MOGUĆNOST PRIHVATA PROIZVODNJE VJETROELEKTRANA U EES REPUBLIKE HRVATSKE

THE FEASIBILITY OF THE INTEGRATION OF WIND POWER PLANTS INTO THE ELECTRIC POWER SYSTEM OF THE REPUBLIC OF CROATIA

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U članku se prezentiraju rezultati analiza provedenih radi određivanja mogućnosti prihvata proizvodnje vjetroelektrana u elektroenergetski sustav Republike Hrvatske i njihovog priključka na postojeću prijenosnu mrežu, koje su poslužile kao podloge HEP Operatoru prijenosnog sustava d.o.o. za postavljanje gornje veličine izgradnje vjetroelektrana u iznosu od 360 MW koje sustav u ovom trenutku može prihvatiti.

This article presents the results of an analysis performed in order to determine the feasibility of integrating the generation of wind power plants into the electric power system of the Republic of Croatia and their connection to the existing transmission network, for the purpose of providing a basis for the HEP Transmission System Operator (HEP Operator prijenosnog sustava d.o.o.) to establish the upper limits for the construction of wind power plants of 360 MW, which the system is currently capable of integrating.

Ključne riječi: mogućnost prihvata, prijenosna mreža, vjetroelektrane

Key words: feasibility of integration, transmission network, wind power plants

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1 UVOD

Svijest o globalnim klimatskim promjenama koje se događaju u posljednje vrijeme generirala je sve veću zabrinutost koja se ponajviše očituje povećanim interesom za obnovljivim izvorima energije. Energija vjetra je na taj način postala tehnologija koja se najbrže razvija i u kojoj je došlo do najvećeg napretka u elektroenergetskom sektoru. Velikom interesu za iskorištavanje vjetropotencijala svjedočimo i u našoj zemlji. Iako su trenutačno u pogonu svega dvije manje vjetroelektrane (VE) ukupne snage oko 17 MW, ukupan interes potencijalnih investitora u Hrvatskoj premašuje iznos od 1 500 MW instalirane snage u mogućim vjetroelektranama (VE) [1]. Zbog karakteristika proizvodnje VE, prvenstveno često spominjane promjenljivosti i njene stohastičke prirode, elektroenergetski sustav nije u mogućnosti prihvatiti sve planirane i moguće VE. Ograničenja u prihvatu VE proizlaze iz ograničene prijenosne moći elektroenergetske mreže na koju se priključuju, te iz ograničenih mogućnosti pružanja pomoćnih usluga sustava, prvenstveno P/f i Q/U regulacije koju pružaju postojeći konvencionalni izvori.

U članku se razmatra problematika plasmana proizvodnje VE u prijenosnu mrežu na području Hrvatske s obzirom na njenu današnju izgrađenost, te zahtjevi za regulacijskim uslugama unutar sustava (P/f, Q/U regulacija) koje izaziva povećani udio VE u proizvodnji električne energije, što je detaljno analizirano u [2]. Problematika plasmana proizvodnje VE analizira se sa statičkog aspekta (tokovi snaga, $n-1$ sigurnost) kako bi se provjerile mogućnosti prijenosne mreže da prenese njihovu proizvodnju s obzirom na dopuštena opterećenja vodova i naponske prilike, uz zadovoljavajuću sigurnost pogona definiranu Mrežnim pravilima [3].

Dinamičke analize nisu provedene zbog nepoznatih izvedbi vjetroturbina koje će se koristiti, no pri svakom pojedinačnom zahtjevu za priključak nove VE, HEP Operator prijenosnog sustava (HEP OPS) mora imati analizu dinamičkog utjecaja rada VE na elektroenergetski sustav, osobito s obzirom na njihovo ponašanje u slučajevima kratkih spojeva te oscilacije i regulaciju frekvencije i napona [4]. Regulacijske usluge na razini sustava s aspekta regulacije djelatna snaga-frekvencija (P/f) te jalova snaga-napon (Q/U) promatrane su na temelju zabilježenih satnih opterećenja hrvatskog elektroenergetskog sustava (EES) 2005. godine, satnog angažmana svih elektrana i razmjena sa susjednim elektroenergetskim sustavima, procjenama angažiranih snaga VE s obzirom na oscilacije u brzinama vjetra mjeren-

1 INTRODUCTION

Awareness of recent global climate changes has raised increasing concerns, which are most evident in the growing interest in renewable energy sources. Wind energy has become the most quickly developing technology in which the greatest progress has been made in the power sector. We are also witnessing great interest in the exploitation of wind power potential in Croatia. Although only two small wind power plants (WPPs) are in operation in our country at the present time, with a total installed capacity of approximately 17 MW, the overall interest by potential investors exceeds 1 500 MW of the installed capacity of potential wind power plants [1]. Due to the generation characteristics of wind power plants, first of all their frequently mentioned variability and stochastic nature, the electric power system is not capable of integrating all the planned and potential wind power plants. The limited integration of wind power plants is due to the limited transmission capacity of the power network to which they are connected and the limited possibilities for providing ancillary services, especially the P/f and Q/U control that the existing conventional sources provide.

The problem of integrating wind power plant generation into the transmission network in the territory of Croatia is discussed in this article, taking into account the present status and requirements for ancillary services within the system (P/f, Q/U control), which necessitate an increased percentage of wind power plants in electricity generation, as analyzed in greater detail in Ref. [2]. The problem of integrating wind power plant generation is analyzed from the static aspect (power flows, $n-1$ security) in order to determine the capability of the transmission network for the transmission of their generation output, regarding the maximum line loading and voltage conditions, with satisfactory security as defined by the Grid Code [3].

Dynamic analyses have not been performed because the specific models of the wind turbines to be used are still not known. However, for each individual application for the connection of a new wind power plant, the HEP Transmission System Operator must have an analysis of the dynamic impact of the WPP operation on the electric power system, particularly regarding its behavior in the event of short circuits, fluctuations and the control of frequency and voltage. Ancillary services on the system level from the aspect of the control of the active power-frequency (P/f) and the reactive power-voltage (Q/U) are considered on the basis of the recorded hourly loads of the Croatian electric power system (EPS) in the year 2005, the hourly operation of all the power plants and the exchanges with neighboring electric power systems, estimates of the dispatched power of the wind power plants regarding fluctuation in wind im na različitim lokacijama duž Hrvatske, te postojećih mogućnosti pružanja regulacijskih usluga unutar hrvatskog EES-a baziranih prvenstveno na karakteristikama postojećih sinkronih generatora HEP Proizvodnje d.o.o (HEP Proizvodnja).

velocity measured at various locations throughout Croatia, and existing possibilities for providing ancillary services within the Croatian electric power system, based primarily on the characteristics of the existing synchronous generators of HEP Generation (HEP Proizvodnja d.o.o).

2 MODEL ELEKTROENERGETSKOG SUSTAVA

Elektroenergetski sustav Hrvatske modeliran je u PSS/E formatu. Model se temelji na situaciji u sustavu 2005. godine, a obuhvaća sve vodove naponskih razina 400 kV, 220 kV i 110 kV, mrežne transformatore 400/220 kV, 400/110 kV i 220/110 kV, blok transformatore u elektranama, sve generatore prikazane na generatorskom naponu, te terete modelirane na 110 kV sabirnicama trafostanica. Model također uključuje susjedne elektroenergetske sustave unutar jugoistočne Europe (BiH, Srbija, Crna Gora, Rumunjska, Bugarska, Grčka, Albanija, Makedonija), srednje i istočne Europe (Mađarska, dio Ukrajine), te jednog dijela ostale mreže UCTE (Slovenija, Austrija, Italija).

Promatrana su sljedeća karakteristična pogonska stanja unutar hrvatskog EES-a 2005. godine:

- vršno opterećenje,
- minimalno zimsko opterećenje,
- maksimalno ljetno opterećenje,
- minimalno ljetno opterećenje.

Zabilježena opterećenja hrvatskog EES-a (preuzeta iz programskog sustava DAM korištenog u Nacionalnom dispečerskom centru u Zagrebu), kao i vremena njihova nastanka, u razmatranim pogonskim stanjima prikazuje tablica 1.

2 THE ELECTRIC POWER SYSTEM MODEL

The Croatian electric power system model is provided in PSS/E format. This model is based upon the system status during the year 2005 and encompasses all the 400 kV, 220 kV and 110 kV power lines; the 400/220 kV, 400/110 kV and 220/110 kV network transformers; the unit transformers in the power plants, all the generators at generator voltage, and the model of the load connected to the 110 kV substation busbars. The model also includes the neighboring electric power systems within South Eastern Europe (Bosnia and Herzegovina, Serbia, Montenegro, Rumania, Bulgaria, Greece, Albania and Macedonia), Central and Eastern Europe (Hungary and part of the Ukraine), and one part of the other Union for the Coordination of the Transmission of Electricity - UCTE network (Slovenia, Austria and Italy).

The following operating conditions within the Croatian electric power system in 2005 were considered:

- peak load,
- minimum winter load,
- maximum summer load,
- minimum summer load.

The recorded loads of the Croatian electric power system (taken from the DAM program system used at the National Dispatch Center in Zagreb), as well as the times of their occurrence under the operating conditions considered, are shown in Table 1.

Tablica 1 — Karakteristična opterećenja EES—a Hrvatske 2005. godine
Table 1 — Characteristic loads of the electric power system in Croatia during the year 2005

Godišnje doba / Season	Opterećenje / Load [MW]			
	Maksimalno / Maximum	Dan i sat / Date and time	Minimalno / Minimum	Dan i sat / Date and time
Zima / Winter	2 900	02. 03. / 20 h	1 264	20. 03. / 05 h
Ljeto / Summer	2 382	29. 07. / 22 h	1 109	16. 08. / 04 h

Na temelju prikupljenih podataka postavljeni su modeli EES RH u PSS/E formatu koji odgov-

On the basis of the data collected, models of the electric power system of the Republic of Croatia araju prethodno spomenutim karakterističnim pogonskim stanjima, a koji su poslužili za daljnja razmatranja mogućnosti priključka vjetroelektrana na prijenosnu mrežu.

were established in PSS/E format, which correspond to the previously mentioned characteristic operating conditions and which served for the further consideration of the possibility of integrating wind power plants into the transmission network.

3 ANALIZA MOGUĆNOSTI PRIKLJUČKA VJETROELEKTRANA NA PRIJENOSNU MREŽU S ASPEKTA NJENE PRIJENOSNE MOĆI

3.1 Analiza pojedinačnih makrolokacija vjetroelektrana

Na temelju podataka prikupljenih od potencijalnih investitora i ranije provedenih analiza u Energetskom institutu Hrvoje Požar (EIHP) određene su najvjerojatnije lokacije budućih VE u Republici Hrvatskoj kako je prikazano u tablici 2.

3 ANALYSIS OF THE POSSIBILITIES OF THE INTEGRATION OF WIND POWER PLANTS INTO THE TRANSMISSION NETWORK FROM THE ASPECT OF TRANSMISSION CAPACITY

3.1 Analysis of individual macro locations for wind power plants

Based upon the data collected from potential investors and previous analysis performed by the Energy Institute Hrvoje Požar (EIHP), the most likely locations were determined for future wind power plants in the Republic of Croatia, as presented in Table 2.

