SIGURNOST POGONA I IDENTIFIKACIJA MOGUĆIH MJESTA ZAGUŠENJA PRIJENOSNE MREŽE JUGOISTOČNE EUROPE U TRŽIŠNOM OKRUŽENJU

SECURITY OF OPERATION AND IDENTIFICATION OF POSSIBLE BOTTLENECKS IN SOUTHEAST EUROPE TRANSMISSION NETWORK UNDER MARKET CONDITIONS

Mr. sc. Davor Bajs, dr. sc. Nijaz Dizdarević, mr. sc. Goran Majstrović,
Energetski institut Hrvoje Požar, Savska 163, 10000 Zagreb,Hrvatska
Davor Bajs, MSc, Nijaz Dizdarević, PhD, Goran Majstrović, MSc,
Hrvoje Požar Institute for Energy, Savska 163, 10000 Zagreb, Croatia

Na temelju rezultata proračuna tokova snaga i analize sigurnosti pogona visokonaponske prijenosne mreže u jugoistočnoj Europi, uz tržišno određen angažman proizvodnih postrojenja, opisane su osnovne značajke mreže i identificirana moguća mjesta zagušenja. Ti su proračuni izvedeni u sklopu projekta REBIS (eng. Regional Balkans Infrastructure Study), koji financira Europska komisija, odnosno GIS (eng. Generation Investment Study), studije izgradnje novih proizvodnih kapaciteta u regiji. Tržišni angažman proizvodnih postrojenja u jugoistočnoj Europi u stanjima prognoziranog vršnog opterećenja sustava 2010. i 2015. godine, za različita hidrološka stanja, određen je s pomoću programa WASP (IAEA) i GTMax (Argonne NL). Proračuni tokova snaga izvedeni su uporabom programskog paketa PSS/E (Siemens PTI). U radu se posebice razmatraju simulirani angažman elektrana i pogon prijenosne mreže unutar sustava u Republici Hrvatskoj.

Based on the results of calculations of power flows and on the analysis of the operation of the HV transmission network in Southeast Europe, with the market focus on generation facilities, the basic characteristics of the network are described and possible bottlenecks identified. The calculations were done within the EC-funded REBIS project (Regional Balkans Infrastructure Study) and the Generation Investment Study (GIS) of new power generation capacities in the region. The market offering of generation facilities in Southeast Europe at forecast system peak loads in 2010 and 2015, for different hydrological conditions, was determined by the WASP (IAEA) and GTMax (Argonne NL) software. Calculations of power flows were carried out by using the PSS/E software (Siemens PTI). The article particularly discuses simulated power plant output and the operation of the transmission network in the Republic of Croatia.

Ključne riječi: analize sigurnosti, jugoistočna Europa, tokovi snage, tržišni angažman elektrana
Key words: market offering of power plants, power flows, security analyses, Southeast Europe

1 UVOD

U sklopu projekta REBIS (eng. Regional Balkans Infrastructure Study), financiranoga kroz program CARDS Europske komisije, izrađena je GIS (eng. Generation Investment Study) studija potrebne izgradnje proizvodnih postrojenja na području jugoistočne Europe [1]. U vrijeme pisanja ovoga članka (ožujak, 2005.) GIS studija predana je naručitelju u obliku draft-verzije. PriceWaterhouseCoopers (PWC), Montgomery Watson Harza (MWH) i Atkins glavni su izvođači studije.

Osnovna je zadaća GIS studije identifikacija prioriteta izgradnje novih proizvodnih postrojenja u jugoistočnoj Europi te novih interkonekcijskih vodova radi podupiranja tržišnog angažmana postojećih i novih elektrana koje će sudjelovati na regionalnom energetskom tržištu. Promatrano je razdoblje od 2005. do 2020. godine, a optimiranje izgradnje novih elektrana izvršeno je za tri scenarija pogona elektroenergetskih sustava (EES): 1) optimiranje izgradnje elektrana izoliranih EES-a u regiji, 2) optimiranje izgradnje elektrana na razini regije u cjelini bez tržišnih odnosa, 3) optimiranje izgradnje elektrana na razini regije unutar tržišnog okruženja. Radi određivanja potrebne izgradnje novih elektrana i angažmana svih proizvodnih postrojenja u regiji upotrijebljeni su programski paketi WASP i GTMax.

GTMax je upotrijebljen za treći analizirani scenarij pogona EES-a jugoistočne Europe unutar regionalnog tržišta električne energije. S pomoću GTMaxa simulira se pogon EES-a u tržišnom okruženju na taj način da se maksimira profit elektroenergetskih kompanija uz minimum troškova pogona sustava, istodobno zadovoljavajući fizikalna ograničenja pogona sustava. Simulacijom tržišnih prilika 2010. i 2015. godine s pomoću GTMax modela dobiveni su različiti scenariji angažmana postojećih elektrana unutar tržišta jugoistočne Europe te potrebna izgradnja novih proizvodnih postrojenja koja imaju tržišno opravdanje u regionalnim okvirima. Scenariji su formirani prema promatranim hidrološkim prilikama (prosječna, suha i vlažna hidrologija), visini opterećenja (referentni scenarij porasta potrošnje i opterećenja, visoki scenarij porasta potrošnje i opterećenja) i razmjenama snage između regije i vanjskih sustava poput UCTE, Ukrajine i Turske.

S obzirom na to da GTMax model uključuje vrlo grubi prikaz prijenosnih sposobnosti mreže, za određeni broj scenarija izvedeni su detaljni proračuni tokova snaga i analize sigurnosti uporabom regionalnog modela prijenosnih sustava RTSM (eng. Regional Transmission System Model) izrađenog u sklopu projekta SECI (eng. South East Cooperation Initiative). RTSM je izrađen u svjetski relevantnom programskom paketu PSS/E (eng. Power System

1 INTRODUCTION

Within the framework of the Regional Balkans Infrastructure Study (REBIS), funded from the CARDS program of the European Commission, the Generation Investment Study (GIS) was prepared concerning the necessary construction of power generation facilities in Southeast Europe [1]. When this article was written in March 2005, the draft GIS was submitted to the customer. PriceWaterhouseCoopers (PWC), Montgomery Watson Harza (MWH) and Atkins were the main contributors to the study.

The basic task of GIS was to identify the priorities in the construction of new production facilities and new interconnection lines in SEE to support the market offering of the existing and new power plants on the regional electricity market. The period under scrutiny was between 2005 and 2020, and the optimisation of the construction of new power plants was undertaken for three scenarios of power system operation: 1) Optimisation of the construction of isolated power system facilities in the region, 2) Optimisation of the construction of power plants at the regional level without market implications, 3) Optimisation of the construction of power plants at the regional level with market implications. In defining the necessary construction of new power plants and the offering of all the power generation facilities in the region, WASP and GTMax software was used.

GTMax was used for the third analysed power system scenario for the SEE regional electric market. With GTMax, the power system was simulated under market conditions by maximising the profit of power companies at the minimum system operating costs, simultaneously taking into account the physical limitations of the system operation. By simulating market conditions for 2010 and 2015 with the GTMax model, different scenarios for the engagement of the existing power plants in the SEE market were obtained as well as for the necessary construction of new power generation facilities justified in terms of the regional market. The scenarios were created in accordance with the observed hydrological conditions (average, dry and wet), load levels (reference scenario of the increase in consumption and load, high scenario of the increase in consumption and load) and the power exchange between the region and the external systems such as UCTE, Ukraine and Turkey.

Considering that the GTMax model includes a very rough presentation of transmission capabilities of the network, in a number of scenarios, detailed calculations of power flows and the analyses of operational security were conducted on the regional transmission system model (RTSM) set up within the framework of the SECI (South East Cooperation Initiative) project. The RTSM was developed with the globally relevant PSS/E software (Power System Simulator for Engineering) [2]. The analysis of the operation of the transmission network in SEE is contained in the closing part of GIS as Appendix 12: PSS/E Analyses and Results.

Simulator for Engineering) [2]. Analiza pogona prijenosne mreže jugoistočne Europe sadržana je u završnom izvještaju GIS studije kao njezin dodatak (Appendix 12: PSS/E Analyses and Results). Analize su izvedene u prvom tromjesečju 2005. godine u Energetskom institutu Hrvoje Požar (EIHP) u Zagrebu i Elektrokoordinacijskom centru (EKC) u Beogradu.

Zadaća analiza provedenih programskim paketom PSS/E na regionalnome modelu prijenosnih sustava jugoistočne Europe (RTSM) sastoji se u sagledavanju izgrađenosti internih prijenosnih mreža pojedinih zemalja u regiji te njihove povezanosti interkonekcijskim vodovima radi omogućavanja tržišnog angažmana postojećih i novih proizvodnih postrojenja za različita hidrološka stanja, bilance regije i visine opterećenja. Sagledavanje se izvodi sa stajališta prepoznavanja eventualno potrebnih investicija u mrežama radi osiguravanja tržišnog angažmana elektrana unutar normalnog (raspoložive sve grane mreže) i izvanrednog pogona (neraspoloživa jedna grana mreže).

Analize su obuhvatile proračune tokova snaga i (n-1) procjenu sigurnosti. Promatrana su dva aspekta pogona: opterećenja prijenosnih grana s obzirom na njihove termičke granice i naponske prilike u mreži. Identificirana su moguća mjesta zagušenja te su analizirane mogućnosti njihova otklanjanja. Također je procijenjena uloga novih interkonekcijskih vodova u regiji predviđenih za izgradnju unutar analiziranog razdoblja (2010. do 2015. godine).

U članku su opisani osnovni rezultati analiza provedenih s pomoću PSS/E programskog paketa. Razmotrena je uloga EES-a Republike Hrvatske unutar tržišta električne energije u jugoistočnoj Europi, u prvom redu kroz aspekt tržišnog angažmana proizvodnih postrojenja, očekivanih razmjena sa susjednim sustavima te pogona i sigurnosti rada prijenosne mreže. Opisane analize predstavljaju prve simulacije rada EES-a Republike Hrvatske unutar tržišnog okruženja koje pružaju bitne rezultate za pomoć HEP grupi u postavljanju strategije rada i izgradnje proizvodnih postrojenja te u sagledavanju pogona planirane prijenosne mreže u srednjoročnom i dugoročnom razdoblju.

2 OPIS GTMax i PSS/E MODELA PRIJENOSNOG SUSTAVA

GTMax model postavljen je na temelju rezultata WASP analize potrebne izgradnje i angažmana elektrana u drugom analiziranom scenariju koji podrazumijeva regionalni pogon elektroenergetskih sustava jugoistočne Europe, ali bez tržišnog nadmetanja. Slika 1 prikazuje zemlje koje su uključene u model. Promatra se izolirana regija jugoistočne Europe. GTMaxom je

Analyses were carried out in the first quarter of 2005 at the Hrvoje Požar Institute for Energy, Zagreb and the Electrocoordination Centre (ECC) in Belgrade.

The goal of the analyses conducted with the PSS/E software on the regional model of SEE transmission systems (RTSM) consisted in noting the state of development of internal transmission networks in individual countries of the region and their interconnection lines to enable the market offering of the existing and new power generation facilities for different hydrological conditions, regional balance and load levels. This was done by recognising possible necessary investment in the networks with a view to the market engagement of power plants in normal operation (all network branches available) and in emergency operation (one network branch non-available).

Analyses included the calculations of power flows and the (n-1) security estimate. Two operational aspects were observed: load in transmission branches considering their thermal limits and voltage in the network. Possible bottlenecks were identified and how they could be overcome. The role of the new interconnection lines in the region scheduled for construction in the period under scrutiny (2010-2015) was also analysed.

The article describes the basic results of the analyses conducted by the PSS/E software. The role of the power system in the Republic of Croatia was considered within the framework of the SEE electricity market, primarily from the aspect of the market engagement of power generation facilities, the expected exchange with the neighbouring systems, and the operation and transmission network security. The analyses mentioned are the first simulations of the power system in the Republic of Croatia under market conditions, providing important outcomes to help the HEP Group set up a strategy for the operation and construction of power generation facilities and to consider the operation of the transmission network planned in the medium term and in the long term.

