, n, is defined as the ratio between the speed of light in vacuum, c, and the speed of light in a certain substance, v:

$$n = \frac{c}{v} \, . \qquad (1)$$

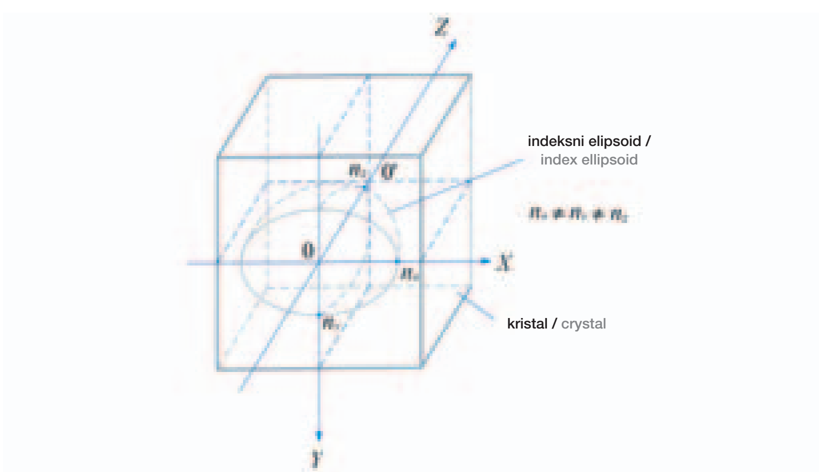
Postavi li se u točki ulaza svjetlosti u kristal koordinatni sustav X, Y, Z koji je paralelan s kristalografskim osima i nanesu indeksi loma vala svjetlosti koja u tom smjeru titra dobit će se u krajnjim točkama prostorna ploha koja se zove optička indikatrisa ili indeksni elipsoid, dan izrazom:

If at the point of the light's incidence on the crystal a coordinate system X, Y, Z, is set, which is parallel to the crystallographic axes and denote the wave refractive indexes of the light vibrating in that direction, at the boundary points a spatial plane is obtained called the indicatrix or index ellipsoid, as per the equation:

$$\left(\frac{x}{n_x}\right)^2 + \left(\frac{y}{n_y}\right)^2 + \left(\frac{z}{n_z}\right)^2 = 1 \, , \qquad (2)$$

gdje su, n_x, n_y, n_z indeksi lomova u smjeru koordinatnih osi X, Y, Z, slika 1.

where, n_x, n_y, n_z are refractive indexes in the direction of coordinate axes X, Y, Z, Figure 1.



Slika 1 Kristalografske osi i indeksni elipsoid
Figure 1 Crystallographic axes and indeks ellipsoid

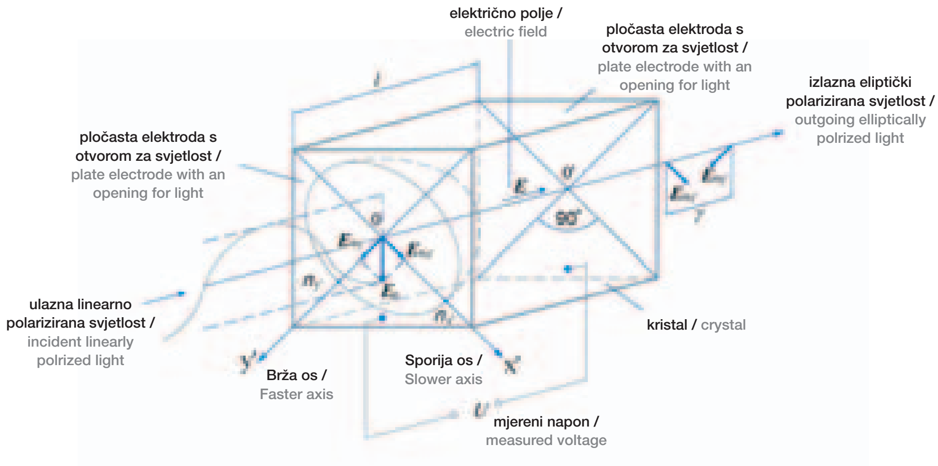
Kada se narine električno polje E u smjeru osi kristala Z, dolazi do zakretanja osi indeksnog elipsoida na x' i y' i do promjene indeksa loma $n_{x'}$ i $n_{y'}$. Promjenom jakosti električnog polja mjenja se vrijednost indeksa loma.