Tablica 2 — Potencijalna instalirana snaga vjetroelektrana u Republici Hrvatskoj prema vjerojatnostima izgradnje
Table 2 — Potential installed capacity of the wind power plants in the Republic of Croatia according to the likelihood of construction

Vjerojatnost izgradnje / Construction probability	Ukupna instalirana snaga / Total installed capacity [MW]	
	Ukupno / Total	Kumulativno / Cumulative
Izgrađeno / Constructed	17,2	17,2
Vjerojatno / Likely (sc1)	1 560,5	1 577,7
Razmatranje / Considered (sc2)	896	2 473,7
Preliminarno razmatranje / Preliminary consideration (sc3)	700	3 173,7
Malo vjerojatno / Unlikely (sc4)	165	3 338,7
Vrlo malo vjerojatno / Very unlikely (sc5) /	60	3 398,7

Budući da je očito kako elektroenergetski sustav ne može prihvatiti sve navedene VE, analize opisane u ovom članku ograničavaju se samo na prvi scenarij izgradnje (sc1) koji obuhvaća moguću izgradnju novih VE ukupne instalirane snage 1 560,5 MW. Na slikama 1 i 2 prikazana je regionalna distribucija snaga VE u razmatranom scenariju izgradnje, odnosno distribucija snaga po pojedinim čvorištima mreže 110 kV, određene na temelju poznatih mikrolokacija i instaliranih snaga VE u razmatranju. U najvjerojatnijem scenariju izgradnje sve VE izgradile bi se na području Dalmacije, Kvarnera i Istre. Njihova ukupna instalirana snaga po pojedinim područjima iznosila bi:

- šire dubrovačko područje 115 MW,
- šire splitsko područje 461 MW,
- šire šibensko područje 119,2 MW,

Since it is evident that the electric power system cannot accept all the above wind power plants, the analyses described in this article are limited to the first construction scenario (sc1), which includes the possibility of constructing new WPPs with a total installed capacity of 1 560,5 MW. In Figures 1 and 2, the regional distribution of the installed capacity of the WPPs in the construction scenario considered, i.e. power distribution according to the individual nodes of a network 110 kV, is presented, determined on the basis of the known micro locations and installed capacity of the WPPs under consideration. In the most likely scenario for the construction of all the WPPs, construction would occur in the territory of Dalmatia, Kvarner and Istria. Their total installed capacity according to individual regions would be as follows:

- Dubrovnik and vicinity 115 MW,
- Split and vicinity 461 MW,

— šire zadarsko područje 186 MW,
— šire kninsko područje 123 MW,
— područje Like 256,5 MW,
— šire senjsko područje 142 MW,
— područje Istre 175 MW.

Velika većina razmatranih VE u najvjerojatnijem scenariju izgradnje priključila bi se na prijenosnu mrežu, budući da se radi o vjetroparkovima snaga od 15 MW do 120 MW. Na temelju dosadašnjih istraživanja izgradnja vjetroparkova većih snaga ne ocjenjuje se realnim, iako su pojedini investitori deklarirali moguću izgradnju vjetroparkova većih od 120 MW. Prosječna snaga VE analiziranih unutar scenarija 1 (sc1) iznosi 41 MW.

Izvan je opsega ovog rada dubinsko ispitivanje pojedinih lokacija ili projekata, odnosno investitorskih odluka, te su lokacije na kojima postoje ispitivanja vjetra za potrebe ove studije uzete u obzir kao relevantne bez daljnjeg kritičkog osvrta. Naime, cilj odabira lokacija nije arbitraža koji od nositelja projekata ima prednost, već identifikacija i izrada baze potencijalnih lokacija VE prihvatljivih s tehničkog i prostornog stanovišta.

Ne ulazeći dublje u izvedbe priključka pojedinih VE na prijenosnu mrežu (spoj na postojeću TS 110/*x* kV, uvod/izvod voda 110 kV), analize koje slijede izvršene su uz pretpostavku da će sve razmatrane VE biti priključene direktnim vodom na neku od postojećih TS 110/*x* kV unutar mreže 110 kV. Time se ne prejudicira konačan zahtjev koji će HEP OPS postavljati pred investitore u pogledu priključka VE na prijenosnu mrežu. Veći broj razmatranih VE znatnije je udaljen od nekog od postojećih čvorišta mreže 110 kV pa bi direktni spoj na to čvorište rezultirao visokim troškovima za investitora, a istodobno se jedan broj VE nalazi u blizini trase nekog od postojećih vodova 110 kV pa bi u tom slučaju priključak uvodom/izvodom postojećeg voda na trafostanicu (TS) sagrađenu u krugu vjetroparka bio prihvatljivije rješenje. O prihvatljivosti T spoja VE na mrežu 110 kV ovom se prilikom neće govoriti, budući da nema utjecaja na konačno rješenje ove analize. Ukoliko se pojedine mikrolokacije pridruže najbližim čvorištima mreže 110 kV ili 35 kV dobiva se ukupna instalirana snaga VE u najvjerojatnijem scenariju izgradnje kako je prikazano tablicom 3.

— Šibenik and vicinity 119,2 MW,
— Zadar and vicinity 186 MW,
— Knin and vicinity 123 MW,
— the Lika region 256,5 MW,
— Senj and vicinity 142 MW,
— the Istrian region 175 MW.

The great majority of the WPPs considered in the most likely construction scenario would be connected to the transmission network, since this concerns wind farms with installed capacity from 15 MW to 120 MW. Based upon the investigations to date, the construction of wind farms with higher installed capacity is not deemed realistic, although individual investors have announced the possible construction of wind farms with installed capacity greater than 120 MW. The average installed capacity of the wind power plants analyzed within Scenario 1 is 41 MW.

In-depth investigation of individual locations or projects is outside the scope of this paper, i.e. investor decisions. The locations where the wind profiles have been determined for the purpose of this study are taken into account as relevant, without further critical review. The goal of choosing locations is not arbitrage or to provide an advantage to some of the project parties, but the identification and construction of a database of potential wind power plant locations which would be acceptable from the technical and physical planning standpoints.

Without entering further into the types of the connections of the individual WPPs to the transmission network (connection to the existing 110/*x* kV substations and connection to a 110 kV power line), the following analyses were performed under the assumption that all the WPPs considered would be connected by a direct line to one of the existing 110/*x* kV substations within the network 110 kV. Thereby, the final requirements that the HEP Transmission System Operator (HEP TSO) would place on investors in regard to the connection of WPPs to the existing network would not be prejudiced. A large number of the WPPs considered are located at significant distances from some of the existing network nodes 110 kV. Therefore, direct connection to those nodes would incur high expenses for investors. At the same time, a number of WPPs are located in the vicinity of the routes of some of the existing lines 110 kV, so that in this case the connection of the existing line to a substation constructed within the existing wind power farm would be a more acceptable solution. The acceptability of a T connection of the WPPs to the network 110 kV will not be discussed on this occasion because it has no bearing upon the final solution of this analysis. If we assign individual micro locations to the closest nodes of the network 110 kV or 35 kV, we obtain the total installed capacity of the WPPs in the most likely construction scenario, as presented in Table 3.

Tablica 3 — Čvorišta naponske razine 110 kV (35 kV, 10 kV) za priključak vjetroelektrana u najvjerojatnijem scenariju izgradnje
Table 3 — Nodes of voltage level 110 kV (35 kV, 10 kV) for the connection of wind power plants in the most likely construction scenario

Čvorište / Node 110 (35) kV	Ukupna snaga / Total power [MW]
Pag	16
Gračac	256,5
Obrovac	120
Knin	123
Peruča	75
Konjsko	56
Bilice	119,2
Benkovac	50
Vrboran	30
Kraljevac	45
Ston	115
Zakučac	30
Sinj	115
Kaštela	25
Trogir	85
Crikvenica	30
Senj	112
Plomin	15
Raša	50
Buzet	110
UKUPNO / TOTAL	1 577,7

U nastavku se statički obrađuje pojedinačan priključak VE na pojedina čvorišta mreže 110 kV, te se na osnovi $n-1$ kriterija određuje maksimalna snaga koju je moguće priključiti na određeno čvorište 110 kV. Pri tome se razmatraju pogonska stanja unutar kojih je angažman svake pojedinačne VE jednak njenoj instaliranoj snazi što će biti rijedak slučaj, no mjerodavan prema Mrežnim pravilima za dimenzioniranje prijenosne mreže, odnosno odobravanje priključka proizvodnim postrojenjima na mrežu. Pri tom se ne komentira niti razmatra opravdanost ili mogućnost izgradnje VE većih instaliranih snaga od onih uz koje je $n-1$ kriterij zadovoljen, no treba voditi računa o činjenici da je deterministički $n-1$ kriterij vrlo restriktivan prema novim proizvodnim postrojenjima, jer ne uključuje probabilistički aspekt problema, odnosno vjerojatnost pojedinih ispada i događaja u mreži koji ograničavaju instaliranu snagu proizvodnih postrojenja koja se na nju priključuju.

Osim toga, proizvodnju VE je za vrijeme kritičnih događaja ili ispada moguće ograničiti i tako unutar određenog vremenskog razdoblja

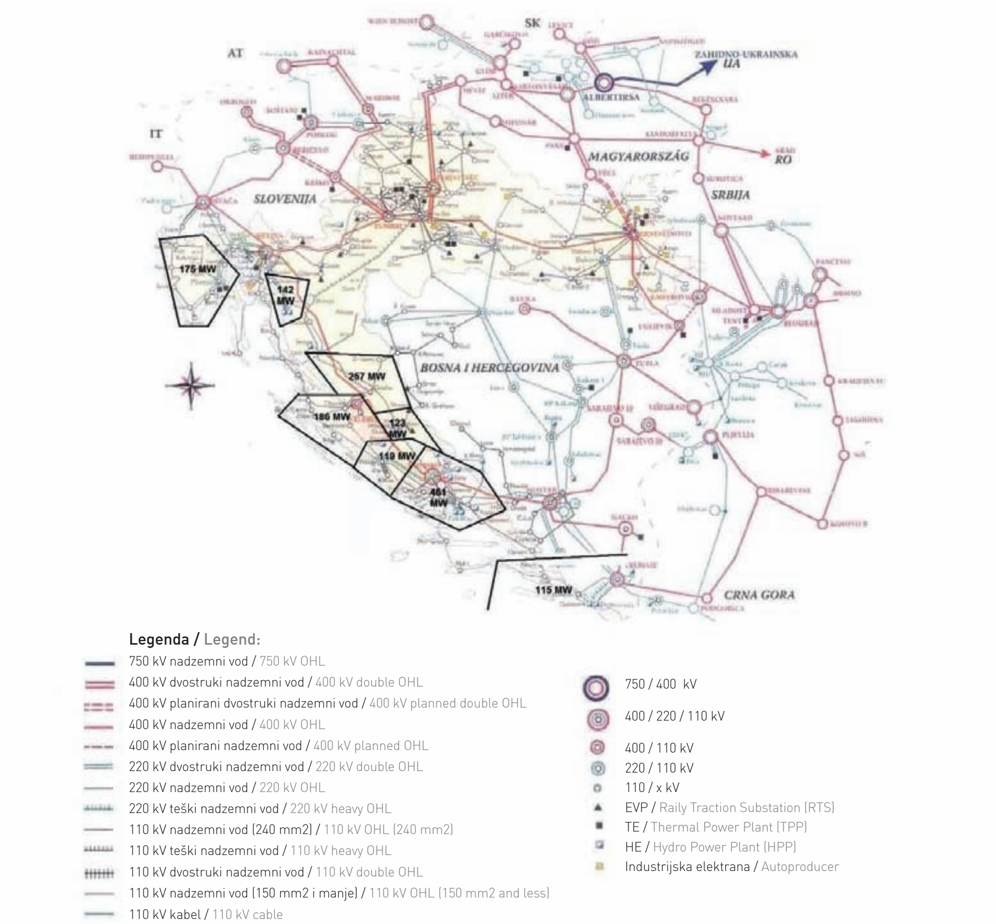
In this article, an individual connection of the WPPs to an individual 110 kV node is statically processed and, based upon the $n-1$ security criterion, the maximum power that can be connected to a specific 110 kV node is determined. It is necessary to consider the operating conditions of the plants where the output of each individual WPP is equal to its installed capacity, which will be a rare instance but relevant according to the stipulations of the Grid Code for dimensioning (designing) the transmission network, i.e. approving the connection of power plants to the network. No commentary or consideration is provided in this article regarding the justification or the possibility of constructing WPPs of greater installed capacities than those in which the $n-1$ security criterion is met, but it is necessary to take into account that the deterministic $n-1$ security criterion is highly restrictive toward new power generating plants because it does not include probabilistic reliability assessment, i.e. the probability of individual failures and events in the network which limit the installed capacity of the power plants connected to it.