2 DESCRIPTION OF THE GTMax and PSS/E TRANSMISSION SYSTEM MODELS

The GTMax model was set up on the basis of the outcomes of the WASP analysis with regard to the necessary construction and engagement of power plants under the second analysed scenario of the regional operation of SEE power systems, without involving the market competition. Figure 1 shows the countries included in the model. The SEE region is observed in isolation. GTMax was used to analyse the reference sub-scenario within the WASP in question which includes the mean increase in the consumption of electricity in the region, the expected fuel price in the period under scrutiny, and the decommission and rehabilitation of individual power generation facilities analiziran referentni podscenarij unutar razmatranog WASP scenarija koji podrazumijeva srednji porast potrošnje električne energije u regiji, očekivane cijene goriva u razmatranom razdoblju te izlazak iz pogona i revitalizaciju postojećih proizvodnih postrojenja prema planovima svakog elektroprivrednog poduzeća u regiji.

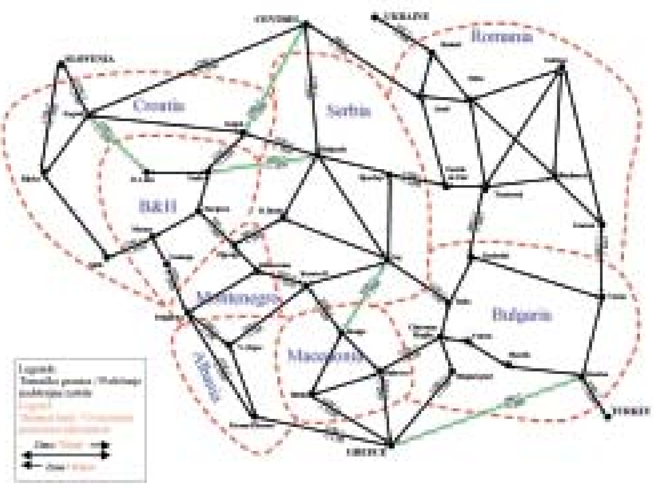
Prikaz prijenosnog sustava unutar GTMax modela (slika 2) vrlo je pojednostavljen i obuhvaća ekvivalentne grane kojima je pridružena određena prijenosna moć. Ako je u simulacijama rada tržišta prijenosna moć neke grane prekoračena, izvodi se preraspodjela angažmana proizvodnih postrojenja. Za određivanje opterećenja pojedinih grana ne izvode se proračuni tokova snaga, već se granama pridružuju određene tržišne transakcije. Očito je da na taj način nije moguće sveobuhvatno sagledati pogon stvarnoga prijenosnog sustava za zadani angažman elektrana. GTMax ne razmatra sigurnost pogona prema (n-1) kriteriju.

in accordance with the plans of each individual power company in the region.

The presentation of the transmission system within the GTMax model (Figure 2) is very simplified, and it includes the equivalent branches with particular transmission capacities attributed. If in the simulation of the market operation the transmission capacity of a branch is exceeded, the engagement of power generation facilities is rearranged. In determining the load for individual branches, no power flow calculations were undertaken - the branches are attributed particular market transactions. Apparently, this makes it impossible to comprehensively consider the operation of the actual transmission system for the given engagement of power plants. GTMax does not include operational security according to the (n-1) criterion.

Slika 1
Zemlje uključene u GTMax model
Figure 1
Countries included in the GTMax model

Slika 2
Topologija mreže jugoistočne Europe 2010. i 2015. godine unutar GTMax modela
Figure 2
SEE network topology in the GTMax model for 2010 and 2015



Za razliku od GTMax modela, gdje je prikaz prijenosnog sustava jugoistočne Europe vrlo ograničen, PSS/E regionalni model prijenosnog sustava jugoistočne Europe (RTSM) sadrži detaljno modelirane grane 400 kV, 220 kV, 150 kV i 110 kV, opterećenja modelirana u svim čvorištima 110 kV i kompletan prikaz elektrana kao skupina generatora i pripadnih blok-transformatora. RTSM za 2010. godinu sadrži ukupno 4 182 čvorišta, 661 elektranu i 752 generatora, 2 824 tereta, 5 144 vodova i 1 238 transformatora. Kao granice opterećenja grana unutar RTSM definirana su gornja dopuštena termička opterećenja vodova i prividne snage transformatora. U modelu se zadaje angažman svakoga generatora i visina tereta u svakom čvorištu mreže gdje je modelirano opterećenje, te bilanca svakoga pojedinačnog sustava (proizvodnja - opterećenje), pa se na zadanoj konfiguraciji mreže izvode proračuni tokova snaga i (n-1) analiza sigurnosti. Konfiguracija prijenosne mreže jugoistočne Europe, na način kako je modelirana u PSS/E, predočena je na slici 3. PSS/E model uključuje još i prijenosne mreže Slovenije, Mađarske, zapadne Ukrajine, Grčke, Turske i ekvivalent UCTE sustava. Konfiguracija prijenosne mreže RH prema PSS/E modelima za 2010. i 2015. godinu predočena je na slici 4 [3].

Unlike the GTMax model, where the presentation of the SEE transmission system is very limited, the PSS/E regional model (RTSM) contains details of 400 kV, 220 kV, 150 kV and 110 kV branches, with the loads modelled at all the 110 kV nodes, plus a complete overview of power plants as a group of generators and their unit-transformers. The RTSM for the year 2010 contains a total of 4,182 nodes, 661 power plants and 752 generators, 2,824 loads, 5,144 lines and 1,238 transformers. The load limits within the RTSM include the definition of top allowed thermal loads of power lines and the apparent transformer power. The model defines the utilisation of each generator and the level of load at each node of the network where the load is modelled, plus the balance of each individual system (generation-load), and calculations of power flows and the (n-1) security analysis are carried out with regard to the given configuration of the network. The configuration of the SEE transmission network as modelled in the PSS/E is shown in Figure 3. The PSS/E model also includes the transmission networks of Slovenia, Hungary, West Ukraine, Greece, Turkey and the equivalent of the UCTE system. The configuration of the transmission network of Croatia according to the PSS/E models for the years 2010 and 2015 is shown in Figure 4 [3].

Slika 3
Prijenosna mreža jugoistočne Europe 2010. i 2015. godine (postojeći i planirani interkonekcijski vodovi)
Figure 3
Transmission network of Southeast Europe in 2010 and 2015 (existing and planned interconnection lines)

Zbog drugačijeg modeliranja elektroenergetskih sustava unutar GTMax i PSS/E modela najprije je bilo potrebno izvesti njihovo usklađivanje. Elektranama u GTMax modelu pridruženi su odgovarajući generatori iz PSS/E modela, te je na osnovi dobivenih GTMax scenarija unesen njihov angažman za svaki ispitivani scenarij. S obzirom na to da je GTMax model

Because of the different modelling of electric power systems within the GTMax and PSS/E models, it was first necessary to harmonise them. Power plants in the GTMax model are associated with the appropriate generators from the PSS/E model, and on the basis of the obtained GTMax scenarios their engagement was entered for each examined scenario. Considering that the GTMax sadržavao određeni broj elektrana priključenih na 35 kV naponskoj razini (posebice istaknuto u Rumunjskoj zbog velikog broja malih hidroelektrana), za njihov je angažman u PSS/E modelu smanjeno ukupno opterećenje svakog sustava u kojem se takve elektrane nalaze. Budući da PSS/E RTSM sadrži očekivana opterećenja 3. srijede u siječnju 2010. godine, za svaki su sustav linearno promijenjena opterećenja čvorišta kako bi ukupno opterećenje svakog sustava odgovaralo modeliranom GTMax stanju.

Nakon proračuna tokova snaga u svakom su scenariju opterećenja sustava iterativno korigirana kako bi se uključili i gubici u mrežama koje GTMax model ne razmatra. Tako su analiziranim opterećenjima sustava u GTMax modelu odgovarale sume opterećenja i gubitaka svakog sustava u PSS/E regionalnom modelu. U odnosu na bilance svakog sustava u GTMax modelu koje proizlaze iz tržišnog angažmana elektrana i modeliranog opterećenja svakog sustava, iste su korigirane u PSS/E modelu po načelu zemljopisnog položaja svake elektrane (npr. angažman pola snage NE Krško u GTMax modelu uključen je u bilancu Hrvatske, a u PSS/E modelu je izdvojen iz bilance; angažman generatora 2 HE Dubrovnik je u GTMax modelu uključen u bilancu BiH, a u PSS/E modelu uključen je u bilancu Hrvatske).

model contained a number of power plants connected at the 35 kV voltage level (particularly in Romania with the large number of small hydroelectric power plants), their engagement in the PSS/E was deducted from the total load of each system with such power plants. Since the PSS/E RTSM contains the expected loads on the 3rd Wednesday in January 2010, loads were linearly changed for each system node to have the total load of each system correspond to the GTMax model.

Following the calculation of power flows, under each scenario system loads are iteratively corrected to also accommodate the network losses which the GTMax model does not take into account. Consequently, the analysed system loads in the GTMax model correspond with the sum of loads and losses in each system within the PSS/E regional model. Regarding the balance of each system within the GTMax model deriving from the market engagement of power plants and the modelled load of each system, the same was corrected in the PSS/E model according to the geographic position of each power plant (e.g. in the GTMax model half the capacity of the Krško power plant is included in the balance of Croatia, and in the PSS/E model it is excluded form the balance; the output of generator 2 of the Dubrovnik hydroelectric power plant is included in the balance of Bosnia-Herzegovina in the GTMax model, whereas in the PSS/E model it is included in the balance of Croatia).

Slika 4
Planirana konfiguracija prijenosne mreže RH 2010. godine (PSS/E model za 2010. i 2015. godinu)

Figure 4
Planned configuration of the transmission network of the Republic of Croatia in 2010 (PSS/E model for 2010 and 2015)

U posljednjem koraku usklađivanja modela harmonizirane su analizirane topologije mreže unutar GTMax i PSS/E modela na taj način da su konfiguracije mreže u razmatranoj 2010. i 2015. godini bile iste u oba modela. Analize pogona prijenosnog sustava u 2015. godini su za sve scenarije angažmana elektrana (opisani u idućem poglavlju) izvedene u dva podscenarija: 1) na očekivanoj topologiji mreže u 2010. i 2) na očekivanoj topologiji mreže u 2015. godini. Smisao je ovih podscenarija u ocjeni opravdanosti izgradnje vodova planiranih između 2010. i 2015. godine s aspekta podržavanja tržišnog angažmana elektrana u regiji.

In the last step of model harmonisation, the network topologies analysed in the GTMax and PSS/E models were harmonised, the network configurations for the years 2010 and 2015 being the same in both models. Analyses of the transmission system operation in 2015 for all scenarios of power plant engagement (described in the following section) were conducted under two sub-scenarios: 1) the expected network topology for 2010, and 2) the expected network topology for 2015. The meaning of these scenarios lies in the estimate of feasibility of the construction of power lines planned between 2010 and 2015 from the aspect of supporting the market engagement of power plants in the region.

3 ANALIZIRANI SCENARIJI ANGAŽMANA ELEKTRANA

Ukupno je analizirano 15 različitih scenarija s aspekta hidrologije, opterećenja sustava, razmjena snage između jugoistočne Europe i UCTE, Ukrajine i Turske, te topologije mreže. Za svaki vremenski presjek analizirano je ukupno pet scenarija od kojih su tri nazvana osnovnim scenarijima (eng. Base case), a dva dodatnim scenarijima (eng. Sensitivity case), s tim da su za 2015. godinu analizirani i scenariji s obzirom na topologiju mreže (topologija 2010., topologija 2015.). Tablica 1 prikazuje sve analizirane scenarije.