Linearno polarizirana svjetlosna zraka, predočena svjetlosnim vektorom E_0, koja ulazi u kristal u smjeru osi Z, može se rastaviti u dvije komponente $E_{0x'}$ i $E_{0y'}$. One titraju u kristalu u ravninama s različitim indeksima loma, slika 2.

When the electric field E is applied in the direction of the Z axis of the crystal, the axes of the index ellipsoid will shift to x' and y' , the refractive indexes will change into $n_{x'}$ and $n_{y'}$. Changing the intensity of the electric field will change the refractive index value.

A linearly polarized light ray, represented by a light vector E_0, which intersects the crystal in the direction of the Z axis, can be decomposed into two components $E_{0x'}$ and $E_{0y'}$. They vibrate in the crystal, in planes which have different refractive indexes, Figure 2.

Slika 2
Zakretanje i deformiranje indeksnog elipsoida zbog električnog polja i zaostajanje svjetlosnog vektora u ravnini x'.
Figure 2
Rotation and deformation of an indeks ellipsoid due to the electric field and lagging of the light vectot in an x' plane



Pod djelovanjem električnog polja dolazi na izlazu iz kristala do faznog pomaka među tim komponentama za kut γ, odnosno za duljinu δ [1]:

Under the influence of the electric field, the phase shift between the components at the crystal's exit will be γ angle, i.e. length of δ [1]:

$$\delta = (n_{x'} - n_{y'}) \cdot l , \tag{3}$$

gdje je l duljina kristala u smjeru širenja svjetlosti.

Prema Pokelsovim zapažanjima:

where l is the length of the crystal in the direction of light propagation.

In accordance with Pockels' observations:

$$(n_{x'} - n_{y'}) = K_P \cdot E , \tag{4}$$

gdje je K_P Pockelsova konstanta za dati kristal.

where K_P is the Pockels constant for the relevant crystal.

Fazna razlika γ u radijanima iznosi:

Phase difference γ, in radians, is:

$$\gamma = 2\pi \cdot \frac{\delta}{\lambda} = 2\pi \cdot \frac{K_P}{\lambda} \cdot E \cdot l = 2\pi \cdot \frac{K_P}{\lambda} \cdot U \,. \quad (5)$$

Fazni pomak γ u kristalu kod uzdužnog Pockelsovog učinka ne ovisi o duljini kristala l, već o narinutom naponu U.

Za mjerenje treba imati slog kao na slici 3, koji se sastoji redom od: izvora svjetlosti, polarizatora, Pockelsovog kristala, analizatora i fotodetektora. Svjetlosni izvor može biti svjetleća dioda (LED) uskog spektra zračenja, velike životne dobi oko 10^5 sati. Polarizator je optička prizma ili pločica od sintetičkih materijala polaroida, a daje svjetlo koje titra samo u jednoj ravnini. Ravnine titranja u polarizatoru na slici 3 označene su crticama. Iza polarizatora je Pockelsov kristal ili ćelija na koji je narinut mjereni napon. Analizator je ista naprava kao i polarizator. PIN fotodetektor je fotodioda kod koje su P i N tip poluvodiča razdvojeni vrlo tankim prozirnim izolatorom. Struja kroz fotodiodu razmjerna je broju svjetlosnih čestica, fotona, koji upadnu na izolator, to jest jakosti svjetlosti. PIN fotodetektor je pouzdan i ima dug životni vijek. Pravci propuštanja polarizatora i analizatora su okomiti ili pod kutom od 45° zavisno od izvedbe. Fotodetektor mjeri samo jakost svjetlosnog vektora, koji se prema Malusovom [2] zakonu mijenja s kvadratom amplitude svjetlosnog vektora. Svjetlosna jakost iza polarizatora jednaka je onoj ispred analizatora bez obzira na međusobni fazni pomak komponenta svjetlosnog vektora. Tek kada te dvije komponente svjetlosnog vektora prođu kroz analizator dat će jakost svjetla ovisno o njihovom faznom pomaku γ.

Integral električnog polja E duž nekog puta l između točke a (fazni vodič) i točke b (zemlja) daje napon između tih točaka:

The phase shift γ in a crystal with a longitudinal Pockels effect does not depend on the length of the crystal l, but on the applied voltage U.