Moreover, WPP generation at times of critical events or failures can be limited within a specific time period to preserve the security of system operation. Analysis očuvati sigurnost pogona sustava. Analize za svako pojedinačno čvorište priključenja VE izvršene su za četiri promatrana karakteristična pogonska stanja 2005. godine ovisno o opterećenju EES.

S obzirom na zgusnute lokacije promatranih potencijalnih VE u nastavku će se razmatrati i istodobni angažman svih promatranih u najvjerojatnijem scenariju.

for each individual node to which a WPP is connected has been performed for four characteristic operating conditions in the year 2005, depending on the system load.

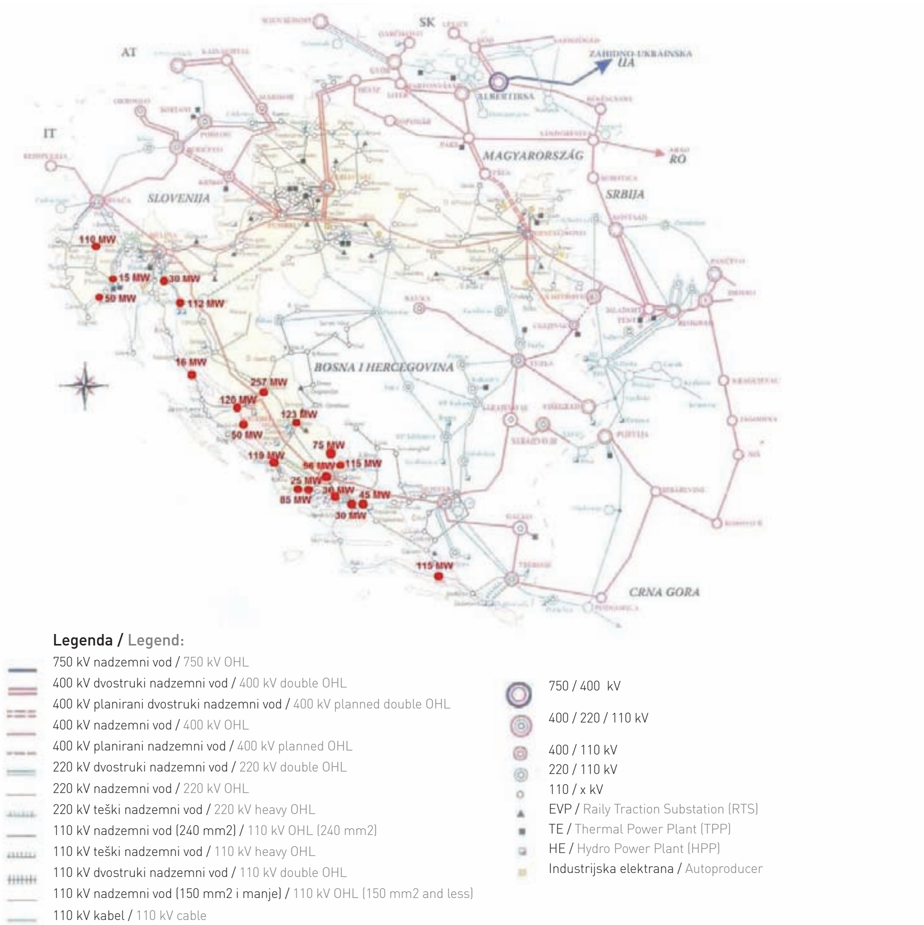
Due to the density of the locations of the potential WPPs under consideration, there will be a discussion of the coherent operation of all the WPPs studied in the most likely scenario.



Slika 1 — Regionalna distribucija snaga vjetroelektrana u najvjerojatnijem scenariju moguće izgradnje
Figure 1 — Regional wind power plant capacities in the most likely construction scenario

Time će se uočiti eventualna ograničenja koja bi se pojavila u slučaju istodobne realizacije svih razmatranih projekata. Time će se odrediti maksimalna apsorpcijska moć prijenosne mreže uz jednaku vjerojatnost realizacije svih projekata u najvjerojatnijem scenariju izgradnje. HEP OPS neće svim kandidatima istodobno odobriti priključak na mrežu, već će formirati određene kriterije redoslijeda dodjele priključka.

In this manner, the eventual limitations will be noted that could occur in the case of the simultaneous implementation of all the projects being studied. Thus, the maximum absorption capacity of the transmission network for the equal likelihood of the implementation of all the projects in the most likely construction scenario will be determined. The transmission system operator will not approve connection to the network for all the candidates at the same time but will determine specific criteria for the sequence of the assignment of connections.



Slika 2 — Distribucija snaga vjetroelektrana u najvjerojatnijem scenariju moguće izgradnje po čvorištima mreže 110 kV
Figure 2 — Wind power plant capacities in the most likely construction scenario according to the nodes of the 110 kV Network

Tablica 4 prikazuje analizirane instalirane snage VE po pojedinim čvorištima mreže 110 kV u najvjerojatnijem scenariju izgradnje, te maksimalno dozvoljene snage pojedinačnih VE priključenih na pojedina čvorišta mreže na temelju $n-1$ kriterija i evakuacijskih sposobnosti prijenosne mreže (određene na način da se promatraju opterećenja mreže uz samo jednu grupu VE pojedinačno u pogonu priključenih na isto čvorište mreže). Pri tom treba spomenuti da je za pojedina čvorišta moguć priključak i većih instaliranih snaga VE.

U tablici 4 navedeni su također kritični događaji i preopterećeni vodovi koji ograničavaju maksimalnu snagu pojedinačnih VE koje je moguće priključiti na pojedina čvorišta mreže 110 kV. Na temelju tih događaja moguće je dalje promatrati potrebnu izgradnju mreže kako bi se povećala njena evakuacijska sposobnost za prihvat veće instalirane snage VE u pojedinim čvorištima.

Table 4 presents the analyzed installed capacities of the WPPs at individual network nodes 110 kV in the most likely construction scenario and the maximum allowed power of the individual WPPs connected to individual network nodes on the basis of $n-1$ security criterion and the transmission network capacities (determined in such a manner that the network loading is studied when only one group of WPPs is in operation individually and connected to the same network node). It is necessary to mention that it is possible to connect a greater installed capacity of WPPs to an individual node.

Table 4 also includes critical events and the overloaded lines that limit the maximum power of individual WPPs that could be connected to an individual network node 110 kV. On the basis of these events, it is also possible to study the network strengthening necessary in order to increase its capacity for accepting greater installed capacities of WPPs in individual nodes.

Na temelju izvršenih proračuna može se preliminarno zaključiti da evakuacijske sposobnosti mreže 110 kV za prihvat većeg broja VE značajno povećavaju sljedeće investicije u mreži:

— uvod/izvod jedne trojke DV 2x110 kV Zakučac – Meterize u TS Vrboran,
— zamjena postojećeg DV 110 kV Melina – Vinodol novim DV 2x110 kV Melina – Vinodol,
— izgradnja DV 110 kV Knin (Drniš) – Konjsko (vezano za izgradnju EVP Žitnić),
— formiranje RP 110 kV Vodnjan i izgradnja DV 2x220(110) kV Plomin – Vodnjan.

On the basis of the calculations performed, we can draw a preliminary conclusion that the capacity of a network 110 kV for accepting a large number of WPPs significantly increases the following investments in the network:

— connection of the 2x110 kV Zakučac – Meterize OHL circuit in the Vrboran Substation,
— replacement of the existing 110 kV Melina – Vinodol OHL with the new 2x110 kV Melina – Vinodol OHL,
— construction of the110 kV Knin (Drniš) – Konjsko OHL (in connection with the construction of the Žitnić Railway Substation),
— construction of the110 kV Vodnjan Switchyard and construction of the 2x220 (110) kV Plomin – Vodnjan OHL.

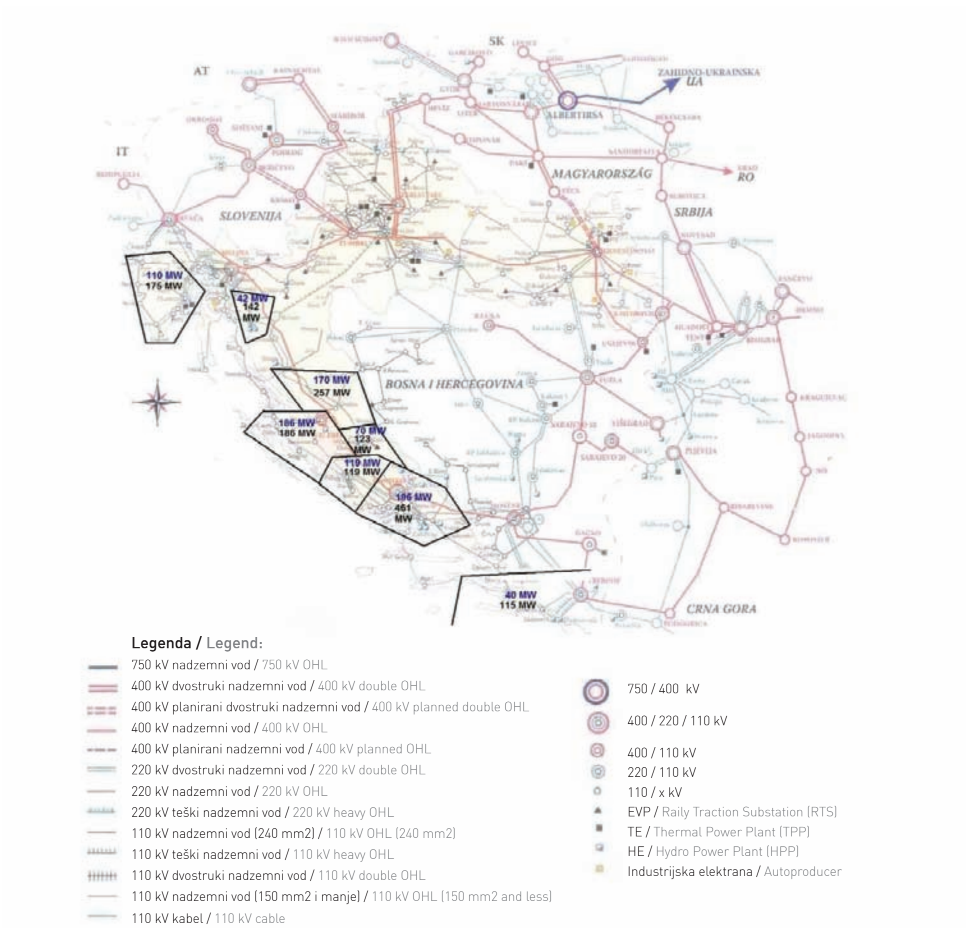
Tablica 4 — Maksimalno dozvoljene snage pojedinačnih vjetroelektrana priključenih na pojedina čvorišta mreže 110 kV
Table 4 — Maximum allowed power of individual wind power plants connected to individual nodes of the network 110 kV