Tri su osnovna scenarija uključivala tržišni angažman elektrana u stanju normalne, suhe i vlažne hidrologije pri referentnom vršnom opterećenju sustava u 2010. i 2015. godini. Dva su dodatna scenarija za svaki vremenski presjek postavljena s obzirom na veću stopu porasta potrošnje električne energije (eng. High load scenario) i razmjene snage između jugoistočne Europe i okolnih sustava (eng. Power import/export scenario).

3 ANALYSED SCENARIOS OF POWER PLANT ENGAGEMENT

Analyses included 15 different scenarios in terms of hydrological conditions, system load, power exchange between Southeast Europe and UCTE, Ukraine and Turkey, and network topology. For each point in time five scenarios were analysed: three base cases, and two sensitivity cases; for the year 2015, scenarios were also analysed in terms of network topology (topology for 2010, topology for 2015). Table 1 shows all the scenarios analysed.

Three base cases included the market engagement of power plants under the conditions of a normal, dry, and wet hydrological conditions at reference peak loads of the system in 2010 and 2015. Two additional scenarios for each point in time were set up: the high load scenario, and the power import/export scenario.

Tablica 1 - Analizirani GTMax scenariji u PSS/E regionalnom modelu prijenosne mreže
Table 1 - Analysed GTMax scenarios in the PSS/E regional model of transmission network

Osnovni slučajevi / Base cases		
Godina / Year	Hidrologija / Hydrology	Topologija / Topology
2010.	Prosječna / Average Suha / Dry Vlažna / Wet	2010.
2015.	Prosječna / Average Suha / Dry Vlažna / Wet	2010. 2015. 2010. 2015. 2010. 2015.
Dodatni slučajevi / Sensitivity cases		
Opis / Description	Godina / Year	Topologija / Topology
Uvoz/Izvoz / Import/Export	2010. 2015.	2010. 2010. 2015.
Visoki porast opterećenja / High load	2010. 2015.	2010. 2010. 2015.

Tablice 2 i 3 prikazuju bilance sustava u osnovnim scenarijima prosječne hidrologije 2010. i 2015. godine, pri čemu su u redovima označenim s a) bilance svake zemlje u GTMax modelu, a u redovima označenim s b) bilance u odgovarajućem PSS/E modelu nakon njegova usklađenja s GTMax modelom (uključivanje gubitaka, pridruživanje zemljopisnog položaja elektrana, smanjenje opterećenja za angažman elektrana priključenih na niže naponske razine < 110 kV).

Tables 2 and 3 show the balance of the base cases with the average hydrology in 2010 and 2015: lines marked a) contain the balance of each country within the GTMax model, lines marked b) contain the corresponding PSS/E model balance following its harmonisation with the GTMax model (deducting losses, considering the geographical position of power plants, the decrease in the load by the engagement of the power plants connected to lower voltage levels (<110 kV)).

Tablica 2 - Bilance sustava jugoistočne Europe u stanju prosječne hidrologije 2010. godine
Table 2 - Balance of the SEE system under average hydrological conditions in 2010

Zemlja / Country		Opterećenje / Load (MW)	HE / Hydroelectric PP (MW)*	TE i NE / Thermo & Nuclear PP (MW)	Ukupan angažman / Total (MW)	Višak (+) / Manjak (-) / Surplus(+)/Deficit(-) (MW)
Albanija / Albania	a) b)	1 338 1 338	757 757	140 140	897 897	-441 -441
Bosna i Hercegovina / Bosnia-Herzegovina	a) b)	2 077 2 029	1 591 1 439	826 826	2 417 2 265	341 236
Bugarska / Bulgaria	a) b)	6 193 6 113	554 474	6 426 6 426	6 980 6 900	787 787
Hrvatska / Croatia	a) b)	3 217 3 186	1 018 1 092	749 411	1 767 1 503	-1 450 -1 683
Makedonija / Macedonia	a) b)	1 229 1 218	232 220	730 730	962 950	-268 -268
Crna Gora / Montenegro	a) b)	687 687	228 540	0 0	228 540	-459 -147
Rumunjska / Romania	a) b)	7 797 7 022	2 996 2 256	5 730 5 696	8 726 7 952	930 930
Srbija i UNMIK*** / Serbia&UNMIK***	a) b)	7 112 7 112	2 582 2 270	5 090 5 090	7 672 7 360	560 248
JI Europa UKUPNO / SE Europe TOTAL	a) b)	29 649 28 705	9 958 9 048	19 691 19 319	29 649 28 367	0 -338**

* uključene reverzibilne HE
** polovica angažmana NE Krško (Slovenija) dispečirana za EES Hrvatske
*** eng. United Nations Interim Administration Mission in Kosovo

* Incl. reversible hydroelectric power plants
** Half the output capacity of the Krško nuclear power plant (Slovenia) dispatched to the power system of Croatia
*** United Nations Interim Administration Mission in Kosovo

WASP analiza pokazuje da je u razdoblju između 2005. i 2010. godine na području jugoistočne Europe tržišno opravdano izgraditi sljedeća nova proizvodna postrojenja, koja su stoga uključena u odgovarajućim osnovnim modelima GTMax i PSS/E:

- NE Černavoda 2 (Rumunjska),
- TE Kolubara 1 (Srbija),
- TE Kosovo 500 MW (UNMIK).

U scenariju visokog opterećenja 2010. godine (prosječna hidrologija) pojavljuju se dodatne nove elektrane u regiji:

- HE Zhur (UNMIK),
- KTE 300 MW (Hrvatska),
- KTE 500 MW (Hrvatska),
- KTE 500 MW (UNMIK).

The WASP analysis shows that in the period between 2005 and 2010 it is economically justifiable to build the following new power generation facilities, which are thus included in the appropriate basic GTMax and PSS/E models:

- Cernavoda 2 nuclear power plant (Romania),
- Kolubara 1 thermoelectric power plant (Serbia),
- Kosovo 500 MW thermoelectric power plant (UNMIK).

In the high load scenario for the year 2010 (average hydrology) there are additional new electric power plants in the region:

- Zhur hydroelectric power plant (UNMIK),
- CCPP 300 MW (Croatia),
- CCPP 500 MW (Croatia),
- CCPP 500 MW (UNMIK).

Novim KTE na području Hrvatske u GTMax modelima pridružene su makrolokacije Osijek (KTE 500 MW) i Zagreb (KTE 300 MW), a one u PSS/E modelu priključene su na 400 kV sabirnice TS Ernestinovo i 220 kV sabirnice TE Sisak.

Izuzevši navedene elektrane u scenariju visokog opterećenja pojavljuje se još dodatnih osam hidroelektrana: HE Buk Bijela i HE Srbinje (BiH, Crna Gora), HE Glavatičevo (BiH), HE Dabar (BiH), HE Komarnica (Crna Gora), HE Kostanica (Crna Gora), HE Andrijevo i HE Zlatica (Crna Gora).

In GTMax models new CCPPs in Croatia are located in Osijek (500 MW) and Zagreb (300 MW), whereas those in the PSS/E model are connected to the 400 kV buses at the Ernestinovo substation and the 220 kV buses at the Sisak thermoelectric power plant.

In addition to the aforementioned power plants, the high load scenario includes another eight hydroelectric power plants: Buk Bijela and Srbinje (Bosnia-Herzegovina, Montenegro), Glavatičevo (Bosnia-Herzegovina), Dabar (Bosnia-Herzegovina), Komarnica (Montenegro), Kostanica (Montenegro), Andrijevo and Zlatica (Montenegro).

Tablica 3 - Bilance sustava jugoistočne Europe u stanju prosječne hidrologije 2015. godine
Table 3 - Balance of the SEE system under average hydrological conditions in 2015

Zemlja / Country		Opterećenje / Load (MW)	HE / Hydroelectric PP (MW)*	TE i NE / Thermo & Nuclear PP (MW)	Ukupan angažman / Total (MW)	Višak (+) / Manjak (-) / Surplus(+)/Deficit(-) (MW)
Albanija / Albania	a) b)	1 614 1 614	978 978	140 140	1 118 1 118	-496 -496
Bosna i Hercegovina / Bosnia-Herzegovina	a) b)	2 410 2 358	1 648 1 491	826 826	2 474 2 317	64 -41
Bugarska / Bulgaria	a) b)	6 688 6 619	533 465	6 854 6 854	7 387 7 319	699 699
Hrvatska / Croatia	a) b)	3 752 3 721	986 1 060	1 595 1 257	2 581 2 317	-1 171 -1 404
Makedonija / Macedonia	a) b)	1 438 1 427	379 367	720 720	1 099 1 087	-340 -340
Crna Gora / Montenegro	a) b)	694 694	230 542	191 191	421 733	-273 39
Rumunjska / Romania	a) b)	9 056 7 973	3 424 2 547	5 680 5 474	9 104 8 021	48 48
Srbija i UNMIK*** / Serbia&UNMIK***	a) b)	7 499 7 499	2 584 2 272	6 383 6 383	8 967 8 655	1 468 1 156
JI Europa UKUPNO / SE Europe TOTAL	a) b)	33 151 31 906	10 762 9 722	22 389 21 845	33 151 31 568	0 -338**

* uključene reverzibilne HE
** polovica angažmana NE Krško (Slovenija) dispečirana za EES Hrvatske
*** eng. United Nations Interim Administration Mission in Kosovo

* Incl. reversible hydroelectric power plants
** Half the output capacity of the Krško nuclear power plant (Slovenia) dispatched to the power system of Croatia
*** United Nations Interim Administration Mission in Kosovo

U scenariju razmjena snage između jugoistočne Europe i okolnih sustava (unutar stanja prosječne hidrologije) razmatrane su sljedeće razmjene (istodobne):

- uvoz 750 MW iz UCTE,
- uvoz 500 MW iz Turske,
- izvoz 500 MW u Grčku i
- uvoz 750 MW iz Ukrajine.

WASP analiza pokazuje da u razmatranom scenariju razmjene nisu opravdane TE Kolubara i TE Kosovo 500 MW, pa su one izuzete iz modela za 2010. godinu.

The power import/export scenario (under average hydrological conditions) included the following (simultaneous) import/export:

- import 750 MW from UCTE,
- import 500 MW from Turkey,
- export 500 MW to Greece, and
- import 750 MW from Ukraine.

The WASP analysis shows that in the scenario in question the thermoelectric power plants of Kolubara and Kosovo 500 MW were not justified, so they were excluded from the model for the year 2010.

WASP analiza pokazuje da je u razdoblju između 2010. i 2015. godine na području jugoistočne Europe tržišno opravdano izgraditi sljedeća nova proizvodna postrojenja, koja su stoga uključena u odgovarajuće osnovne modele GTMax i PSS/E:

- NE Černavoda 3 (Rumunjska),
- TE Kolubara 2 (Srbija),
- TE Kosovo 2 ... 500 MW (UNMIK),
- TE Kosovo 3 ... 500 MW (UNMIK),
- TE Kosovo 4 ... 300 MW (UNMIK),
- dvije TE-TO 100 MW (Rumunjska),
- dvije KTE 300 MW (Hrvatska, makrolokacija Zagreb),
- KTE 500 MW (Hrvatska, makrolokacija Osijek).

U scenariju visokog opterećenja 2015. godine pojavljuju se dodatne nove elektrane u regiji (uključujući 8 prethodno navedenih hidroelektrana):

- NE Belene-Varna (Bugarska),
- TE-TO 100 MW (Srbija),
- KTE 500 MW (Hrvatska, makrolokacija Zagreb),
- dvije TE 300 MW (UNMIK),
- dvije TE 500 MW (UNMIK).

Na temelju WASP analize opisanih scenarija izgradnje novih elektrana na području jugoistočne Europe, promatrajući regiju u cjelini, a ne izdvojene sustave, utvrđena je opravdanost gradnje kombi elektrane snage 300 MW i 500 MW u Hrvatskoj samo u scenariju visokog opterećenja 2010. godine, te u svim scenarijima 2015. godine.