For measuring, the configuration as per Figure 3 is required, consisting of: a light source, polarizer, Pockels crystal, analyzer and photodetector. The light source can be a light emitting diode (LED) of the narrow emitting spectrum, whose lifetime is reaches about 10^5 hours. The polarizer is an optical prism or a plate made from polaroid synthetic materials, and it gives a light that vibrates in one plane only. The vibration planes in the polarizer, Figure 3, are marked with an intermittent line. After the polarizer, there is a Pockels crystal or a cell where the measured voltage is applied. The analyzer is the same device as the polarizer. The PIN photodetector is a photodiode where P and N semiconductor types are separated from each other by a very thin transparent insulator. The current through the photodiode is proportional to the number of light particles, photons, that impact the insulator, i.e. it is proportional to the intensity of light. The PIN photodetector is reliable and has a long lifetime. The transmission axes of the polarizer and analyzer are either perpendicular to each other or inferior to an angle of 45° , depending on the arrangement. The photodetector measures the intensity of the light vector only, which, in accordance with Malus' law [2], changes in relation to the square of the amplitude of the light vector. The intensity of light after the polarizer is equal to the intensity of light before the analyzer, regardless to the mutual phase shift of the light vector components. After these two light vector components have passed through the analyzer, they will provide an intensity of light in relation to their phase shift γ.

The integral of the electric field E along the distance l between point a (live lead) and point b (earth) gives the voltage between these points:

$$U_{ab} = \int_a^b E \cdot \mathrm{d}l \,. \quad (6)$$

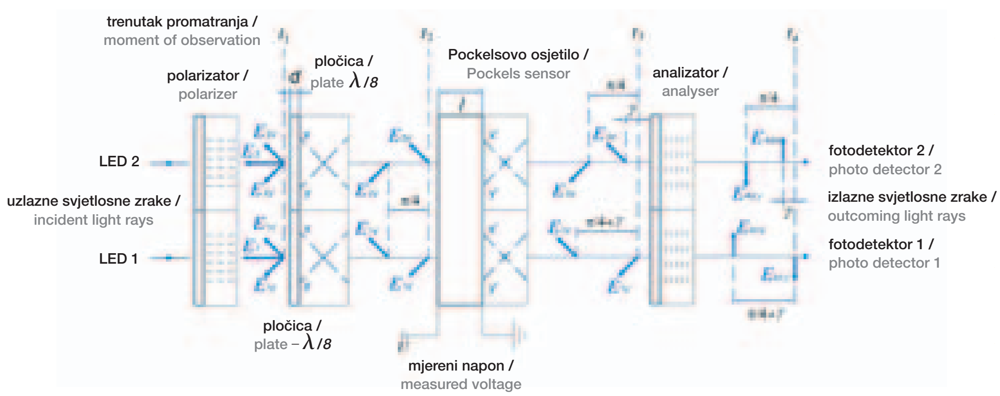
Napon kod koga fazni pomak γ dosegne vrijednost π naziva se poluvalni napon. Za većinu kristala s uzdužnim Pockelsovim učinkom fazni pomak $\gamma = \pi$ postiže se već pri naponu 11 kV do 40 kV,

The voltage value at which the phase shift γ achieves the value π is called a half-wave voltage. For majority of crystals with the longitudinal Pockels effect, the phase shift of $\gamma = \pi$ is achieved ovisno o kristalu [3] i [4]. Kako je fazni napon visokonaponskih vodova znatno viši fazni pomak γ će višestruko prekoračiti vrijednost π. Budući da se kut određuje preko trigonometrijskih funkcija, iste će se vrijednosti funkcija javljati za različite kutove γ, odnosno različite napone. Za otklanjanje te višeznačnosti koriste se elektronički sklopovi (signalni procesori) koji registriraju osim same vrijednosti signala i broj ekstremnih vrijednosti, odnosno koliko je puta prekoračen poluvalni napon. Za Pockelsovo osjetilo najčešće se koriste kristali bizmut-germanijev oksid ($Bi_4Ge_3O_{12}$), ili amonij-dihidrogen fosfat ($NH_4H_2PO_4$).