Priključak VE na čvorište / Connection of the WPP to nodes 110 kV	Ukupna instalirana snaga VE / Total installed capacity of a WPP [MW]		Kritični događaj (ispad) / Critical event (fault)	Preopterećenje / Overloading
	Početno* / Initial	Početno* / Initial		
Pag	16	16	—	—
Gračac	256,5	16	DV / OHL*** 110 kV Gračac — L.Osik	DV / OHL 110 kV Gračac — Obrovac
Obrovac	120	120	—	—
Knin	123	70	DV / OHL 110 kV Bilice — Knin	DV / OHL 110 kV Strmica — B. Grahovo
Peruča	75	0	DV / OHL 2x110 kV Meterize — Vrboran	DV / OHL 2x110 kV Meterize — Vrboran**
Konjsko	56	56	—	—
Bilice	119,2	119,2	—	—
Benkovac	50	50	—	—
Vrboran	30	30	—	—
Kraljevac	45	0	DV / OHL 2x110 kV Meterize — Vrboran	DV / OHL 2x110 kV Meterize — Vrboran *
Ston	115	40	DV/ OHL 110 kV Neum — Ston TL	DV / OHL 110 kV Komolac — Trebinje TL
Zakučac	30	0	DV / OHL 2x110 kV Meterize— Vrboran	DV / OHL 2x110 kV Meterize — Vrboran **
Sinj	115	0	TV / OHL 2x110 kV Meterize — Vrboran	DV / OHL 2x110 kV Meterize — Vrboran **
Kaštela	25	25	—	—
Trogir	85	85	—	—
Crikvenica	30	0	DV / OHL 110 kV Melina — Vinodol	DV—KB / OHL—Cable 110 kV Crikvenica — Krk
Senj	112	42	DV / OHL 110 kV Melina — Vinodol	DV—KB / OHL—Cable 110 kV Crikvenica — Krk
Plomin	15	0	DV / OHL 110 kV Raša — Dubrova	DV / OHL 110 kV Plomin — Šijana
Raša	50	0	DV / OHL 110 kV Plomin — Šijana	DV / OHL 110 kV Raša — Dolinka
Buzet	110	110	—	—
UKUPNO / TOTAL	1 577,7	933,2		

* Moguća izgradnja vjetroelektrana u najvjerojatnijem scenariju izgradnje / Possible construction of wind power plants in the most likely construction scenario
** Ispad jedne trojke i preopterećenje preostale trojke / Loss of one circuit and overloading of the remaining circuit
*** Dalekovod / Overhead

Slike 3 i 4 prikazuju regionalnu distribuciju maksimalno dozvoljenih snaga pojedinačnih VE, te distribuciju maksimalno dozvoljenih snaga pojedinačnih VE po čvorištima mreže 110 kV za najvjerojatniji scenarij izgradnje VE, a s obzirom na postojeće evakuacijske sposobnosti prijenosne mreže. Maksimalno dozvoljene snage VE prikazane su na slikama plavom bojom. Od ukupno 1 577,7 MW instalirane snage vjetroelektrana u najvjerojatnijem scenariju izgradnje, s aspekta evakuacijskih sposobnosti mreže pri pojedinačnom plasmanu snage VE, moguće je prihvatiti 933 MW, a da sigurnost pogona ne bude ugrožena.

Figures 3 and 4 present the regional distribution of the maximum allowed power of individual WPPs and the distribution of the maximum allowed power of individual WPPs according to network nodes 110 kV for the most likely construction scenario of WPPs, taking into account the existing network capacities of the transmission network. The maximum allowed power of the WPPs are presented in blue. Out of a total of 1 577,7 MW installed capacity of WPPs in the most likely construction scenario, from the aspect of the network capacity and individual WPP outputs, it is possible to accept 933 MW, so that the security of the supply will not be jeopardized.



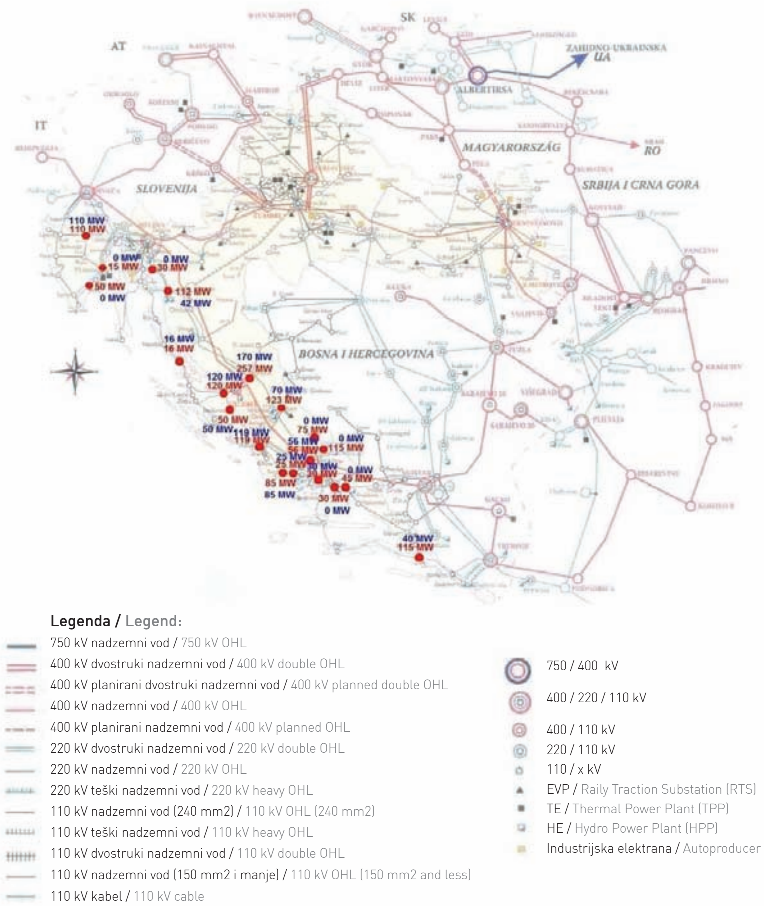
Slika 3 — Regionalna distribucija maksimalno dozvoljenih snaga pojedinačnih vjetroelektrana u najvjerojatnijem scenariju moguće izgradnje

Figure 3 — Regional distribution of the maximum allowed power of individual wind power plants in the most likely construction scenario

Ukupna dozvoljena snaga pojedinačnih VE ovisi naravno o priključnom čvorištu mreže 110 kV pa uz drugačiju prostornu raspodjelu VE suma ukupnih pojedinačnih snaga može značajno varirati na više ili niže. Također u pojedinim čvorištima mreže 110 kV poput Paga, Obrovca, Konjskog, Bilica, Benkovca, Vrborana, Kaštela, Trogira,

The total allowed power of individual WPPs depends, naturally, on the network 110 kV connection nodes. With a different spatial distribution of the WPPs s, the sum of the total individual powers can significantly vary, either higher or lower. Furthermore, on the individual nodes of the network 100 kV such as Pag, Obrovac, Konjsko, Bilica, te Buzeta moguće je priključiti i veću instaliranu snagu VE od onih analiziranih u ovom poglavlju. Daljnja ograničenja s aspekta evakuacijskih sposobnosti mreže proizlaze iz istodobnog plasmana proizvodnje VE što se razmatra u idućem poglavlju.

Benkovac, Vrboran, Kaštela, Trogir and Buzet, it is possible to connect greater installed capacities of WPPs than those analyzed in this chapter. Further limitation from the aspect of the network capacity results from the coherent power generation of WPPs, as discussed in the next chapter.



Slika 4 — Distribucija maksimalno dozvoljenih snaga pojedinačnih vjetroelektrana u najvjerojatnijem scenariju moguće izgradnje po čvorištima mreže 110 kV

Figure 4 — Distribution of the maximum allowed power of individual wind power plants in the most likely construction scenario according to the nodes of the 110 kV Network

3.2 Analiza svih makrolokacija vjetroelektrana

Na temelju analiza iz prethodnog poglavlja i proračuna maksimalno dozvoljenih snaga pojedinačnih grupa VE s aspekta evakuacijskih sposobnosti prijenosne mreže, u nastavku se analizira scenarij kada su sve VE u pogonu pri izrazito povoljnim vremenskim prilikama (vjetar) koje rezultiraju visokim angažmanom svih VE. Promatra se ukupan angažman u iznosu od 80 % instalirane snage svih VE, što je određeno na temelju europskih iskustava prema kojima u dugogodišnjem vremenskom razdoblju ukupna proizvodnja VE nije prelazila 80 % njihove ukupne instalirane snage [5] do [13].

3.2 Analysis of all the macro locations of wind power plants

Based upon analysis from the previous chapter and the calculation of the maximum allowed power of individual groups of WPPs from the aspect of the transmission network capacity, in this paper scenarios are analyzed when all the WPPs are in operation under particularly favorable meteorological conditions (wind), resulting in high power generation of all the WPPs. The total output is considered as 80 % of the installed capacity of all the WPPs, determined on the basis of European experiences, where the total output has not exceeded 80 % of the total installed capacity during the many years of wind power plant operation.

Ova razina istodobnosti u literaturi se uzima kao gornja, konzervativna granica, što će rezultirati većom razinom sigurnosti. Hoće li će to biti slučaj i u Hrvatskoj moguće je provjeriti tek detaljnim analizama istodobnih brzina vjetra u sekundnom i minutnom području na svim potencijalnim lokacijama za izgradnju VE, što je podatak koji autori u ovom trenutku ne posjeduju. Maksimalan angažman svih VE se ne razmatra budući da se takav scenarij ocjenjuje nevjerojatnim.

U analizama se promatraju četiri karakteristična pogonska stanja iz 2005. godine:

— vršno opterećenje,
— minimalno zimsko opterećenje,
— maksimalno ljetno opterećenje,
— te minimalno ljetno opterećenje.