Tablica 4 prikazuje bilance sustava jugoistočne Europe u svim analiziranim scenarijima kao rezultat odgovarajućih GTMax simulacija. Uz tržišno određeni angažman svih elektrana u regiji na osnovi njihove proizvodne cijene električne energije, svakoj je zemlji pridružen određeni suficit ili deficit proizvodnje s obzirom na promatranu razinu opterećenja (vršno opterećenje), te se na temelju tih rezultata može sagledati kako se postojeće elektrane uklapaju u tržište na području jugoistočne Europe.

Simulacije tržišta električne energije u jugoistočnoj Europi pokazuju da će Albanija, Hrvatska, Makedonija i Crna Gora biti izrazito deficitarne zemlje, Bugarska, Bosna i Hercegovina te Srbija uključujući UNMIK bit će izrazito suficitarne zemlje, dok će Rumunjska biti pretežito deficitarna zemlja. Takav je zaključak izveden na osnovi tržišnog angažmana postojećih i novih elektrana u jugoistočnoj Europi koji je proizašao iz GTMax simulacija za 2010. i 2015. godinu.

Iz tablice 4 uočljivo je da će Hrvatska uvoziti između 661 MW i 1 450 MW u stanju vršnog opterećenja (polovica snage NE Krško uključena je u bilancu Hrvatske) iz ostalih dijelova tržišta električne energije

The WASP analysis shows that in the period between 2010 and 2015 it is economically justified to construct the following generation facilities which are, therefore, included in the appropriate basic GTMax and PSS/E models:

- Cernavoda 3 nuclear power plant (Romania),
- Kolubara 2 thermoelectric power plant (Serbia),
- Kosovo 2 thermoelectric power plant... 500 MW (UNMIK),
- Kosovo 3 thermoelectric power plant... 500 MW (UNMIK),
- Kosovo 4 thermoelectric power plant... 300 MW (UNMIK),
- two combined heat and power plants 100 MW (Romania),
- two CCPP 300 MW (Croatia, Zagreb area),
- CCPP 500 MW (Croatia, Osijek area).

In the high load scenario for 2015 there are additional new power plants in the region (including the 8 aforementioned hydroelectric power plants):

- Belene-Varna nuclear power plant (Bulgaria),
- combined heat and power plant 100 MW (Serbia),
- CCPP 500 MW (Croatia, Zagreb area),
- two thermoelectric power plants 300 MW (UNMIK),
- two thermoelectric power plants 500 MW (UNMIK).

On the basis of the WASP analysis of the described scenarios for the construction of new power plants in Southeast Europe - seen as a whole, not by its separate systems - it has been found that the construction of combined cycle power plants of 300 MW and 500 MW in Croatia is justified only under the high load scenario for 2010, whereas it is justified under all scenarios for the year 2015.

Table 4 shows the balance of SEE systems under all the analysed scenarios resulting from the corresponding GTMax simulations. With the market engagement of all the power plants in the region on the basis of their power generation costs, each country has been attributed with a certain surplus or deficit considering the observed load level (peak load), and on the basis of these results it can be noted how the existing power plants fit in the SEE market.

Simulations of the SEE electricity market show that Albania, Croatia, Macedonia and Montenegro will have a serious deficit, that Bulgaria, Bosnia and Herzegovina, and Serbia including UNMIK will have a considerable surplus, whereas Romania will prevailingly have a deficit. Such a conclusion is derived on the basis of the market engagement of the existing and new power plants in SE Europe as presented in the GTMax simulations for 2010 and 2015.

Table 4 shows that Croatia will import between 661 MW and 1 450 MW at peak load (half the output capacity of the Krško nuclear power plant is included in the balance for Croatia) from other market areas. The engagement of jugoistočne Europe. Angažman elektrana u Hrvatskoj za sve ispitivane scenarije prema GTMax analizama predočen je u tablici 5.

power plants in Croatia under all the scenarios examined in the GTMax analyses is shown in Table 5.

Tablica 4 - Bilance zemalja jugoistočne Europe prema GTMax simulacijama regionalnog tržišta
Table 4 - The balance of SEE countries according to GTMax simulations of the regional market

Vremenski presjek / Point in time	Scenarij / Scenario	Bilanca / Balance (MW)[1]								
		ALB / ALB	BiH / B&H	BUG / BULG	**HRV[3] / CRO[3]**	MAK / MAC	CG / MONT	RUM / ROM	SRB[4] / SERB[4]	UKUPNO / TOTAL
2010.	prosječna hidrologija / average	-441	341	787	**-1 450**	-268	-459	930	560	0
	suha hidrologija / dry	-384	898	606	**-661**	-203	-508	-200	454	0
	vlažna hidrologija / wet	-439	124	839	**-1 219**	-132	-443	632	639	0
	visoko opterećenje[2] / High load[2]	-484	246	858	**-863**	-261	-476	-57	1 036	0
	razmjene snage[2] / imp/exp[2]	-440	484	714	**-1 250**	-233	-459	-105	-210	-1 500
2015.	prosječna hidrologija / average	-496	64	699	**-1 171**	-340	-273	48	1 468	0
	suha hidrologija / dry	-720	864	766	**-853**	-444	-396	-369	1 152	0
	vlažna hidrologija / wet	-490	-94	955	**-688**	-557	-257	-123	1 255	0
	visoko opterećenje[2] / high load[2]	-883	116	899	**-1 215**	-617	377	-1 040	2 364	0
	razmjene snage[2] / imp/exp[2]	-588	136	1 006	**-1 312**	-340	-273	-972	842	-1 500

[1] + suficit, - deficit
[2] u stanju prosječne hidrologije
[3] uključujući 338 MW NE Krško, isključujući gen. 2 HE Dubrovnik (angažiran u svim scenarijima 105 MW)
[4] uključujući UNMIK

[1] + surplus, - deficit
[2] Under average hydrological conditions
[3] Including 338 MW from the Krško nuclear power plant, excl. generator 2 of the Dubrovnik hydroelectric power plant (participating in all the scenarios, 105 MW)
[4] Including UNMIK

Ne ulazeći u rezultate GTMax simulacija koji su izvedeni u SEEC-Beograd (eng. South East Europe Consultants), moguće je zaključiti da određeni broj termoelektrana Hrvatske elektroprivrede neće biti konkurentan na tržištu električne energije jugoistočne Europe. To se prije svega odnosi na KTE Jertovec, PTE Osijek, TE Rijeka, TE Sisak i termoelektrane toplane u Zagrebu i Osijeku. Izgradnjom novih kombi blokova snage 500 MW i 300 MW do 2015. godine konkurentna više neće biti ni TE Plomin 1. Stalno mjesto na tržištu pronaći će NE Krško i TE Plomin 2, te nove KTE 500 MW i 300 MW, koje bi se prema WASP proračunima trebale izgraditi. Očito je da proračuni pokazuju kako termoelektrane u Hrvatskoj proizvodnom cijenom električne energije nisu usporedive s termoelektranama u Bugarskoj, Bosni i Hercegovini, Srbiji i na Kosovu.

Without discussing the results of the GTMax simulations conducted by SEEC-Belgrade (South East Europe Consultants), it may be concluded that a number of thermoelectric power plants in the Croatian power system will not be competitive on the SEE regional electricity market. This before all is true of the Jertovec combined cycle power plant, the gas-fired Osijek power plant, the Rijeka thermoelectric power plant, the Sisak thermoelectric power plant, and the combined heat and power plants in Zagreb and Osijek. With the construction of new combined power units of 500 MW and 300 MW by 2015, the Plomin 1 thermoelectric power plant will not be competitive either. A permanent position on the market will be occupied by the Krško nuclear power plant and the Plomin 2 thermoelectric power plant, as well as by new combined cycle thermoelectric power plants of 500 MW and 300 MW, which according to the WASP calculations should be built. Apparently, the calculations show that thermoelectric power plants in Croatia are not comparable in their power costs to thermoelectric power plants in Bulgaria, Bosnia and Herzegovina, Serbia and Kosovo.

Tablica 5 - Angažman elektrana (MW) u Hrvatskoj prema GTMax simulacijama tržišta električne energije jugoistočne Europe
Table 5 - Engagement of power plants (MW) in Croatia according to GTMax simulations of SEE electricity market

Elektrana / Powerplant	Scenariji / Scenarios									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
HE i RHE / **Hydro & Reversible**										
Rijeka	16	16	37	14	16	18	14	37	16	22
Senj	216	216	216	216	216	216	216	216	216	216
Sklope	23	23	23	23	23	23	23	15	22	23
Vinodol	84	14	44	29	20	43	24	52	84	29
Đale	16	12	10	24	41	24	16	22	22	31
Golubić	7	4	7	7	7	7	5	7	7	7
Miljacka	24	24	23	14	22	24	24	24	21	24
Kraljevac	9	5	7	5	5	8	9	18	5	5
Peruća	19	9	9	42	32	20	7	24	19	42
Orlovac	79	23	125	113	230	84	22	237	69	129
Zakučac	155	299	438	180	253	160	299	486	168	217
Dubrovnik G-1	108	105	105	108	108	108	105	105	108	108
Čakovec	81	27	29	81	77	81	38	35	81	76
Dubrava	47	31	68	27	35	38	48	71	35	36
Gojak	48	48	48	48	48	48	48	48	48	48
Ozalj 1	0	0	0	0	0	0	0	0	0	0
Ozalj 2	0	0	0	0	0	0	0	0	0	0
Varaždin	86	56	59	70	86	86	86	73	86	81
Velebit	0	11	0	0	0	0	193	0	0	0
TE i NE / **Thermo & Nuclear**										
Osijek TE-TO	10	10	10	0	10	0	0	0	0	0
Osijek PTE	0	0	0	0	0	0	0	0	0	0
Plomin 1	110	110	110	110	110	0	0	0	0	0
Plomin 2	192	192	192	192	192	192	192	192	192	192
Rijeka	0	303	0	0	0	0	0	0	0	0
Jertovec	0	0	0	0	0	0	0	0	0	0
Krško	338	338	338	338	338	338	338	338	338	338
Sisak	90	396	90	90	90	0	0	0	0	0
Zagreb EL-TO A	9	35	9	9	9	9	35	9	9	9
Zagreb EL-TO B	0	46	0	0	0	0	0	0	0	0
Zagreb TE-TO K	0	202	0	0	0	0	100	0	0	0
Zagreb TE-TO A	0	0	0	0	0	0	0	0	0	0
Zagreb TE-TO C	0	0	0	0	0	0	0	0	0	0
NOVE KTE / **NEW CCPP**										
KTE 500 MW Osijek	-	-	-	480	-	480	480	480	250	480
KTE 300 MW Sisak	-	-	-	288	-	288	288	288	288	288
KTE 300 MW Zagreb	-	-	-	-	-	288	288	288	288	0
KTE 500 MW Zagreb	-	-	-	-	-	-	-	-	480	-
UKUPNO / **TOTAL (MW)**	**1 767**	**2 555**	**1 998**	**2 508**	**1 967**	**2 581**	**2 898**	**3 063**	**2 852**	**2 440**

Scenariji:
1 - prosječna hidrologija 2010.
2 - suha hidrologija 2010.
3 - vlažna hidrologija 2010.
4 - visoko opterećenje, prosječna hidrologija 2010.
5 - uvoz 1 500 MW iz UCTE i Ukrajine, prosječna hidrologija 2010.
6 - prosječna hidrologija 2015.
7 - suha hidrologija 2015.
8 - vlažna hidrologija 2015.
9 - visoko opterećenje, prosječna hidrologija 2015.
10 - uvoz 1 500 MW iz UCTE i Ukrajine, prosječna hidrologija 2015.