Izvedba Pockelsovog osjetila prikazana na slici 3 [5] koristi dva svjetlosna puta da bi jednoznačno odredila vrijednost kuta γ unutar raspona od π radijana.

at a voltage value ranging from 11 kV to 40 kV, depending on the crystal [3] and [4]. As the phase voltage of the high voltage lines is significantly higher, the phase shift γ will many times exceed the value of π. As the angle is determined by trigonometric functions, the same function values will be obtained for different γ angles, i.e. different voltages. In order to eliminate this ambiguity, use is made of electronic circuits (signal processors) that, besides the signal value itself, register the number of extreme values (i.e. how many times the half-wave voltage has been exceeded). The crystals that are most used for the Pockels sensor are bismuth-germanium oxide ($Bi_4Ge_3O_{12}$) and ammonium-dihydrogen phosphate ($NH_4H_2PO_4$).

The Pockels sensor configuration as presented by Figure 3 [5] uses two light paths in order to unambiguously define the γ angle value within the range of π radians.



Slika 3
Pockelsovo osjetilo s dva svjetlosna puta
Figure 3
Pockels sensor with two light paths

Svjetlosni vektori E_1 i E_2, koji su prošli kroz polarizator, rastavljaju se na međusobno okomite komponente $E_{1x'}$, $E_{1y'}$, $E_{2x'}$ i $E_{2y'}$. Njihove ravnine titranja paralelne su sa zakrenutim osima indeksnog elipsoida Pockelsovog osjetila. Na prvom svjetlosnom putu nalazi se kristalna pločica $-\lambda/8$, a na drugom $\lambda/8$. Kristalna pločica $-\lambda/8$ propušta komponentu $E_{1x'}$ s manjom brzinom nego $E_{1y'}$. Debljina pločice d, odabrana je tako da se dobije fazni pomak $-\pi/4$. Prolaskom svjetlosti kroz Pockelsovo osjetilo, koje je pod naponom U, dolazi do daljnjeg pomaka među komponentama za kut γ. Pravci propuštanja polarizatora i analizatora su međusobno okomiti. Na izlazu iz analizatora amplitude svjetlosnog vektora komponente svjetlosnih zraka su:

The light vectors E_1 and E_2, after having passed through the polarizer, are decomposed to mutually perpendicular components $E_{1x'}$, $E_{1y'}$, $E_{2x'}$, i $E_{2y'}$. Their vibration planes are parallel with the shifted axes of the index ellipsoid of the Pockels sensor. In the first light path there is a crystal plate $-\lambda/8$, while in the second light path there is a crystal plate $\lambda/8$. The crystal plate $-\lambda/8$ transmits the component $E_{1x'}$ at a lower speed than $E_{1y'}$. The thickness of plate d was selected in order to get the phase shift of $-\pi/4$. Passing the light through the Pockels sensor, which is below the voltage , contributes to a further shift between the components, by an angle of γ. The transmission lines of the polarizer and analyzer are perpendicular to each other. At the analyzer exit, the amplitudes of the light vector of light ray components are:

$$E_{A1x'}(t) = E_{A1x} \cdot \sin(\omega t - \frac{\pi}{4} - \gamma), \tag{7}$$

$$E_{A1y'}(t) = -E_{A1y} \cdot \sin \omega t, \tag{8}$$

$$E_{A2x'}(t) = E_{A2x} \cdot \sin(\omega t - \gamma), \tag{9}$$

$$E_{A2y'}(t) = -E_{A2y} \cdot \sin(\omega t - \frac{\pi}{4}), \tag{10}$$

gdje su:

E_{A1x}, E_{A1y}, E_{A2x}, E_{A2y} – amplitude svjetlosnih vektora na ulazu u analizator,

$E_{A1x'}(t)$, $E_{A1y'}(t)$, $E_{A2x'}(t)$, $E_{A2y'}(t)$ – trenutni iznosi u smjeru propuštanja.

Analizator propušta dio komponenti svjetlosnog vektora u smjeru njegove osi, te se zbrajaju na fotodetektoru. Jakost svjetlosti na fotodetektorima je:

where:

E_{A1x}, E_{A1y}, E_{A2x}, E_{A2y} – amplitudes of the light vectors at the analyzer input,

$E_{A1x'}(t)$, $E_{A1y'}(t)$, $E_{A2x'}(t)$, $E_{A2y'}(t)$ – momentarily values in the conducting direction.