Analize su izvršene na način da se na modelima za ukupan angažman VE u iznosu od 80 % njihove ukupne instalirane snage najprije smanjuje uvoz snage, a zatim i angažman termoelektrana s najvećom cijenom proizvodnje poput PTE Osijek, KTE Jertovec, TE Sisak i TE Rijeka.

U tablici 5 prikazane su analizirane dozvoljene pojedinačne instalirane snage VE po pojedinim čvorištima mreže 110 kV, određene na temelju pojedinačnih maksimalnih angažmana VE u najvjerojatnijem scenariju izgradnje, te procijenjene maksimalno dozvoljene snage VE priključenih na pojedina čvorišta mreže na temelju $n-1$ kriterija i evakuacijskih sposobnosti prijenosne mreže pri istodobnom visokom angažmanu svih VE, određenom na temelju pretpostavke da visok angažman odgovara 80 %–noj instaliranoj snazi svih VE. U tablici su također navedeni kritični događaji i preopterećeni vodovi koji ograničavaju maksimalnu snagu pojedinačnih VE koje je moguće priključiti na pojedina čvorišta mreže 110 kV.

This level of coherent operation in the literature is taken as the upper conservative limit, providing a greater level of security. Whether this will be the case in Croatia can only be confirmed by detailed analysis of the simultaneous wind speeds at one–second and one–minute intervals at all the potential locations for the construction of WPPs, data which the authors do not have at the present. The maximum output of all the WPPs has not been considered because such a scenario is considered to be unlikely.

In the analyses, four characteristic operating conditions from 2005 were considered:

— peak load,
— minimum winter load,
— maximum summer load, and
— minimum summer load.

The analyses were performed in such a manner that the power exchange is first reduced in the models in which the total output of the WPPs is set to 80 % of their total installed capacity, and then the power output of the thermal power plant with the highest generation price such as the Osijek Combined Cycle Gas Unit, the Jertovec Combined Cycle Gas Unit, the Sisak Thermal Power Plant and the Rijeka Thermal Power Plant.

Table 5 presents the analyzed allowed individual installed capacities of the WPPs according to the individual nodes of the network 110 kV, determined on the basis of individual maximum outputs of the WPPs in the most likely construction scenario and the maximum allowed power of the WPPs connected to the network nodes on the basis of $n-1$ security criterion and the network capacities of the transmission network during coherent high power output from all the WPPs, determined on the basis of the assumptions that high power output corresponds to 80 % of the installed capacities of all the WPPs. The table also presents the cited critical events and overloaded lines that limit the maximum power of the individual WPPs that can be connected to the individual network nodes 100 kV.

Tablica 5 — Maksimalno dozvoljene snage vjetroelektrana u najvjerojatnijem scenariju njihove izgradnje, priključenih na pojedina čvorišta mreže 110 kV
Table 5 — Maximum allowed power of the wind power plants in the most likely scenario for their construction, connected to individual network nodes 110 kV

Priključak VE na čvorište / Connection of the WPPs to nodes 110 kV	Ukupna instalirana snaga VE / Total installed capacity of the WPPs [MW]			Kritični događaj (ispad) / Critical event fault	Preopterećenje / Overloading
	Početno* / Initial	Dozvoljeno pri pojedinačnom angažmanu / Allowed for individual operation	Dozvoljeno pri istodobnom angažmanu / Allowed for coherent operation		
Pag	16	16	6,3	DV / OHL 400 kV Melina — Obrovac	DV—KB / OHL — Cable 110 kV Novalja — Rab
Gračac	256,5	170	170	—	—
Obrovac	120	120	120	—	—
Knin	123	70	70	—	—
Peruča	75	0	0	—	—
Konjsko	56	56	56	—	—
Bilice	119,2	119,2	119,2	—	—
Benkovac	50	50	50	—	—
Vrboran	30	30	30	—	—
Kraljevac	45	0	0	—	—
Ston	115	40	40	—	—
Zakučac	30	0	0	—	—
Sinj	115	0	0	—	—
Kaštela	25	25	25	—	—
Trogir	85	85	85	—	—
Crikvenica	30	0	0	—	—
Senj	112	42	42	—	—
Plomin	15	0	0	—	—
Raša	50	0	0	—	—
Buzet	110	110	110	—	—
UKUPNO / TOTAL	1 577,7	933,2	923,5		

* Moguća izgradnja vjetroelektrana u najvjerojatnijem scenariju izgradnje / The possibility of constructing wind power plants in the most likely construction scenario

Od ukupno 1 577,7 MW instalirane snage VE u najvjerojatnijem scenariju izgradnje, s aspekta evakuacijskih sposobnosti mreže pri pojedinačnom plasmanu snage VE moguće je prihvatiti 923,5 MW, a da sigurnost pogona ne bude ugrožena. Izgradnjom svih VE unutar najvjerojatnijeg scenarija izgradnje dodatno se smanjuje mogućnost priključka VE na trafostanicu Pag (sa 16 MW na 6,3 MW), tako da ukupna procijenjena instalirana snaga VE koja se može priključiti na mrežu iznosi 923,5 MW.

Nužno je spomenuti da navedena ukupna snaga VE ovisi o priključnom čvorištu mreže 110 kV, pa stoga uz drugačiju prostornu raspodjelu VE, tj. dinamiku izgradnje suma ukupnih pojedinačnih snaga može značajno varirati na više ili niže. Analogno, drugačiji raspored izgradnje rezultirao bi drugačijom istodobnošću proizvodnje, što također ima značajnog utjecaja na ograničenja navedena u ovom poglavlju.

Of the total 1 577,7 MW of the installed capacities of the WPPs in the most likely construction scenario, from the aspect of the network capacities and individual WPP output it is possible to accept 923,5 MW without jeopardizing operating security. With the construction of all the WPPs within the most likely construction scenario, the possibility of connecting a WPP to the Pag Substation (from 16 MW to 6,3 MW) is reduced, so that the total estimated installed capacity of the WPPs that can be connected to the network is 923,5 MW.

It is necessary to mention that the cited total power of the WPPs depends on the network connection nodes 110 kV. Therefore, with a different spatial distribution of the WPPs, i.e. construction schedule, the sum of the total individual power can vary significantly, either higher or lower. Analogously, a different construction schedule would result in different simultaneity of generation, which also has a significant impact on the limitations described in this chapter.

4 PROCJENA ISTODOBNOSTI ANGAŽMANA VJETROELEKTRANA

4.1 Raspoloživost podataka o brzinama vjetra

Mjerenja brzine vjetra na različitim lokacijama duž jadranske obale prikupljena su očitanjima s mjernih stanica u vlasništvu EIHP-a, ustupanjem od strane potencijalnih investitora u vjetroelektrane, te na temelju podataka Državnog hidrometereološkog zavoda (DHMZ). Za analize prikazane u ovom poglavlju promatrano je razdoblje od 14.06.2005. do 31.07.2006. godine, a mjerenja brzine vjetra i kretanje snaga VE iz najvjerojatnijeg scenarija izgradnje (sc1) prikupljene su za većinu razmatranih VE smještenih na području četiri dalmatinske županije (Dubrovačko-netervanska, Splitsko-dalmatinska, Šibensko-kninska, Zadarska županija), te Ličko-senjske županije. Podaci nažalost nisu prikupljeni za potencijalne VE na području Istarske županije.

Podaci o brzinama vjetra prikupljeni su sa sedam mjernih stanica smještenih unutar pet županija. Posebnom analizom određene su angažirane snage VE koje odgovaraju pripadnim brzinama vjetra na pojedinim lokacijama. Istodobnost podataka o brzinama vjetra najveća je za razdoblje od 1.10.2005. do 31.12.2005. godine, pa se opisane analize uglavnom temelje na podacima iz tog razdoblja. Promatranjem mogućeg rada većeg broja VE smještenih na udaljenim lokacijama opaža se efekt ublažavanja varijacija ukupne proizvodnje VE, u odnosu na situaciju kad bi sve VE bile smještene unutar manjeg područja, pa je vrlo važno analizirati podatke koji se odnose na isti vremenski period. Podaci o kretanju snage VE odnose se na razdoblje od jednog sata [MWh/h], što znači da su snage VE procijenjene na temelju prosječnih satnih vrijednosti brzina vjetra na različitim lokacijama. Finiji podaci za minutna ili sekundna područja autorima nisu bili dostupni.

To znači da se svi rezultati i zaključci prikazani u ovom poglavlju temelje na usporedbama satnih vrijednosti promatranih veličina, što svakako unosi određenu pogrešku zbog promjena brzine vjetra unutar sekundnog i minutnog razdoblja. Inozemna iskustva govore da vjetar vrlo malo mijenja brzinu unutar sekundnog i minutnog područja, a oscilacije su izraženije unutar 15 minutnog područja i dulje, što znači da je promatranje satnog područja restriktivnije po zahtjeve koje VE unose u elektroenergetski sustav pa su rezultati na strani sigurnosti.

4 ASSESSMENT OF THE COHERENT GENERATION OF THE WIND POWER PLANTS

4.1 Availability of data on wind velocities

Wind velocity measurements at various locations along the Adriatic coast were collected from readings at metering stations owned by the EIHP and by potential investors in WPPs, as well as on the basis of data from the Croatian Meteorological and Hydrological Service (DHMZ). For the analyses presented in this chapter, the period from June 14, 2005 to July 31, 2006 was considered, and the measured wind velocities and power fluctuation of the WPPs from the most likely construction scenario (Sc1) were collected from the majority of the WPPs studied in the territories of four Dalmatian counties (Dubrovnik-Neretva, Split-Dalmatia, Šibenik-Knin and Zadar Counties), and Lika — Senj County. Unfortunately, data were not collected for the potential WPPs in the territory of Istria County.

Data on wind velocities were collected from seven metering stations located in five counties. Through separate analysis, the wind power plant capacities that correspond to the wind velocities at individual locations were determined. The simultaneity of the data on wind velocities was greater for the period from October 1, 2005 to December 31, 2005, so the described analyses are primarily based upon the data from this period. By studying the potential operations of a large number of WPPs located at distant locations, the decrease in the fluctuations in the total generation of the WPPs is noted, in comparison to the situation that would occur if all the WPPs were located within a smaller area. Therefore, it is very important to analyze the data that refer to the same period of time. The power fluctuation data of WPPs refer to a one—hour period [MWh/h], which means that the generating capacities of the WPPs were assessed on the basis of the average hourly values of the wind velocities at various locations. More precise data for minutes or seconds were not available to the authors.

This means that all the results and conclusions presented in this chapter are based upon comparisons of the hourly values of the observed parameters, which introduces a certain level of error due to the changes in wind velocity within the period of a second or minute. Experience in other countries indicates that changes in wind velocity are very small within the one—second and one—minute intervals and fluctuations are expressed within the 15—minute interval or longer, which means that the hourly period considered is more restrictive regarding the requirements that the wind power plants impose upon the electric power system and, therefore, the results are on the side of security.

4.2 Kretanje snage vjetroelektrana na pojedinačnim lokacijama

Analizom podataka o istodobnim brzinama vjetra određene su neke važne karakteristike budućih VE priključenih na pojedina čvorišta mreže. Iste su prikazane u tablici 6.

4.2 Fluctuation in the power output of wind power plants at individual locations

Through analysis of the data on the simultaneous wind velocities, several significant characteristics of the future WPPs connected to individual network nodes were determined, as presented in Table 6.