Scenarios:
1 - average hydrological conditions in 2010
2 - dry hydrological conditions in 2010
3 - wet hydrological conditions in 2010
4 - high load, average hydrological conditions in 2010
5 - import of 1 500 MW from UCTE and Ukraine, average hydrological conditions in 2010
6 - average hydrological conditions in 2015
7 - dry hydrological conditions in 2015
8 - wet hydrological conditions in 2015
9 - high load, average hydrological conditions in 2015
10 - import of 1 500 MW from UCTE and Ukraine, average hydrological conditions in 2015

4 PRORAČUNI TOKOVA SNAGA I ANALIZE SIGURNOSTI (n-1)

Za sve scenarije tržišnog angažmana elektrana izvedeni su proračuni tokova snaga i analize sigurnosti prema (n-1) kriteriju na očekivanoj konfiguraciji prijenosne mreže jugoistočne Europe 2010. i 2015. godine. Topologija mreže 2015. godine uključuje samo nekoliko novih vodova (u odnosu na konfiguraciju 2010.) na području južne Srbije, Makedonije i Kosova:

- DV 400 kV Niš - Leskovac - Vranje - Skoplje,
- DV 400 kV Kosovo - V. Dejes (Albanija),
- DV 400 kV Zemlak (Albanija) - Bitolj (Makedonija).

Analiza tokova snaga uključuje opterećenost interkonekcijskih i internih vodova, opterećenost transformatora 400/x kV i 220/x kV, te naponski profil u mreži uz zadane angažmane elektrana pri vršnom opterećenju sustava. Sigurnost pogona procijenjena je uobičajenim kriterijem neraspoloživosti jedne grane sustava (n-1), pri čem su promatrani sljedeći ispadi:

- svih interkonekcijskih vodova,
- svih internih 400 kV i 220 kV vodova, izuzevši radijalne (u slučaju dvosistemskih dalekovoda promatran je ispad samo jedne trojke),
- svih transformatora 400/x kV.

Za dopuštenu opteretivost vodova uzete su njihove termičke granice, a kod transformatora su promatrane njihove prividne snage. Za dopuštene raspone napona u mreži definirane su sljedeće vrijednosti: ±5 % U_n na 400 kV, te ±10 % U_n na 220 kV i 110 kV. Sva pogonska stanja kod kojih dolazi do narušavanja dopuštene opteretivosti grana ili naponskih prilika u mreži pri raspoloživim svim granama, ili neraspoloživoj jednoj grani mreže, procijenjena su kao nesigurna.

4.1 Proračuni tokova snaga i analize sigurnosti za scenarije 2010. godine

4.1.1 Osnovni scenariji ovisni o hidrologiji (prosječna, suha, vlažna)

U sklopu osnovnih scenarija razmatrana su: razmjena snage na području jugoistočne Europe za scenarije tržišnog angažmana elektrana tijekom planiranoga vršnog opterećenja elektroenergetskog sustava, ovisno o hidrološkim prilikama, a uz uravnoteženu regiju (razmjena s okolnim sustavima jednaka nuli), opterećenja interkonekcijskih vodova i internih 400 kV i 220 kV grana (vodovi 400 kV i 220 kV, transformatori 400/x kV i 220/x kV) te raspon naponskih prilika u svim čvorištima 400 kV i 220 kV na području jugoistočne Europe.

4 CALCULATION OF POWER FLOWS AND SECURITY ANALYSES (n-1)

For all the scenarios of the market engagement of power plants, the calculations of power flows and security analyses have been carried out according to the (n-1) criterion for the expected configuration of the transmission network in Southeast Europe in 2010 and 2015. The topology of the network in 2015 includes only a few new power lines (compared with the configuration in 2010) in southern Serbia, Macedonia and Kosovo:

- 400 kV Niš - Leskovac - Vranje - Skopje line,
- 400 kV Kosovo - V. Dejes (Albania) line,
- 400 kV Zemlak (Albania) - Bitola (Macedonia) line.

The analysis of power flows includes the load of interconnection and internal power lines, the load of the 400/x kV and 220/x kV transformers, and the voltage profile in the network with set power plant engagement at the peak system loads. The security of operation has been estimated by applying the normal criterion of non-availability of a system (n-1), taking into account the following outages of:

- all the interconnection lines,
- all the internal 400 kV and 220 kV lines, except the radial ones (in the double circuit transmission lines, the outage of only one triplet),
- all the 400/x kV transformers.

The permitted load capacity of the power lines were their thermal limits, whereas in transformers their apparent power was observed. Permitted voltage fluctuation in the network was defined as follows: ±5 % U_n for 400 kV, and ±10 % U_n for 220 kV and 110 kV. All the operative conditions under which the permitted branch load or voltage in the network were compromised, with all the branches available or with one non-available network branch, were rated as insecure.

4.1 Calculation of power flows and security analyses for scenarios in 2010

4.1.1 Basic scenarios in terms of hydrology (average, dry, wet)

Within the basic scenarios the following was considered: the export/import of power in SEE under the scenarios of market engagement of power plants during the planned peak loads of the electric power system, depending on the hydrological conditions, in a balanced region (zero exchange with neighbouring systems); the load of interconnection lines and internal 400 kV and 220 kV branches (400 kV and 220 kV lines, 400/x kV and 220/x kV transformers); and the range of voltage fluctuation at all 400 kV and 220 kV nodes in Southeast Europe.

Promatran je EES Hrvatske: u stanju prosječne hidrologije kroz slovensko-hrvatsku granicu ulazi 309 MW, kroz mađarsko-hrvatsku granicu 366 MW, srpsko-hrvatsku 333 MW te kroz bosansko-hrvatsku granicu ulazi 674 MW. Pri vlažnoj hidrologiji razmjene snage se mijenjaju, pa kroz slovensko-hrvatsku granicu ulazi 286 MW, kroz mađarsko-hrvatsku granicu 306 MW, srpsko-hrvatsku 356 MW, te kroz bosansko-hrvatsku granicu 505 MW. U stanju suhe hidrologije u Hrvatsku ulazi 147 MW iz Slovenije, 31 MW iz Mađarske, 195 MW iz Srbije i 522 MW iz Bosne i Hercegovine.

Najveći broj interkonekcijskih vodova u regiji opterećen je manje od 50 % s obzirom na njihovu termičku granicu. Najopterećeniji interkonekcijski vod (> 50 % I_t) je DV 400 kV Sofija - Niš, no termička granica toga voda u modelu je postavljena na nižu vrijednost od realne s Bugarske strane (NEK je postavio model Bugarske).

Opterećenja internih 400 kV i 220 kV grana u najvećem broju kreću se ispod polovice dopuštenog termičkog opterećenja vodova odnosno prividne snage transformatora. Opterećenije su grane (> 80 % I_t ili S_n):

- transformatori 220/110 kV Fier 2 u Albaniji (89 % - 106 % S_n), u svim analiziranim hidrološkim stanjima,
- transformator 220/110 kV Fundeni u Rumunjskoj (84 % - 87 % S_n), u svim analiziranim hidrološkim stanjima,
- transformator 400/110 kV Ugljevik u BiH (85 % S_n) u stanju prosječne hidrologije,
- transformator 400/220 kV Mintia u Rumunjskoj (96 % S_n) u stanju prosječne hidrologije,
- DV 2x220 kV Lotru - Sibiu u Rumunjskoj (99,5 % I_t) u stanju vlažne hidrologije, i
- DV 220 kV Tg.Jiu - Parosen u Rumunjskoj (87 % I_t) u stanju vlažne hidrologije.

U različitim hidrološkim prilikama dolazi do visokog opterećenja ili preopterećenja određenog broja 110 kV vodova, u prvom redu u Albaniji (jedan vod), Bosni i Hercegovini (dva voda), Bugarskoj (jedan vod), Hrvatskoj (četiri voda), Rumunjskoj (dva voda) i Srbiji (dvanaest vodova). Visokoopterećeni 110 kV vodovi u Hrvatskoj su Komolac - Plat, TE-TO - Resnik i TE-TO - Žitnjak, a preopterećen je 110 kV vod Županja - Orašje.

Naponske se prilike u najvećem broju čvorišta nalaze unutar dopuštenih granica, a naponi su blago povišeni (> 420 kV, > 242 kV) u nekoliko čvorišta u Bugarskoj. Preniski naponi u mreži nisu nigdje detektirani. Mogućnosti uporabe kompenzacijskih uređaja (kondenzatorske baterije, prigušnice, rad generatora u kompenzacijskim režimima) ili ostalih uređaja za regulaciju tokova jalove snage (transformatori s automatskom regulacijom napona) ili tokova djelatne snage (transformatori s poprečnom regulacijom) nisu

Observing the power system of Croatia revealed: under average hydrological conditions, 309 MW come in through Slovenian-Croatian border, 366 MW through Hungarian-Croatian border, 333 MW through Serbian-Croatian border, and 674 MW through Bosnian-Croatian border. Under wet hydrological conditions, the exchange of power changes: 286 MW come in through Slovenian-Croatian border, 306 MW through Hungarian-Croatian border, 356 MW through Serbian-Croatian border, and 505 MW through Bosnian-Croatian border. Under dry hydrological conditions 147 MW come in to Croatia from Slovenia, 31 MW from Hungary, 195 MW from Serbia and 522 MW from Bosnia-Herzegovina.

Most of the interconnection lines in the region carry the load of less than 50 % in terms of their thermal limits. The most heavily loaded interconnection line (> 50 % I_t) is the 400 kV Sofia-Niš line, but in the model the thermal limit of that line was set lower than real on Bulgarian part (NEK set up the model of Bulgaria).

The load of the internal 400 kV and 220 kV branches is mostly below one half of the permitted thermal load of the power lines i.e. the apparent transformer power. The branches under load (> 80 % I_t or S_n) are:

- 220/110 kV Fier 2 transformers in Albania (89 % - 106% S_n), under all analysed hydrological conditions,
- 220/110 kV Fundeni transformer in Romania (84 % - 87 % S_n), under all analysed hydrological conditions,
- 400/110 kV Ugljevik transformer in B&H (85 % S_n) under average hydrological conditions,
- 400/220 kV Mintia transformer in Romania (96 % S_n) under average hydrological conditions,
- 2x220 kV Lotru-Sibiu line in Romania (99,5 % I_t) under wet hydrological conditions, and
- 220 kV Tg.Jiu-Parosen line in Romania (87 % I_t) under wet hydrological conditions.

Under different hydrological conditions there is a high load on a certain number of 110 kV lines, primarily in Albania (one line), Bosnia-Herzegovina (two lines), Bulgaria (one line), Croatia (four lines), Romania (two lines) and Serbia (twelve lines). Highly loaded 110 kV lines in Croatia are Komolac-Plat, CHP-Resnik and CHP-Žitnjak, plus the 110 kV Županja-Orašje line.

The voltage fluctuations at most nodes are within the tolerated limits, with slightly increased voltages (> 420 kV, > 242 kV) at several nodes in Bulgaria. Too low network voltages were not detected. The possibilities for using compensation installations (capacitor units, attenuators, generator operation under compensation regimes) or other installations for the regulation of reactive power flows (transformers with automatic voltage regulation) or the active power flows (transformers with cross regulations) were not analysed. Security analyses (n-1) show that under all three analysed hydrological conditions assumed for the year 2010 there is a possibility for insecure situations caused by individual branch outages and analizirani. Analize (n-1) sigurnosti pokazuju da su za sva tri analizirana hidrološka stanja 2010. godine moguće nesigurne situacije prouzrokovane ispadom pojedinih grana i preopterećenjima u mreži. Sva se nesigurna stanja događaju u internim mrežama Rumunjske, Albanije i Srbije, a vezana su uz ispade pojedinih transformatora 400/220 kV (Mintia, Bucuresti Sud u Rumunjskoj) i 400/110 kV (Brasov, Dirste u Rumunjskoj, Niš u Srbiji), te ispade vodova 400 kV u Rumunjskoj i 220 kV u Albaniji i Srbiji (šire područje Beograda). Većinu kritičnih ispada moguće je izbjeći dispečerskim mjerama (preraspodjela proizvodnje, sekcioniranje mreže). Ispad bilo kojeg interkonekcijskog voda na području jugoistočne Europe ne dovodi do nesigurnog pogona.