The analyzer passes part of the light vector components in the direction of its axis, they are summed up by the photodetector. Intensity of light at the photodetectors is:

$$I_1 = I_0 \cdot \sin^2(\frac{\gamma}{2} + \frac{\pi}{8}), \tag{11}$$

$$I_2 = I_0 \cdot \sin^2(\frac{\gamma}{2} - \frac{\pi}{8}), \tag{12}$$

gdje je I_0 jakost svjetlosti na izlazu iz polarizatora. Iz para mjerenih vrijednosti fotodetektora (11) i (12) može se odrediti kut γ, odnosno mjereni napon (5).

where I_0 is the intensity of light at the polarizer exit. From the measured photodetector values (11) and (12), the angle γ, i.e. measured voltage (5) are determined.

3 OPTIČKI NAPONSKI PRETVARAČ S POPREČNIM POCKELSOVIM UČINKOM

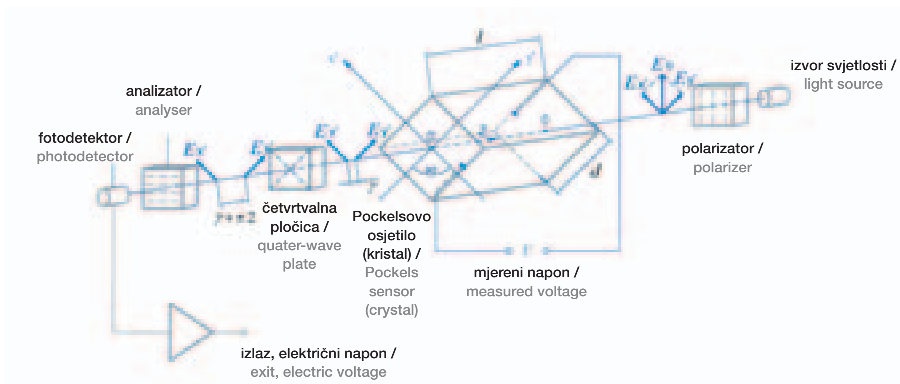
Kod osjetila s poprečnim Pockelsovim učinkom okomito na pravac širenja svjetlosti narinuto je električno polje. Mjereni napon je nekoliko kilovolta pa se osjetilo koristi u sprezi s kapacitivnim djeliteljem napona. Na slici 4 prikazana je izvedba pretvarača koji se sastoji od izvora svjetlosti, polarizatora, osjetila od kristala litij-niobata ($LiNbO_3$), analizatora i fotodetektora. Iza fotodetektora nalazi se elektronički sklop za obradu električnog signala. Pri tome se redovito koristi amplitudna detekcija [5] i [6].

3 OPTICAL VOLTAGE TRANSDUCER WITH THE TRANSVERSE POCKELS EFFECT

At the sensors with the transverse Pockels effect, perpendicularly to the direction of light propagation an electric field is applied. The measured voltage is at the level of several kilovolts, therefore the sensor is used with a capacitive voltage divider. Figure 4 shows a transducer configuration consisting of a light source, polarizer, sensor from the lithium niobate ($LiNbO_3$) crystal, analyzer and photodetector. After the photodetector, there is an electronic circuit for processing the electrical signal. Amplitude detection is normally used [5] and [6].

Slika 4 Mjerenje napona korištenjem poprečnog Pockelsovog učinka s amplitudnim detektiranjem

Figure 4 Voltage measurement using transverse Pockels effect with amplitude detection



Svjetlosni vektor E_0 se razlaže na komponente E_x, i E_y, koje titraju u međusobno okomitim ravninama. Narinuto električno polje mijenja brzine svjetlosti u tim ravninama. Nastala fazna razlika γ prema izrazu (5), ako se uvrsti za jakost polja $E = U/d$, jednaka je:

The light vector E_0 is decomposed into the components E_x, and E_y, which vibrate in mutually perpendicular planes. The applied electric field changes the speeds of light in these planes. The resulting phase difference γ in accordance with (5), if the value of $E = U/d$ is taken for the electric field intensity, is equal to:

$$\gamma = 2\pi \frac{K_P \cdot U}{\lambda \cdot d} \cdot l \,. \qquad (13)$$

Potrebna osjetljivost na promjenu napona može se postići izborom dimenzija kristala l i d. Kad nema narinutog napona fazni pomak γ je nula, te projekcije vektora E_x, i E_y, u ravninu propuštanja analizatora daju komponente svjetlosnih vektora koje se poništavaju. Da bi područje rada bilo u linearnom dijelu sinusne funkcije umetnuta je četvrtvalna pločica koja pravi dodatni fazni pomak