Tablica 6 — Karakteristične neistodobne promjene snage proizvodnje vjetroelektrana po pojedinim priključnim čvorištima u razdoblju od 1.01.2005. do 31.12.2005.
Table 6 — Characteristic non—coherent changes in the power generation of wind power plants according to individual connection nodes during the period from October 1 to December 31, 2005.

Čvorište / Nodes	Maksimalne satne promjene snage proizvodnje / Maximum hourly changes in generation [MWh/h]	Prosječne satne promjene snage proizvodnje / Average hourly changes in generation [MWh/h]	Ukupan broj sati s promjenom snage proizvodnje većom od 50 % planirane instalirane snage / Total number of hours with changes in generation over 50 % of the planned installed capacity [h]	Maksimalne satne promjene snage proizvodnje / Maximum hourly changes in generation [MWh/h]	Prosječne satne promjene snage proizvodnje za ograničenu veličinu izgradnje / Average hourly changes in generation for limited construction [MWh/h]	Ukupan broj sati s promjenom snage proizvodnje većom od 50 % ograničene instalirane snage / Total number of hours with changes in generation greater than 50 % of the limited installed capacity [h]
Pag	16,30	1,42	61	6,42	0,56	77
Gračac	130,19	12,30	2	107,77	10,18	3
Obrovac	103,39	7,13	15	103,39	7,13	15
Knin	170,85	12,89	10	62,23	4,29	17
Konjsko	41,13	3,39	20	41,13	3,39	20
Bilice	93,44	8,87	19	93,44	8,87	19
Benkovac	42,74	2,95	15	42,74	2,95	15
Vrboran	21,91	1,81	19	21,91	1,81	19
Ston	114,98	7,78	27	40,24	2,72	30
Kaštela	19,57	1,86	17	19,57	1,86	17
Trogir	67,05	6,36	19	67,05	6,36	19
Senj	108,07	9,43	34	40,56	3,59	55
Peruća	55,12	5,23	15	55,12	5,23	15
Kraljevac	33,16	2,73	19	33,16	2,73	19
Zakučac	20,90	1,72	16	20,90	1,72	16
Sinj	82,65	6,81	18	82,65	6,81	18
Crikvenica	28,51	2,49	51	28,51	2,49	51

4.3 Istodobno kretanje snaga vjetroelektrana

U ovom poglavlju promatran je istodobni pogon svih VE iz najvjerojatnijeg scenarija njihove izgradnje (sc1), prema njihovim ukupnim instaliranim snagama, te na temelju dozvoljenih snaga određenih analizom evakuacijskih sposobnosti mreže na koju se priključuju. Radi se o ukupno 1 577,7 MW instalirane snage u 39 VE smještenih na širem području Dubrovnika, Splita, Šibenika, Zadra, Knina, Gračaca, Senja i Istre, od čega je na postojeću konfiguraciju prijenosne mreže na temelju njenih evakuacijskih mogućnosti moguće priključiti ukupno 923,5 MW.

Kvaliteta ulaznih podataka i njihova istodobnost opisana je u prethodnom poglavlju. Najveća istodobnost podataka odnosi se na razdoblje

4.3 Simultaneous fluctuations in the power output of wind power plants

In this chapter, the coherent operation of all the WPPs in the most likely construction scenario 1 (Sc1) is considered, according to their total installed capacity, and on the basis of the allowed installed capacity determined through the analysis of the capacities of the network to which power plants are connected. This concerns a total of 1 577,7 MW installed capacity in 39 WPPs located in the broad region of Dubrovnik, Split, Šibenik, Zadar, Knin, Gračac, Senj and Istria, of which a total of 923,5 MW can be connected to the existing configuration of the transmission network on the basis of its capacity.

The quality of the input data and their simultaneity are described in the previous chapter. The greatest od 1.10.2005 do 31.12.2005. pa će se najviše pažnje posvetiti obradi podataka iz tog razdoblja. Unutar tog razdoblja poznati su podaci za 34 VE smještene na području pet županija, pa su dovoljno reprezentativni za donošenje generalnih zaključaka o očekivanim kretanjima snage VE u Hrvatskoj. Moguće pogreške u generalnim zaključcima proizlaze iz sljedećeg:

- obrađeno je kraće vremensko razdoblje unutar jedne godine, a za ovakvu vrstu analiza trebalo bi obraditi višegodišnje razdoblje,
- nisu poznati podaci za buduće VE smještene na području Istre,
- kretanja snage pojedinih VE procijenjene su na temelju najbližih mjernih stanica relativno udaljenih od razmatranih lokacija, radi čega stvarna kretanja snage mogu odstupati od procijenjenih.

Podaci o kretanjima snaga svih obrađenih vjetroelektrana odnose se na sljedeće:

- sve VE u najvjerojatnijem scenariju izgradnje s ukupno instaliranom snagom P_{ins}= 1 577,7 MW,
- dozvoljene VE s obzirom na evakuacijske sposobnosti postojeće prijenosne mreže prema analizama s ukupnom instaliranom snagom P_{ins}= 923,5 MW.

Analizirane su satne promjene snage vjetroelektrana, odnosno srednje satne vrijednosti njihove moguće proizvodnje [MWh/h]. Osnovne rezultate prikazuje tablica 7. Promatrajući cjelokupno razdoblje malo duže od godinu dana, ali s nepotpunim podacima o brzinama vjetra na lokacijama budućih VE, primjećuje se da će uz maksimalan istodobni angažman svih VE u iznosu od 1 421,63 MWh/h (bez onih na području Istre), maksimalne satne oscilacije ukupne snage proizvodnje iznositi oko 563 MWh/h (oko 40 % P_{VEmax}, odnosno oko 39 % P_{VEins}). U razdoblju od 1.10. do 31.12.2005. godine maksimalna snaga ostaje ista, a maksimalne oscilacije iznose oko 547 MW (oko 38 % P_{VEmax}, odnosno oko 37 % P_{VEins}).

Ukoliko se analiziraju samo VE koje je moguće priključiti na prijenosnu mrežu s obzirom na njene sadašnje evakuacijske sposobnosti, može se zaključiti da bi unutar razdoblja 1.10. do 31.12. 2005. godine maksimalan angažman svih VE iznosio oko 860 MWh/h, uz maksimalne satne promjene snage u iznosu od oko 375 MWh/h (oko 44 % P_{VEmax}, odnosno oko 43 % P_{VEins}).

simultaneity of data refers to the period from October 1 to December 31, 2005, so the most attention will be devoted to the processing of data from this period. Within this period, data are known for 34 WPPs located in the territories of five counties, which are sufficiently representative for reaching general conclusions on the anticipated fluctuations in the power output of the wind power plants in Croatia. Potential errors in the general conclusions can result from the following:

- a period of one year has been processed, although for this type of analysis it would be necessary to process a period of several years,
- data for the future WPPs located in the territory of Istria are unknown,
- fluctuations in the power of individual WPPs were calculated on the basis of the closest metering stations from the locations studied, due to which the actual power fluctuations may differ from those estimated.

Data on power fluctuations of all the processed WPPs refer to the following:

- all the WPPs in the most likely construction scenario P_{ins}= 1 577,7 MW,
- allowed WPPs regarding the capacity of the existing transmission network according to analyses P_{ins}= 923,5 MW.

Hourly fluctuations in the power output of wind power plants, i.e. average hourly values of potential WPP generation [MWh/h] are analyzed. The basic results are presented in Table 7. Considering the entire period of slightly over one year, but with incomplete data on wind velocities at the locations of the future WPPs, we note that in addition to the maximum coherent output of all the WPPs in an amount of 1 421,63 MWh/h (without the WPPs in the territory of Istria), the maximum hourly fluctuation of the total power output is approximately 563 MWh/h (approximately 40 % P_{VEmax}, respectively approximately 39 % P_{VEins}). In the period from October 1 to December 31, 2005, the maximum power remains the same and the maximum fluctuation is approximately 547 MW (approximately 38 % P_{VEmax}, respectively approximately 37 % P_{VEins}).

If we only analyze the WPPs that can be connected to the transmission network according to its present capabilities, we conclude that within the period from October 1 to December 31, 2005, the maximum output of all the WPPs was approximately 860 MWh/h, with maximum hourly power changes of approximately 375 MWh/h (approximately 44 % P_{VEmax}, respectively approximately 43 % P_{VEins}).

Tablica 7 — Procjena kretanja snage svih vjetroelektrana iz scenarija 1 (sc1)
Table 7 — Estimated fluctuation of the power of all the wind power plants from scenario Sc1

Razdoblje promatranja / Period studied	$P_{ins} \approx$ 1 577,7 MW		$P_{ins} \approx$ 923,5 MW	
	P_{max} [MWh/h]	ΔP_{max}	P_{max} [MWh/h]	ΔP_{max}
14.06.2005. – 31.07.2006.	1 421,63	562,80	–	–
01.10.2005. – 31.12.2005.	1 421,63	547,16	860,40	375,44

Promatrajući satne promjene snaga VE primjećuje se da se usprkos maksimalnim promjenama u iznosu od 563 MWh/h za sve VE u razdoblju od 14.06.2005. do 31.07.2006., odnosno 547 MW za razdoblje od 1.10. do 31.12.2005. godine, te 375 MW za dozvoljene u razdoblju od 1.10. do 31.12.2005. godine, prosječne satne promjene kreću oko dosta manjih iznosa (između 36 MW i 56 MW ovisno o ukupnoj instaliranoj snazi VE – tablica 8). Broj sati u kojima se promjene snage svih vjetroelektrana kreću unutar iznosa većih od 300 MW iznosi oko 0,09 % promatranog vremena za dozvoljene, odnosno između 0,55 % i 1 % promatranog vremena za sve VE.

Na temelju prikazanih veličina može se zaključiti da vjetroelektrane priključene na EES Republike Hrvatske neće znatno mijenjati svoju snagu unutar satnog područja u većini vremena tijekom godine, no uz veće oscilacije snage na satnoj razini izrazito stohastičkog karaktera, reda veličine do 50 % od ukupne instalirane snage VE, pa sustav u svakom trenutku mora moći pružiti odgovarajuću rezervu (sekundarna i tercijarna *P/f* regulacija), radi održavanja nazivne frekvencije i ugovorenih prekograničnih razmjena.

Considering the hourly fluctuations in the power output of WPPs, we note that despite the maximum fluctuation in the amount 563 MWh/h for all the WPPs in the period of June 14, 2005 to July 31, 2006, respectively 547 MW for the period from October 1 to December 31, 2005, and 375 MW for the allowed WPPs during the period from October 1 to December 31, 2005, the average hourly fluctuations range from fairly small amounts (between 36 MW and 56 MW, depending on the total installed capacity of the WPP–Table 8). The number of hours in which the fluctuation in the power of all the WPPs ranges within amounts greater than 300 MW is approximately 0,09 % of the time studied for the allowed WPPs, respectively between 0,55 % and 1 % of the time studied for all the WPPs.