4.1.2 Dodatni scenariji ovisni o opterećenju (visoki porast opterećenja) i uvozu snage (uvoz 1 500 MW iz UCTE i Ukrajine)

U sklopu dodatnih scenarija visokog opterećenja i uvoza 1 500 MW iz UCTE i Ukrajine razmatrana su: razmjena snage na području jugoistočne Europe 2010. godine, opterećenja interkonekcijskih vodova i internih 400 kV i 220 kV grana (vodovi 400 kV i 220 kV, transformatori 400/x kV i 220/x kV) te raspon naponskih prilika u svim čvorištima 400 kV i 220 kV na području jugoistočne Europe za analizirane dodatne scenarije.

Promatran je EES Hrvatske pri visokom porastu opterećenja (P_{max} = 3 371 MW) i stanju prosječne hidrologije: kroz slovensko-hrvatsku granicu ulazi 264 MW, kroz mađarsko-hrvatsku 31 MW, srpsko-hrvatsku 239 MW te kroz bosansko-hrvatsku granicu 562 MW. U scenariju uvoza 1 500 MW iz UCTE i Ukrajine kroz slovensko-hrvatsku granicu ulazi 774 MW, kroz mađarsko-hrvatsku 356 MW, srpsko-hrvatsku 140 MW te kroz bosansko-hrvatsku granicu 214 MW.

U stanjima visokog opterećenja i uvoza 1 500 MW povećavaju se opterećenja interkonekcijskih vodova i internih grana, no pri punoj raspoloživosti ne dolazi do preopterećenja ni jednog interkonekcijskog voda, a u scenariju visokog opterećenja preopterećuju se transformatori 220/110 kV Fier u Albaniji (102 % - 111 % S_n) i dva 220 kV voda u Rumunjskoj (Tg. Jiu - Paroseni i Urechesi - Tg. Jiu 1). U oba dodatna scenarija naponske su prilike unutar su dopuštenih granica, izuzevši scenarij uvoza u kojem nekoliko čvorišta 400 kV i 220 kV u bugarskoj mreži ima blago povišene napone.

Analiza sigurnosti prema (n-1) kriteriju pokazuje veći popis kritičnih ispada pri višoj stopi porasta opterećenja, a događaju se u mrežama Rumunjske, Srbije i Albanije. I u stanju uvoza 1 500 MW kritični su ispadi vezani za Rumunjsku, Srbiju i Albaniju, ali je njihov broj nešto manji nego u situaciji prosječne hidrologije i uravnoteženog sustava jugoistočne Europe.

network overloads. All the insecure conditions occurred in the internal networks of Romania, Albania and Serbia in connection with the outages of individual 400/220 kV transformers (Mintia, Bucuresti Sud in Romania) and 400/110 kV transformers (Brasov, Dirste in Romania, Niš in Serbia), plus the outages of the 400 kV lines in Romania and the 220 kV lines in Albania and Serbia (Belgrade area). Most of the critical outages can be avoided by dispatching measures (rearrangement of power generation, network sectioning). An outage of any interconnection line in Southeast Europe does not lead to insecure operation.

4.1.2 High load and import/export scenarios (import of 1 500 MW from UCTE and Ukraine)

Under the high load and export/import (1 500 MW from UCTE and Ukraine) scenarios the following was observed: the export/import of power in SEE in 2010, the load of interconnection lines and internal 400 kV and 220 kV branches (400 kV and 220 kV lines, 400/x kV and 220/x kV transformers) and the range of voltage fluctuation at all 400 kV and 220 kV nodes in SEE for the scenarios analysed.

Croatia's electric power system was observed under high load increase (P_{max} = 3 371 MW) and the average hydrological conditions: 264 MW come in through Slovenian-Croatian border, 31 MW through Hungarian-Croatian border, 239 MW through Serbian-Croatian border, and 562 MW through Bosnian-Croatian border. In the scenario of the import of 1 500 MW from UCTE and Ukraine, 774 MW come in through Slovenian-Croatian border, 356 MW through Hungarian-Croatian border, 140 MW through Serbian-Croatian border, and 214 MW through Bosnian-Croatian border.

Under the conditions of high load and the import of 1 500 MW, the load of interconnection lines and internal branches rises, but under the conditions of full availability there is no overload of any interconnection line, whereas under the high load scenario 220/110 kV Fier transformers in Albania (102 % - 111 % S_n) and two 220 kV lines in Romania are overloaded (Tg. Jiu - Paroseni and Urechesi - Tg. Jiu 1). Under both high load and export/importa scenarios the voltage conditions were within the tolerated limits, except under the export/import scenario when several 400 kV and 220 kV nodes in the Bulgarian network have slightly increased voltages.

The security analysis according to the (n-1) criterion shows a longer list of critical outages under high load in the networks of Romania, Serbia and Albania. Under the conditions of the import of 1 500 MW, critical outages occur in Romania, Serbia and Albania, but their number is slightly lower than under the average hydrological conditions and a balanced SEE system.

4.2 Proračuni tokova snaga i analize sigurnosti za scenarije 2015. godine

4.2.1 Osnovni scenariji ovisni o hidrologiji (prosječna, suha, vlažna)

U scenarijima tržišnog angažmana elektrana tijekom planiranoga vršnog opterećenja elektroenergetskog sustava 2015. godine, razmatrana su: razmjena snage na području jugoistočne Europe ovisno o hidrološkim prilikama, uz uravnoteženu regiju (razmjena s okolnim sustavima jednaka nuli), te na očekivanoj konfiguraciji mreže 2015. godine, opterećenja interkonekcijskih vodova i internih grana 400 kV i 220 kV (vodovi 400 kV i 220 kV, transformatori 400/x kV i 220/x kV) te raspon naponskih prilika u svim čvorištima 400 kV i 220 kV na području jugoistočne Europe.

U pogledu EES Hrvatske, u stanju prosječne hidrologije 2015. godine kroz slovensko-hrvatsku granicu ulazi 304 MW, kroz mađarsko-hrvatsku 28 MW, srpsko-hrvatsku 301 MW te kroz bosansko-hrvatsku granicu 771 MW. U vlažnoj hidrologiji razmjene se mijenjaju, pa kroz slovensko-hrvatsku granicu ulazi 258 MW, kroz mađarsko-hrvatsku 9 MW u smjeru Mađarske, kroz srpsko-hrvatsku 246 MW, te bosansko-hrvatsku granicu 426 MW. U stanju suhe hidrologije u Hrvatsku ulazi 248 MW iz Slovenije, 199 MW iz Srbije i 733 MW iz Bosne i Hercegovine, a u Mađarsku se daje 94 MW.

Najveći broj interkonekcijskih vodova u regiji opterećen je manje od 50 % s obzirom na njihovu termičku granicu. Najopterećeniji interkonekcijski vod (> 50 % I_t) je DV 220 kV Sarajevo 20 - Piva. Opterećenja internih grana 400 kV i 220 kV u najvećem se broju slučajeva kreću ispod polovice termičke granice vodova, odnosno prividne snage transformatora. Opterećenije su grane (> 80 % I_t ili S_n):

- transformatori 220/110 kV Fier 2 (112 % - 125 % S_n), 220/110 kV Elbassan (83 % - 90 % S_n), 220/110 kV Fierze (83 % - 87 % S_n) i 220/110 kV Tirana 2 (82 % - 84 % S_n) u Albaniji, u svim analiziranim hidrološkim stanjima,
- transformatori 220/110 kV Fundeni u Rumunjskoj (81 % - 104 % S_n), u svim analiziranim hidrološkim stanjima,
- transformatori 220/110 kV Beograd 3 u Srbiji (83 % - 98 % S_n), u svim analiziranim hidrološkim stanjima,
- transformator 400/110 kV Ugljevik u BiH (80 % - 89 % S_n), u svim analiziranim hidrološkim stanjima,
- transformator 400/220 kV Urechesti (98 % - 103 % S_n) u Rumunjskoj, u stanju prosječne i vlažne hidrologije,
- transformator 220/110 kV Zrenjanin (81 % - 82 % S_n) u Srbiji, u stanju prosječne i vlažne hidrologije,
- transformator 400/220 kV Iernut u Rumunjskoj (81 % S_n) u stanju suhe hidrologije,

4.2 Calculation of power flows and security analyses under scenarios for 2015

4.2.1 Basic scenarios in terms of hydrological conditions (average, dry, wet)

Under the scenario of the market engagement of power plants during the planned peak load of the electric power system in 2015, the following was considered: the import/export within Southeast Europe depending on the hydrological conditions, with a balanced region (zero exchange with the neighbouring systems) and the expected network configuration in 2015; the load of the interconnection lines and 400 kV and 220 kV internal branches (400 kV and 220 kV lines, 400/x kV and 220/x kV transformers); and the voltage fluctuation range at all the 400 kV and 220 kV nodes in Southeast Europe.

Observing the power system of Croatia revealed that under the average hydrological conditions in 2015, 304 MW come in through Slovenian-Croatian border, 28 MW through Hungarian-Croatian border, 301 MW through Serbian-Croatian border, and 771 MW through Bosnian-Croatian border. Under the wet hydrological conditions export/import changes to allow 258 MW through Slovenian-Croatian border, 9 MW through Croatian-Hungarian border towards Hungary, 246 MW through Serbian-Croatian border, and 426 MW through Bosnian-Croatian border. Under the dry hydrological conditions 248 MW come into Croatia from Slovenia, 199 MW from Serbia and 733 MW from Bosnia-Herzegovina, whereas 94 MW are transmitted to Hungary.

Most of the interconnection lines in the region carry the load of less than 50 % in terms of their thermal limits. The most heavily loaded interconnection line (> 50 % I_t) is the 220 kV Sarajevo 20-Piva line. The load of the internal 400 kV and 220 kV branches mostly stays below one half of the thermal limits of the lines i.e. the apparent power of transformers. Branches with greater load (> 80 % I_t or S_n) are:

- 220/110 kV Fier 2 (112 % - 125 % S_n), 220/110 kV Elbassan (83 % - 90 % S_n), 220/110 kV Fierze (83 % - 87 % S_n) and 220/110 kV Tirana 2 (82 % - 84 % S_n) transformers in Albania, under all analysed hydrological conditions,
- 220/110 kV Fundeni transformers in Romania (81% - 104 % S_n), under all analysed hydrological conditions,
- 220/110 kV Belgrade 3 transformers in Serbia (83 % - 98 % S_n), under all analysed hydrological conditions,
- 400/110 kV Ugljevik transformer in B&H (80 % - 89 % S_n), under all analysed hydrological conditions,
- 400/220 kV Urechesti transformer in Romania (98 % - 103 % S_n), under average and wet hydrological conditions,
- 220/110 kV Zrenjanin transformer in Serbia (81%-82% S_n), under average and wet hydrological conditions,

- transformator 400/220 kV Bucuresti Sud u Rumunjskoj (85% S_n) u stanju vlažne hidrologije,
- DV 220 kV RRashbull - Tirana 2 u Albaniji (88% - 90 % I_t) u svim analiziranim hidrološkim stanjima,
- DV 220 kV Beograd 3 - Obrenovac u Srbiji (87% - 104 % I_t) u svim analiziranim hidrološkim stanjima i
- više DV 220 kV u Rumunjskoj.

U različitim hidrološkim prilikama dolazi također do visokog opterećenja ili preopterećenja određenog broja 110 kV vodova u većini razmatranih zemalja.

Naponske se prilike u najvećem broju 400 kV i 220 kV čvorišta kreću unutar dopuštenih granica, a naponi su blago povišeni (> 420 kV) samo u jednom čvorištu u Bugarskoj (Maritsa East 400 kV) ako se proračuni izvode na očekivanoj topologiji mreže 2015. godine, koja uključuje nekoliko novih 400 kV interkonekcijskih vodova između Srbije i Makedonije (Niš - Skoplje), Kosova i Albanije (Kosovo B - V. Dejes) te Makedonije i Albanije (Bitolj - Zemlak). Proračuni na topologiji mreže iz 2010. godine koja ne uključuje spomenute interkonekcijske vodove pokazuju na preniske napone u pojedinim 400 kV (Elbassan, V. Dejes, Tirana 2) i 220 kV (Fier 2, Babice) čvorištima u Albaniji, pri čem se naponi u 400 kV mreži spuštaju do 367 kV, a u 220 kV mreži do 188 kV.