The required sensitivity to the change of voltage can be gained by selecting the crystal's dimensions, l and d. When there is no applied voltage, the phase shift γ is equal to zero, the vector projections E_x, and E_y, pass the components of light vectors into the analyzer transmission plane; these components cancel each other out. In order to keep the operation range in a linear part of the sine function, a quarter-

$\pi/2$. Time se dobije ukupni fazni pomak od $\gamma + \pi/2$ među svjetlosnim vektorima, čije su projekcije u ravnini propuštanja analizatora, slika 4:

wave plate has been inserted; the plate produces an additional phase shift of $\pi/2$. This results in a total phase shift of $\gamma + \pi/2$ between the light vectors whose projections are in the transmission plane of the analyzer, Figure 4:

$$E_{Ax'}(t) = E_{Ax} \cdot \sin \omega t, \tag{14}$$

$$E_{Ay'}(t) = -E_{Ay} \cdot \sin(\omega t + \gamma + \frac{\pi}{2}). \tag{15}$$

gdje su:

E_{Ax}, E_{Ay} – amplitude svjetlosnog vektora ispred analizatora,

$E_{Ax'}$ (t), $E_{Ay'}$ (t) – trenutne vrijednosti u smjeru propuštanja.

Uz jednake amplitude geometrijski zbroj daje:

where:

E_{Ax}, E_{Ay} – amplitudes of the light vectors at the analyzer input,

$E_{Ax'}$ (t), $E_{Ay'}$ (t) – momentarily values in the conducting direction.

With the same amplitudes, the geometrical sum is:

$$E_{rez}(t) = 2\, E_A \cdot \sin(\frac{\gamma + \frac{\pi}{2}}{2}) \cdot \cos(\frac{2\omega t + \gamma + \frac{\pi}{2}}{2}). \tag{16}$$

Ako se s I_o označi jakost svjetlosti iza polarizatora, jakost svjetlosti I na fotodetektoru je:

If I_o is the intensity of light after the polarizer, the intensity of light I at the photodetector is:

$$I = \frac{1}{2} I_0 (1 + \sin \gamma). \tag{17}$$

Istosmjerni član se može izlučiti pa se dobije:

A direct member is extracted, hence:

$$I = k \cdot I_0 \cdot \sin \gamma. \tag{18}$$

Konstanta k uzima u obzir i gubitke svjetlosti. Polazna jakost svjetlosti I_o je stalna, a na kristal se dovode niži naponi da kut γ bude mali. Tada je vrijednost sinusa kuta približno jednaka samom kutu, pa je γ u linearnoj ovisnosti o mjerenom naponu.

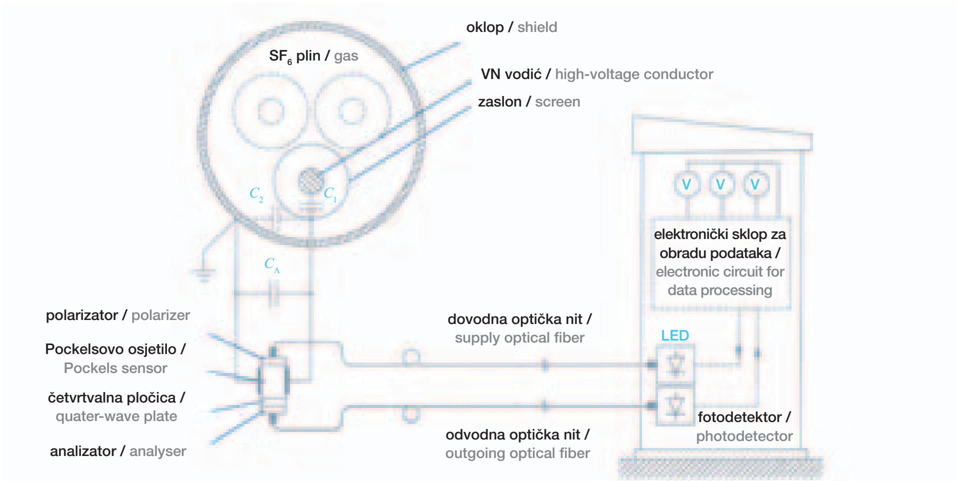
Shema optičkog naponskog pretvarača primijenjenog u plinom SF_6 izoliranom postrojenju dana je na slici 5. Ovdje je kapacitivno djelilo sastavljeno od kapaciteta C_1 između visokonaponskog vodiča i njegovog zaslona, dok kapacitet C_2 predstavlja kapacitet između zaslona i uzemljenog oklopa.