On the basis of the values presented, we can conclude that the WPPs connected to the electric power system of the Republic of Croatia will not significantly change its power within an hourly period most of the time during the year. However, greater power fluctuations at the hourly level are of a markedly stochastic character, of an order of magnitude of up to 50 % of the total installed capacity of the WPPs. Therefore, at any moment the system must provide the suitable reserve (secondary and tertiary *P/f* control), in order to maintain the rated frequency and the scheduled cross—border exchanges.

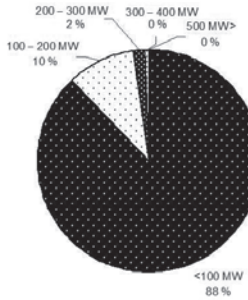
Tablica 8 — Satne promjene kretanja snage svih vjetroelektranaiz scenarija sc1
Table 8 — Hourly fluctuation in the power output of all the wind power plants from the scenario Sc1

Razdoblje promatranja / Period studied	$P_{ins} \approx$ 1 577,7 MW		$P_{ins} \approx$ 923,5 MW	
	ΔP prosječno / average [MWh/h]	ΔP>300 MW (% od promatranog vremena / % of the period studied)	ΔP prosječno / average [MWh/h]	ΔP>300 MW (% od promatranog vremena / % of the period studied)
14.06.2005. – 31.07.2006.	44,48	0,55 %	–	–
1.10.2005. – 31.12.2005.	55,65	1 %	36,29	0,09 %

Slike 5 do 7 prikazuju raspone satnih promjena snage VE i njihovo trajanje u odnosu na ukupno promatrano razdoblje. Iz slika je vidljivo da bi se u slučaju izgradnje VE ukupne instalirane snage 1 578 MW satne promjene snaga kretale do 200 MW u 96 % do 98 % slučajeva, dok bi se

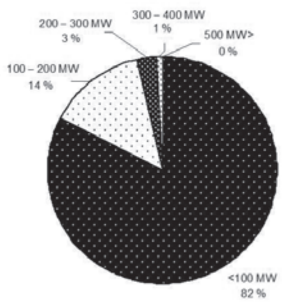
Figures 5 to 7 present the range of the hourly power fluctuations of the wind power plants and their duration in comparison to the total period studied. From the figures, it is evident that in the event of the construction of WPPs of a total installed capacity of 1 578 MW, the hourly power fluctuations would za VE instalirane snage do 924 MW satne promjene kretale do 200 MW u 99 % promatranog vremena. Praktično bi to značilo veliku potrebu za pripremljenom sekundarnom i tercijarnom regulacijom u sustavu radi vrlo kratkotrajnih i izraženih velikih promjena snage proizvodnje VE, ali malo iskorištenje snage sekundarne i tercijarne regulacije.

range up to 200 MW in 96 % to 98 % of the cases, while for the wind power plants of installed capacities of up to 924 MW, the hourly fluctuations would range up to 200 MW in 99 % of the period studied. This would indicate the great need for secondary and tertiary control reserves in the system for very brief and markedly great fluctuations in the power output of WPPs, although secondary and tertiary reserves would be little used.



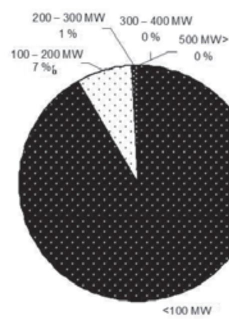
Slika 5 — Ukupno trajanje satnih promjena snage svih vjetroelektrana (P_{ins} = 1 577,7 MW) u razdoblju 14.06.2005. do 31.07.2006.

Figure 5 — Total duration of the hourly fluctuations in the power output of all the wind power plants (P_{ins} = 1 577,7 MW) during the period from June 14, 2005 to July 31, 2006



Slika 6 — Ukupno trajanje satnih promjena snage svih vjetroelektrana (P_{ins} = 1 577,7 MW) u razdoblju od 1.10.2005. do 31.12.2005.

Figure 6 — Total duration of the hourly fluctuations in the power output of all the wind power plants (P_{ins} = 1 577,7 MW) during the period from October 1, 2005 to December 31, 2005

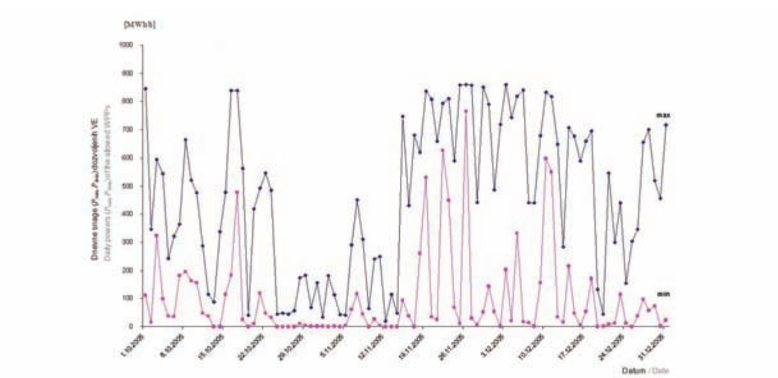


Slika 7 — Ukupno trajanje satnih promjena snage dozvoljenih vjetroelektrana (P_{ins} = 923,5 MW) u razdoblju od 1.10. do 31.12.2005.

Figure 7 — Total duration of the hourly power fluctuations of the allowed wind power plants (P_{ins} = 923,5 MW) during the period from October 1 to December 31, 2005

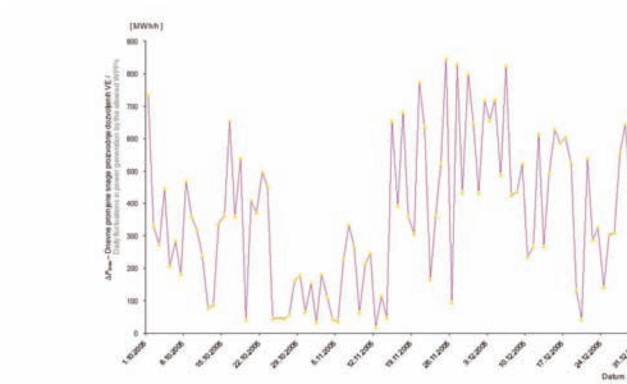
Dnevne varijacije snage proizvodnje dozvoljenih VE ukupne instalirane snage 923,5 MW kreću se u maksimalnom rasponu ($P_{d\,max}$ do $P_{d\,min}$) od 19 MW do 847 MW za promatrano razdoblje od 1.10. do 31.12.2005. godine (slike 8 i 9), što znači da na dnevnoj razini sustav mora za promatranu razinu instalirane snage VE biti sposoban osigurati dodatnu proizvodnju (24 satna rezerva) u iznosu od oko 850 MW (oko 95 % P_{VEins}).
Prosječne maksimalne dnevne varijacije snage VE iznosile su 365 MW unutar promatranog razdoblja.

Daily fluctuation in power generation by the allowed WPPs of a total installed capacity of 923,5 MW are within the maximum range ($P_{d\,max}$ to $P_{d\,min}$) from 19 MW to 847 MW for the period studied from October 1 to December 31, 2005 (Figures 8 and 9), which means that at the daily level the system must be capable of providing additional power generation for the level studied of the installed capacity of the WPP (24-hour reserve) in an amount of approximately 850 MW (approximately 95 % P_{VEins}).
The average maximum daily fluctuation in the power of the WPPs amounted to 365 MW within the period studied.



Slika 8 — Maksimalne i minimalne dnevne snage dozvoljenih vjetroelektrana (P_{ins} = 923,5 MW) u razdoblju od 1.10. do 31.12.2005.

Figure 8 — Maximum and minimum daily power of the allowed wind power plants (P_{ins} = 923,5 MW) during the period from October 1 to December 31, 2005



Slika 9 — Maksimalne dnevne promjene snage proizvodnje dozvoljenih vjetroelektrana (P_{ins} = 923,5 MW) u razdoblju od 1.10. do 31.12.2005.

Figure 9 — Maximum daily fluctuations in power generation by the allowed wind power plants (P_{ins} = 923,5 MW) in the period from October 1 to December 31, 2005

Na među dnevnoj razini (48 satna rezerva) maksimalne varijacije proizvodnje dozvoljenih VE ($P_{dn\,max}$ do $P_{d(n-1)\,min}$) unutar razmatranog razdoblja od 1.10. do 31.12.2005. godine iznosile bi oko 860 MW (oko 98 % P_{VEins}), s prosječnom vrijednošću od 360 MW, što znači da sustav mora biti sposoban u vremenu između 24 i 48 sati osigurati rezervu za puni raspon od 0 do ukupne instalirane snage VE.

At a two—day reserve (48 hour reserve), the maximum fluctuations in power generation of the allowed WPPs ($P_{dn\,max}$ to $P_{d(n-1)\,min}$) within the period studied, October 1 to December 31, 2005, would amount to approximately 860 MW (approximately 98 % P_{VEins}), with an average value of 360 MW, which means that the system must be capable of providing reserves for the full range from 0 to the total installed capacity of the WPPs within a period

Isto vrijedi i za mjesečne oscilacije snage proizvodnje VE.

Na temelju prethodnih analiza može se zaključiti sljedeće:

- sustav mora biti u svakom trenutku sposoban omogućiti sekundarnu i tercijarnu *P/f* regulaciju u najmanjem iznosu otprilike 50 % instalirane snage svih VE (ne uzimajući ovom procjenom u obzir potrebnu rezervu radi varijacija opterećenja u sustavu i obveza prema UCTE. EES Hrvatske je na temelju obveze prema UCTE dužan pružiti 78 MW snage u sekundarnoj regulaciji),
- sustav mora biti sposoban pružiti dnevnu (24 h), među dnevnu (48 h) i mjesečnu rezervu do pune instalirane snage VE,
- velike oscilacije snage proizvodnje VE izrazito su stohastičkog karaktera i događaju se rijetko, tako da će iskorištenje snage sekundarne i tercijarne regulacije u sustavu radi varijacija proizvodnje VE biti malo,
- potrebe za primarnom regulacijom unutar sustava nije moguće ovom prilikom procijeniti jer nisu poznate promjene brzine vjetra i kretanja snaga VE u sekundnom i minutnom području.

5 PROCJENA REGULACIJSKIH SPOSOBNOSTI EES

5.1 Krivulje promjene opterećenja

Satne promjene opterećenja prikupljene su od HEP OPS za 2005. godinu (1.01. do 31.12.2005.). Dnevni dijagrami opterećenja za karakteristične dane u godini (vršno opterećenje, minimalno zimsko, maksimalno ljetno i minimalno opterećenje) imaju sličan oblik. U razdoblju iza ponoći opterećenje EES pada, te dostiže svoj dnevni minimum između 4 i 6 sati ujutro. Nakon toga opterećenje raste i postiže maksimum u tom razdoblju iznosa između 10 i 12 sati prije podne, kada opet blago pada do 16 do 18 sati, nakon čega slijedi porast pa se dnevni maksimum uobičajeno postiže u razdoblju između 20 i 22 h.

Uzroke takvom obliku dnevnog dijagrama opterećenja ovom prilikom nije potrebno analizirati, no važno je napomenuti da dispečerska služba procjenjuje iznose opterećenja za sijedeći dan i na temelju tih procjena slaže vozni red elektrana. Razlike u planiranom i ostvarenom opterećenju preuzima primarna i sekundarna *P/f* regulacija kojom sustav raspolaže, a najveće nesigurnosti proizlaze iz ovisnosti

of between 24 to 48 hours. This also applies to the monthly fluctuations in the power generation of the WPPs.