Analize (n-1) sigurnosti pokazuju da je u svim analiziranim hidrologijama 2015. godine moguć veći broj nesigurnih stanja prouzrokovanih ispadom pojedinih grana i preopterećenjima u mreži nego što je to u 2010. godini. Većina nesigurnih stanja događa se u internim mrežama Rumunjske, Albanije i Srbije. Većinu kritičnih ispada moguće je izbjeći dispečerskim mjerama (preraspodjela proizvodnje, sekcioniranje mreže). Ispad bilo kojeg interkonekcijskog voda na području jugoistočne Europe ne dovodi do nesigurnog pogona.

Usporedbom proračuna za 2015. godinu na očekivanoj topologiji mreže u 2015. godini i proračuna za 2015. godinu na topologiji mreže 2010. godine, primjećuje se pozitivan utjecaj planiranih interkonekcijskih vodova s obzirom na smanjenje gubitaka u regiji, te izbjegavanja određenih nesigurnih stanja, ponajprije u južnoj Srbiji i Albaniji. Planirane investicije u nove interkonekcije između Srbije, Makedonije, Kosova i Albanije ipak nisu ključne za potporu tržišnog angažmana elektrana u regiji.

4.2.2 Dodatni scenariji ovisni o opterećenju (visoki porast opterećenja) i uvozu snage (uvoz 1 500 MW iz UCTE i Ukrajine)

U dodatnim scenarijima visokog opterećenja i uvoza 1 500 MW iz UCTE i Ukrajine razmatrana su: razmjene snage na području jugoistočne Europe 2015. godine, na očekivanoj topologiji mreže za razmatrani vremenski presjek, opterećenja interkonekcijskih vodova i internih grana 400 kV i 220 kV (vodovi 400 kV i

- 400/220 kV Iernut transformer in Romania (81% S_n) under dry hydrological conditions,
- 400/220 kV Bucuresti Sud transformer in Romania (85 % S_n) under wet hydrological conditions,
- 220 kV RRashbull - Tirana 2 line in Albania (88% - 90% I_t) under all analysed hydrological conditions,
- 220 kV Beograd 3 - Obrenovac line in Serbia (87% - 104 % I_t) under all analysed hydrological conditions and
- several 220 kV lines in Romania.

Under different hydrological conditions there is also a high load or an overload of a certain number of 110 kV lines in most of the countries observed.

The voltage fluctuation at most 400 kV and 220 kV nodes are within tolerated limits, with slightly increased voltages (>420 kV) at just one node in Bulgaria (Maritsa East 400 kV), when the calculations are performed for the expected network topology in 2015 which includes a number of new 400 kV interconnection lines between Serbia and Macedonia (Niš - Skopje), Kosovo and Albania (Kosovo B - V. Dejes) and Macedonia and Albania (Bitola - Zemlak). Calculations performed for the network topology in 2010 which does not include the aforementioned interconnection lines indicate too low voltages at individual 400 kV (Elbassan, V. Dejes, Tirana 2) and 220 kV (Fier 2, Babice) nodes in Albania, with the voltage in the 400 kV network falling to 367 kV, and in the 220 kV network to 188 kV.

Security analyses (n-1) show that under all the analysed hydrological conditions for the year 2015 a larger number of insecure conditions is possible, caused by the outage of individual branches and the network overload, then in 2010. Most insecure conditions occur in the internal networks of Romania, Albania and Serbia. Most of the critical outages can be avoided by dispatching measures (rearrangement of power generation, network sectioning). An outage of any interconnection line in Southeast Europe does not lead to insecure operation.

Comparing the calculation for the year 2015 and the expected network topology in 2015 with the calculation for the year 2015 and the network topology in 2010, there is a noticeable effect of the planned interconnection lines in terms of the reduction in losses within the region and the avoidance of insecure conditions, primarily in southern Serbia and in Albania. The planned investment in new interconnections between Serbia, Macedonia, Kosovo and Albania are not essential, though, to supporting market engagement of power plants in the region.

4.2.2 High load and export/import (1 500 MW from UCTE and Ukraine) scenarios

Under the high load and import (1 500 MW from UCTE and Ukraine) scenarios the following was observed: the export/import of electricity in SEE in 2015, with the expected network topology for the period under scrutiny; the load of interconnection lines and internal 400 kV

220 kV, transformatori 400/x kV i 220/x kV) te raspon naponskih prilika u svim čvorištima 400 kV i 220 kV na području jugoistočne Europe za analizirane dodatne scenarije.

Promatran je EES Hrvatske pri visokom porastu opterećenja (P_{max} = 4 067 MW) i stanju prosječne hidrologije; kroz slovensko-hrvatsku granicu ulazi 264 MW, kroz srpsko-hrvatsku 305 MW te kroz bosansko-hrvatsku 1 030 MW, a kroz mađarsko-hrvatsku granicu prolazi 151 MW u smjeru Mađarske. U scenariju uvoza 1 500 MW iz UCTE i Ukrajine kroz slovensko-hrvatsku granicu ulazi 829 MW, kroz mađarsko-hrvatsku 178 MW, srpsko-hrvatsku 175 MW te kroz bosansko-hrvatsku granicu 363 MW.

U situacijama visokog opterećenja i uvoza 1 500 MW povećavaju se opterećenja interkonekcijskih vodova i internih grana, no pri punoj raspoloživosti ne dolazi do preopterećenja niti jednog interkonekcijskog voda, a u scenariju visokog opterećenja preopterećuju su transformatori 220/110 kV Fier u Albaniji (126 % - 138 % S_n), trafsformator 3 220/110 kV Elbassan u Albaniji (105 % S_n), transformatori 400/220 kV Iernut (101 % S_n), Urechesti (120 % S_n), 220/110 kV Fundeni u Rumunjskoj (120 % S_n), te tri voda 220 kV u Rumunjskoj (2x 220 kV Lotru - Sibiu, 220 kV Paroseni - Tg. Jiu, 220 kV Urechesti - Tg. Jiu 1) i jedan vod 220 kV u Albaniji (Rrashbull - Tirana 2).

Naponske prilike u dodatnim scenarijima nisu zadovoljavajuće zbog preniskih napona u dijelovima mreže Rumunjske i Albanije koji prijete mogućim slomom napona. Proračuni tokova snaga za analizirane dodatne scenarije na topologiji mreže 2010. godine nisu dovodili do konvergentnih rješenja u prvom redu zbog sloma napona u Albaniji. Da bi se postiglo konvergentno rješenje, nužno je u model uključiti barem jedan od dvaju planiranih vodova 400 kV između Albanije i Kosova (Kosovo B - V. Dejes) ili Albanije i Makedonije (Zemlak - Bitolj), no naponske prilike su tada nezadovoljavajuće u Albaniji, Crnoj Gori, južnoj Srbiji i Rumunjskoj.

Analize sigurnosti prema (n-1) kriteriju pokazuju veći broj kritičnih ispada pri višoj stopi porasta opterećenja, a događaju se uglavnom u mrežama Rumunjske, Srbije i Albanije (slike 5, 6 i 7). I u situaciji uvoza 1 500 MW kritični su ispadi vezani za Rumunjsku, Srbiju i Albaniju. Kritični je ispad u Hrvatskoj je gubitak transformatora 400/110 kV u TS Žerjavinec, kada se paralelni transformator dovodi na granicu preopterećenja (100 % S_n). To se događa zbog niskog angažmana TE-TO Zagreb (prema GTMax simulacijama), a utjecaj poprečne regulacije na transformatoru 400/220 kV nije ispitivan. U mreži Bosne i Hercegovine pojavljuje se također kritični ispad: gubitak DV 400 kV Tuzla - Banja Luka dovodi do preopterećenja transformatora 400/110 kV u Ugljeviku (101 % S_n).

and 220 kV branches (400 kV and 220 kV lines, 400/x kV and 220/x kV transformers); and the range of voltage fluctuation at all 400 kV and 220 kV nodes in SEE for the scenarios analysed.

Croatia's power system was observed under a high load increase (P_{max} = 4 067 MW) and average hydrological conditions: 264 MW come in through Slovenian-Croatian border, 305 MW through Serbian-Croatian border, and 1 030 MW through Bosnian-Croatian border, whereas 151 MW come out through Hungarian-Croatian border towards Hungary. Under the scenario of importing 1 500 MW from UCTE and Ukraine 829 MW come in through Slovenian-Croatian border, 178 MW through Hungarian-Croatian border, 175 MW through Serbian-Croatian border, and 363 MW through Bosnian-Croatian border.

Under the conditions of high load and the import of 1 500 MW the load of interconnection lines and internal branches rises, but in the case of full availability there is no overload of any interconnection line, whereas under the high load scenario 220/110 kV Fier transformers in Albania (126 % - 138% S_n), 220/110 kV Elbassan 3 transformer in Albania (105% S_n), 400/220 kV Iernut (101% S_n), Urechesti (120% S_n), 220/110 kV Fundeni (120% S_n) transformers in Romania, and three 220 kV lines in Romania (2x 220 kV Lotru - Sibiu, 220 kV Paroseni - Tg. Jiu, 220 kV Urechesti - Tg. Jiu 1) plus one 220 kV line in Albania (Rrashbull - Tirana 2) are overloaded.

The voltage fluctuation under the high load and export/import scenarios are not satisfying because of too low voltages in parts of the network in Romania and Albania threatening a possible voltage breakdown. Calculations of power flows for the scenarios analysed, with the network topology for 2010, did not lead to convergent solutions primarily because of the breakdown of the voltage in Albania. To arrive at a convergent solution it is necessary for the model to include at least one of the two scheduled 400 kV power lines between Albania and Kosovo (Kosovo B - V. Dejes) or between Albania and Macedonia (Zemlak - Bitola), but then the voltage conditions are unsatisfactory in Albania, Montenegro, southern Serbia and Romania.

Security analyses according to the (n-1) criterion show a greater number of critical outages at a higher load, mainly in the networks of Romania, Serbia and Albania (Figures 5, 6 and 7). Even in the case of importing 1 500 MW, critical outages are related to Romania, Serbia and Albania. A critical outage in Croatia involves the loss of the 400/110 kV transformer at the Žerjavinec substation, when the parallel transformer is at the verge of overload (100 % S_n). This is happening because of the low engagement of the Zagreb combined heat and power plant (according to the GTMax simulations), whereas the effect of the cross regulation on 400/220 kV transformer was not examined. In the network of Bosnia-Herzegovina there was also a critical outage: the loss of the 400 kV Tuzla-Banja Luka line leads to the overload of the 400/110 kV transformer in Ugljevik (101 % S_n).

Slika 5
Kritične grane u Rumunjskoj s aspekta tržišnog angažmana elektrana jugoistočne Europe

Figure 5
Critical branches in Romania in terms of market engagement of SEE power plants

Slika 6
Kritične grane u Albaniji s aspekta tržišnog angažmana elektrana jugoistočne Europe

Figure 6
Critical branches in Albania in terms of market engagement of power plants in SEE

Slika 7
Kritične grane u Srbiji s aspekta tržišnog angažmana elektrana jugoistočne Europe

Figure 7
Critical branches in Serbia in terms of market engagement of power plants in SEE

5 ZAKLJUČAK

U sklopu projekta REBIS što ga financira Europska komisija izrađena je studija izgradnje novih proizvodnih postrojenja na području jugoistočne Europe (eng. Generation Investment Study) u razdoblju od 2005. do 2020. godine. U studiji je određena potrebna izgradnja novih elektrana u izoliranom radu svakog sustava, u zajedničkom radu svih sustava te u sklopu regionalnog tržišta električne energije. Za određivanje potrebne izgradnje elektrana i simulaciju tržišta električne energije upotrijebljeni su programski paketi WASP i GTMax. U završnom (trećem) scenariju izgradnje i angažmana proizvodnih postrojenja na području jugoistočne Europe, isti su određeni s obzirom na ulogu i konkurentnost unutar tržišta električnom energijom.