The constant k takes into consideration losses of light. The starting intensity of light I_o is constant, rather low voltages are brought to the crystal, in order to keep the γ angle low. Then, the sine value of the angle will be close to the angle value itself, therefore γ is linearly dependent on the measured voltage.

A scheme of an optical voltage transducer used in a plant isolated by the gas SF_6 is presented by Figure 5. Here, the capacity divider consists of C_1 capacity between the high voltage conductor and its screen, while C_2 is the capacity between the screen and earthed shield. The capacity C_A is added to the

Kapacitet C_A dodan je kapacitetu C_2 tako da se na Pockelsovu osjetilu dobije dovoljno nizak napon. Izvor svjetlosti je LED, valne duljine λ = 0,85 μm, čija se svjetlost vodi optičkom niti (promjera 50 μm) do polarizatora. Polarizator, Pockelsovo osjetilo, četvrtvalna pločica i analizator smješteni su na oklopu. Linearno polarizirano svjetlo dovodi se do PIN fotodetektora s optičkom niti (promjera 200 μm) gdje se pretvara u električni signal, koji se dalje obrađuje amplitudnom detekcijom. Za priključak elektrodinamičkih brojila i releja [5] iz pojačala se može izvesti i analogni izlaz 100 / $\sqrt{3}$ V, snage nekoliko desetaka voltampera.

capacity C_2 in order to get a satisfactorily low voltage at the Pockels sensor. The light source is LED, of wavelength λ = 0,85 μm, whose light is by means of optical fibers (diameter of 50 μm) conducted to the polarizer. The polarizer, Pockels sensor, quarter-wave plate and analyzer are placed on the shield. Linearly polarized light is taken to a PIN photodetector by means of optical fiber (diameter of 200 μm) where it is converted into an electrical signal, which is further processed by amplitude detection. For connecting the electrodynamic counters and relays [5], an analogue output of 100 / $\sqrt{3}$ V, whose power amounts to several tens VA, can be taken out at the amplifier.



Slika 5
Shema spoja optičkog naponskog pretvarača u oklopljenom postrojenju
Figure 5
Layout of the optical voltage transducer in a shielded plant

4 ZAKLJUČAK

Optički naponski pretvarači iskazuju dobra svojstva: postojanost, pouzdanost i točnost pri mjerenju i zaštiti [7], [8], [9] i [10]. Otporni su na elektromagnetske smetnje. Ne trebaju osigurače. Ne sadrže ulje te ne mogu eksplodirati. Naponski i strujni pretvarači mogu se izvesti korištenjem zajedničkih dijelova. To nadalje smanjuje njihovu masu, potreban prostor u postrojenju za njihovo postavljanje, dimenzije nosača i troškove postavljanja. Zbog jednostavnosti građe i dobre izolacije između dijelova koji se nalaze pod visokim naponom i uzemljenih dijelova za očekivati je manji broj preskoka, proboja i drugih kvarova, a time i pouzdaniji rad mreže na koju su priključeni.

4 CONCLUSION

Optical voltage transducers demonstrate favorable properties: stability, reliability and accuracy in measuring and protecting [7], [8], [9] and [10]. They are resistant to electromagnetic disturbances. No fuses are needed. They do not contain oil and cannot explode. The same parts can be used for voltage and current transducers. This will contribute to a reduction of their weight, the required installation space in the plant, the dimensions of the carrying elements and installation costs. Because of the simplicity of configuration and good insulation between the high voltage parts and earthed parts, one may expect fewer skips, breakdowns and other failures, which directly contributes to the higher reliability of the network they are connected to.

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