Određeni broj reprezentativnih scenarija za 2010. i 2015. godinu, karakterističnih po vršnom opterećenju sustava i tržišnom angažmanu posto-jećih i novih elektrana, a ovisnih o hidrološkim prilikama, visini opterećenja i uvozu snage iz okolnih sustava, provjeren je s aspekta pogona i sigurnosti

5 CONCLUSION

Within the REBIS project funded by the European Commission a Generation Investment Study for SEE between 2005 and 2020 was prepared. The study determined the necessary construction of new power plants for the isolated operation of each particular system, for a combined operation of all the systems, and for the operation within the regional electricity market. To determine the necessary construction of power plants and the simulation of the regional electricity market, the WASP and GTMax software packages were used. In the final (third) scenario for the construction and engagement of generation facilities in SEE, the same were determined considering the role and competition within the electricity market.

A number of representative scenarios for 2010 and 2015, characteristic in terms of peak system loads and the market engagement of the existing and new power plants, and depending on hydrological conditions, the load level and the electricity import from the surrounding systems, were verified from the aspect of the operation and security of the transmission network in SEE. The purpose of such pogona prijenosne mreže na području jugoistočne Europe. Svrha je tih analiza ocjenjivanje stanja izgrađenosti mreže i potrebnih investicija u mrežu radi omogućavanja tržišnog angažmana elektrana.

Analize su izvedene korištenjem programskog paketa PSS/E, na regionalnome modelu prijenosnog sustava jugoistočne Europe izrađenom u sklopu projekta SECI.

Spomenuta je studija iznimno važna jer će njezine rezultate uvažavati Europska komisija, svjetske financijske institucije i potencijalni investitori, vezano uz optimizaciju izgradnje elektrana u regionalnom okviru. Također je bitna činjenica da su to prvi proračuni koji su promatrali očekivano otvaranje tržišta električnom energijom na području jugoistočne Europe i simulirali tržišne odnose s aspekta proizvodnje i prijenosa električne energije.

Na temelju izvedenih proračuna generalno se izvode sljedeći zaključci:

- S obzirom na bilance (proizvodnja-potrošnja) svih sustava u jugoistočnoj Europi, očekuje se da će na budućem tržištu električne energije Albanija, Hrvatska, Makedonija i Crna Gora biti iznimno deficitarne zemlje, a BiH, Bugarska, Srbija i UNMIK bit će izrazito suficitarne zemlje. Rumunjska će biti pretežito deficitarna zemlja.
- U regiji će biti opravdano graditi nove nuklearne elektrane (NE Černavoda 2 i 3 u Rumunjskoj za referentnu stopu porasta potrošnje i opterećenja, te NE Belene u Bugarskoj pri visokoj stopi porasta potrošnje i opterećenja), termoelektrane na ugljen (TE Kolubara u Srbiji i TE Kosovo na Kosovu za referentnu stopu porasta potrošnje i opterećenja), kombinirane plinsko-parne elektrane (KTE 500 i KTE 300 MW u Hrvatskoj za referentnu stopu porasta potrošnje i opterećenja 2015. odnosno visoku stopu 2010. godine), termoelektrane-toplane (2x100 MW u Rumunjskoj) i hidroelektrane (HE Zhur na Kosovu te osam HE u Bosni i Hercegovini i u Crnoj Gori za visoku stopu porasta potrošnje i opterećenja).
- Prijenosna mreža na području jugoistočne Europe, s obzirom na očekivanu konfiguraciju 2010. i 2015. godine, neće u potpunosti omogućavati siguran pogon uz tržišni angažman elektrana pri vršnom opterećenju sustava.
- Kritični ispadi i preopterećenja (potencijalna mjesta zagušenja) nalazit će se u internim mrežama Rumunjske, Albanije i Srbije (slike 5, 6 i 7). Određena pojačanja tih mreža bit će nužna radi omogućavanja tržišnog angažmana elektrana i sigurnog pogona sustava prema kriteriju neraspoloživosti jedne grane.
- Ni jedan detektirani kritični ispad nije vezan za postojeće i planirane interkonekcijske vodove

analyses is to evaluate the state of development of the network and the necessary investment in the network in order to enable the market engagement of power plants.

Analyses were conducted by using the PSS/E software package, on a regional model of the transmission system in SEE prepared within the framework of the SECI project.

The study mentioned is extremely important because its results will be recognized by the European Commission, international financial institutions and potential investors, in connection with the optimisation of the construction of power plants within the regional framework. It is also important to stress the fact that these are the first calculations that took into account the expected opening of the SEE electricity market and simulated market relations in terms of the generation and transmission of electricity.

On the basis of the calculations carried out, the following general conclusions can be drawn:

- Taking into account the balance (generation-consumption) in all the SEE systems, it is expected that on the future electricity market Albania, Croatia, Macedonia and Montenegro will have pronounced deficits, whereas B&H, Bulgaria, Serbia and UNMIK will have pronounced surpluses. Romania will mainly have deficit.
- In the region it will be justified to build new nuclear power plants (Cernavoda 2 and 3 in Romania to account for the reference rate of the increase in consumption and load, and Belene in Bulgaria to account for the high rate of the increase in the consumption and load), coal-fired thermoelectric power plants (Kolubara in Serbia and Kosovo in Kosovo to account for the reference rate of the increase in consumption and load), combined gas-steam power plants (CCPP 500 and CCPP 300 MW in Croatia to account for the reference rate of the increase in consumption and load in 2015, or the high rate of the increase in 2010), combined heat and power plants (2x100 MW in Romania) and hydroelectric power plants (Zhur in Kosovo and eight plants in Bosnia-Herzegovina and Montenegro for the high rate of the increase in consumption and load).
- The transmission network in SEE, considering the expected configurations for 2010 and 2015, will not completely enable secure operation under the conditions of market engagement of power plants at the peak system load.
- Critical outages and overloads (potential bottlenecks) will occur in the internal networks of Romania, Albania and Serbia (Figures 5, 6 and 7). Certain reinforcements of these networks will be necessary in order to enable the market engagement of power plants and a secure operation of the system under the conditions of non-availability of one branch.
- No detected critical outage was related to the existing and planned interconnection lines in the region, so the

u regiji, pa će povezanost među različitim sustavima koji će sudjelovati u regionalnom tržištu električne energije biti zadovoljavajuća.
- Interkonekcijski vodovi 400 kV planirani za izgradnju između 2010. i 2015. godine (Skoplje/Makedonija - Vranje/Srbija; Kosovo B/UNMIK - V. Dejes/Albanija; Zemlak/Albanija - Bitolj/Makedonija) smanjuju gubitke u regiji i potpomažu sigurnost pogona s aspekta izbjegavanja sloma napona u Albaniji, ali ne otklanjaju kritične ispade i preopterećenja osim u južnoj Srbiji.
- Ako se na odgovarajući način ne pojačaju interne mreže Rumunjske, Srbije i Albanije, bit će nužno preraspodjeljivati angažman elektrana i time odstupati od tržišnog angažmana, ili poduzeti odgovarajuće dispečerske mjere poput sekcioniranja mreže ili promjene uklopnog stanja (uobičajeno se provodi u Rumunjskoj, ponekad i u Srbiji).

U pogledu elektrana Hrvatske elektroprivrede i prijenosne mreže na području Hrvatske zaključuje se sljedeće:

- Unutar regionalnog tržišta električne energije Hrvatska će biti najveći uvoznik električne energije (deficit će se kretati do 1 450 MW).
- Termoenergetska postrojenja Hrvatske elektroprivrede (izuzevši TE Plomin 2 i NE Krško, te TE Plomin 1 do 2015. godine) neće biti konkurentna na tržištu električne energije. U svim ili većini scenarija tržišnog angažmana elektrana TE Rijeka, TE Sisak, termoelektrane-toplane u Zagrebu i Osijeku, KTE Jertovec i PTE Osijek izvan su pogona, ili su angažirane uz minimalnu snagu.
- U pogonu prijenosne mreže (opterećenja grana, naponske prilike pri vršnom opterećenju) na području Hrvatske uz tržišni angažman elektrana neće biti zagušenja s obzirom na moguće ispade 400 kV i 220 kV grana (ispadi vodova 110 kV izuzeti iz razmatranja).
- Jedini granični slučaj nezadovoljenja (n-1) kriterija u Hrvatskoj vezan je za ispad transformatora 400/110 kV Žerjavinec i preopterećenje paralelnog transformatora (100 % S_n) u razmatranom vremenskom presjeku 2015. godine, pri prosječnoj hidrologiji i uvozu 1 500 MW iz smjera UCTE i Ukrajine (nizak angažman TE-TO i EL-TO Zagreb, preklopka poprečne regulacije transformatora 400/220 kV u Žerjavincu u položaju nula). U ostalim scenarijima nisu zabilježeni kritični događaji i preopterećenja u prijenosnoj mreži Hrvatske.

connection between different systems engaged in the regional electricity market will be satisfactory.
- The 400 kV interconnection lines planned to be built between 2010 and 2015 (Skopje/Macedonia -Vranje/Serbia; Kosovo B/UNMIK - V. Dejes/Albania; Zemlak/Albania - Bitola/Macedonia) reduce the losses in the region and support the operation security in terms of avoiding a voltage breakdown in Albania, but they do not eliminate critical outages and overloads, except in southern Serbia.
- If the internal networks of Romania, Serbia and Albania are not appropriately reinforced, it will be necessary to rearrange the power plant engagement and deviate from the market engagement, or to undertake appropriate dispatching measures such as network sectioning or changing the switching conditions (usually done in Romania, sometimes also in Serbia).

Concerning the power plants of the Croatian power utility and transmission network in Croatia, the following has been concluded:

- Within the regional electricity market, Croatia will be the biggest importer of electricity (deficit up to 1 450 MW).
- Thermoelectric facilities of the Croatian power utility (excluding Plomin 2 thermoelectric power plant and the Krško nuclear power plant, as well as Plomin 1 thermoelectric power plant by 2015) will not be competitive on the electricity market. Under all or most scenarios for the market engagement, the Rijeka thermoelectric power plant, the Sisak thermoelectric power plant, the combined heat and power plants in Zagreb and Osijek, the Jertovec combined gas-steam power plant and the Osijek gas-fired thermoelectric power plant are out of operation or participating with a minimum power.
- In the operation of the transmission network (branch load, voltage conditions at peak loads) in Croatia, the market engagement of power plants will cause no bottlenecks in terms of possible outages of the 400 kV and 220 kV branches (110 kV line outages are excluded from this consideration).
- The only border case of non-conformity with the (n-1) criterion in Croatia is related to the outage of the Žerjavinec 400/110 kV transformer and the overload of the parallel transformer (100 % S_n) in 2015, under average hydrological conditions and with the import of 1 500 MW from UCTE and Ukraine (low engagement of the combined heat and power plants in Zagreb, with the switch of the cross regulation of the Žerjavinec 400/220 kV transformer set to zero position). Under other scenarios no critical events and overloads occurred in the Croatian transmission network.

LITERATURA / REFERENCE

[1] REBIS, GIS (draft version), PWC, MWH, ATKINS, March 2005

[2] Development of The Interconnection of The Electric Power Systems of Seci Member Countries For Better Integration With European Systems: Project of Regional Transmission Network Planning, EKC, EIHP, NEK, ZEKC, 2002

[3] BAJS, D., DIZDAREVIĆ, N., MAJSTROVIĆ, G., MAJSTROVIĆ, M., Dugoročno i kratkoročno planiranje prijenosne mreže Hrvatske elektroprivrede (Razvoj prijenosne mreže do 2010. godine), Energetski institut Hrvoje Požar, Zagreb, 2003.

Uredništvo primilo rukopis:
2005-04-04

Prihvaćeno:
2006-01-11

Manuscript received on:
2005-04-04

Accepted on:
2006-01-11