On the basis of the previous analyses, the following may be concluded:

- At every moment, the system must be capable of facilitating secondary and tertiary *P/f* control in a minimum amount of approximately 50 % of the installed capacity of all the WPPs (not taking into account, the necessary reserve for load variations in the system and the obligations toward the UCTE. The Croatian electric power system in compliance with the obligations toward the UCTE is required to provide 78 MW of the secondary P/f reserve).
- The system must be capable of providing 24–hour, 48–hour and monthly reserve up to the full installed capacity of the WPPs.
- Great fluctuations in the power output of WPPs are of a markedly stochastic character and occur rarely, so that the secondary and tertiary reserves in the system due to the variations in generation would be little used.
- On this occasion, it is not possible to predict the requirements for primary control within the system because the fluctuations in wind velocity and in the power output of WPPs at one–second and one–minute intervals are not known.

5 ASSESSMENT OF THE AVAILABILITY OF ANCILLARY SERVICES

5.1 Load variation curves

Hourly load variations were collected from the HEP Transmission System Operator (HEP OPS) for the year 2005 (from January 1 to December 31, 2005). Daily load diagrams for specific days of the year (peak load; minimum winter, maximum summer and minimum loads) have similar forms. During the period after midnight, the electric power system load drops and reaches its daily minimum between 4 and 6 a.m. After that, the load increases and reaches the maximum during the period between 10 a.m. and noon, declining slightly from 4. to 6 p.m., followed by an increase so that the daily maximum is usually reached during the period from 8 to 10 p.m.

The cause of such a daily load diagram need not be analyzed on this occasion. Nonetheless, it should be mentioned that the dispatcher estimates the amount of load for the next day and sets up the power plant schedule on the basis of these estimates. The difference between the estimated and the actual load is taken over by the primary and secondary *P/f* control of the system. The greatest uncertainty arises from opterećenja o vanjskoj temperaturi kada se opterećenja mogu razlikovati za nekoliko stotina megavata u hladnijem danu u odnosu na dan s višom temperaturom.

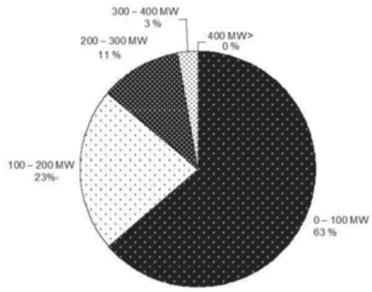
Uvidom u prognozu vremena DHMZ-a očekivani pad temperature moguće je također uzeti u obzir prilikom prognoze opterećenja i sastavljanja voznog reda elektrana, no greška u predviđanju bit će to veća što je veća pogreška u prognozi vremena sa strane DHMZ.

Odnos između maksimalnog i minimalnog godišnjeg opterećenja EES-a iznosi oko 1 : 0,35. Omjer između maksimalnog i minimalnog dnevnog opterećenja za 2005. godinu kretao se između 1 : 0,49 i 1 : 0,69, a maksimalna apsolutna dnevna razlika opterećenja iznosila je 1 334 MW, dok je minimalna apsolutna dnevna razlika iznosila 599 MW. Maksimalna satna promjena opterećenja u 2005. godini iznosila je 419 MW, dok je prosječan iznos satnih promjena iznosio 95 MW. Pri tom su se satne promjene opterećenja do iznosa od 100 MW događale u 63 % vremena godišnje (5 342 sati), dok su se satne promjene veće od 300 MW događale svega u 2,6 % vremena godišnje (222 sata) – slika 10.

the fact that the load depends on the outside temperature. It can differ by several hundred MW on a cold day in comparison to a day with a higher temperature.

From the weather forecast of the Croatian Meteorological and Hydrological Service (DHMZ), an anticipated drop in temperature can be taken into account during the load forecast and the setting up of the power plant schedule, although the forecast error will increase in proportion to the error in the DHMZ weather forecast.

The ratio between the maximum and minimum annual load of the electric power system is approximately 1 : 0,35. The ratio between the maximum and minimum daily load for the year 2005 ranged between 1 : 0,49 and 1 : 0,69, and the maximum absolute daily difference in load was 1 334 MW, while the minimum absolute daily difference was 599 MW. The maximum hourly load change in the year 2005 was 419 MW, while the average amount of hourly change was 95 MW. Hourly load changes up to the amount of 100 MW occurred during 63 % of the year (5 342 hours) while hourly changes greater than 300 MW only occurred during 2,6 % of the year (222 hours) – Figure 10.



Slika 10 — Ukupno trajanje satnih promjena opterećenja u razdoblju od od 1.01.2005. do 31.12.2005.
Figure 10 — The total hourly load changes during the period from January 1 to December 31, 2005

5.2 *P/f* regulacijske sposobnosti postojećih elektrana

Da bi se ocijenile mogućnosti sudjelovanja generatora (elektrana) unutar EES-a Hrvatske u *P/f* regulaciji prikupljeni su podaci o njima od strane HEP Proizvodnje. Podaci se odnose na vrijeme potrebno od hladnog starta do postizanja pune snage, te maksimalnoj brzini promjene proizvodnje u minutnom području.

Hidroelektrane imaju mogućnost vrlo brzog puštanja u pogon od trenutka davanja naloga do maksimalne snage u rasponu od 4 minute do 30 minuta, dok je termoelektranama potrebno puno duže vrijeme, u rasponu od 3 sata (EL–TO Zagreb) do 24 sata (TE Sisak). Izuzetak je kombi blok u TE-TO Zagreb koji je moguće teretiti

5.2 *P/f* control capability of the existing power plants

In order to evaluate the possibilities for the participation of generators (power plants) within the Croatian electric power system in *P/f* control, data were collected on them by HEP Generation (HEP Proizvodnja). The data refer to the time required from a cold start to full power, and the maximum rate of change of power generation at minute time intervals.

Hydroelectric power plants can be put into operation very quickly from the moment the order is given to maximum power within a range of 4 minutes to 30 minutes, while thermal power plants require a much longer time, within a range of from 3 (the Zagreb Cogeneration Plant – ELTO) to 24 hours (the Sisak Thermal Power Plant). The exception is the combined

Bajs, D., Majstrović, G., Mogućnost prihvata vjetroelektrana..., Energija, god. 57(2008), br. 2., str. 124-155
Bajs, D., Majstrović, G., The Feasibility of the Electric power System..., vol. 57(2008), No. 2, pp. 124-155

do maksimalne snage iz hladnog starta za 15 minuta, te KTE Jertovec i PTE Osijek koje je moguće teretiti do pune snage u vremenu od 20 minuta, odnosno 15 minuta, ne ulazeći pri tom u problematiku ekonomske naravi (visoki troškovi proizvodnje ovih dviju TE).

Ukupna snaga koju je moguće interventno angažirati u postojećim elektranama u okvirima tercijarne P/f regulacije ovisi o nizu faktora, prvenstveno o trenutačnom pogonskom stanju koje je definirano s:

- voznim redom elektrana,
- hidrološkim okolnostima,
- opterećenju EES-a, te
- bilanci sustava (programiranim razmjenama).

Utjecaj gornjih parametara na regulacijske sposobnosti unutar EES-a je vrlo značajan. Kod nižih opterećenja EES-a, te kod značajnijeg uvoza električne energije manje je domaćih elektrana u pogonu pa su i ukupne regulacijske sposobnosti unutar sustava manje. Što su hidrološke okolnosti nepovoljnije manje je raspoložive snage u hidroelektranama koje imaju mogućnost brzog puštanja u pogon i brze promjene tereta. Različiti vozni redovi elektrana utječu na ukupne regulacijske sposobnosti unutar sustava budući da različite elektrane imaju različite karakteristike u pogledu P/f regulacije.

Hidroelektrane mogu vrlo brzo mijenjati svoju snagu u rasponu od 0,06 MW/s do 12,5 MW/s (ekvivalentno 3,6 MW/min do 750 MW/min) promatrajući elektrane kao cjeline. Kada bi sve hidroelektrane bile u pogonu s dovoljnom količinom vode ukupna njihova snaga koju je moguće promijeniti u sekundnom području iznosi oko 24 MW, odnosno 1 455 MW promatrajući u minutnom području.

Brzina promjene angažirane snage termoelektrana je manja i kreće se u rasponu od 0,02 MW/s do 0,32 MW/s za pojedinačne elektrane (1 MW/min do 19,4 MW/min). Sa svim termoelektranama u pogonu bilo bi teoretski moguće promijeniti ukupnu njihovu snagu u iznosu od 1,1 MW/s, odnosno 65,3 MW/min (bez NE Krško).

Ukupna rezerva primarne P/f regulacije unutar EES ovisi o elektranama koje su u pogonu za promatrano pogonsko stanje, te njihovim angažiranim snagama, pa je nije moguće točno i jednoznačno odrediti. Može se pretpostaviti da će unutar EES-a postojati dovoljna rezerva primarne P/f regulacije da korigira sekundne promjene brzine vjetra i izlazne snage VE (koje

cycle unit in the Zagreb Cogeneration Plant – TETO, which can receive the maximum load 15 minutes after a cold start, and the combined cycle units in the Jertovec Combined Gas Cycle Unit and the Osijek Combined Gas Cycle Unit, which can receive the maximum load in 20 minutes, respectively 15 minutes. Problems of an economic nature (the high generation costs of these two thermal power plants) are not considered here.

The total reserve capacity that can be provided for emergency operating conditions in the existing power plants within the framework of tertiary P/f control depends on a series of factors, in the first place on the current operating conditions, which can be defined by the following:

- power plant schedule,
- hydrological circumstances,
- electric power system load, and
- system balance (planned power exchange).

The impact of the upper parameters on the control capabilities within an electric power system is highly significant. With lower loads on the EPS and with significant imports of electric energy, there are fewer domestic power plants in operation and the total control capabilities within the system are lower. The more unfavorable the hydrological circumstances, the less available power there is in the hydroelectric power plants that can be set in operation rapidly and change loads quickly. Different electric power plant schedules have an effect on the total control capacities within the system, since different power plants have different characteristics regarding P/f control.

Hydroelectric power plants can change their power very quickly within a range of from 0,06 MW/s to 12,5 MW/s (equivalently 3,6 MW/min to 750 MW/min), considering the power plant as a whole. If all the hydroelectric power plants were in operation with a sufficient amount of water, their total power which could be changed in a secondary region is approximately 24 MW, respectively 1 455 MW at minute time intervals.

The speed of change in the output power of a thermal power plant is lower and ranges from 0,02 MW/s to 0,32 MW/s for individual electric power plants (1 MW/min to 19,4 MW/min). With all the thermal power plants in operation, it would be theoretically possible to change their total power by the amount of 1,1 MW/s, respectively 65,3 MW/min (not including the Krško Nuclear Power Plant).

The total reserves of the primary P/f control within the electric power system depend upon the power plants that are in operation for the operating conditions under consideration, and their dispatched power, and therefore it is not possible to determine them more precisely and unambiguously. It may be assumed that within the electric power system there su prema svjetskim iskustvima vrlo male), no operator prijenosnog sustava će morati voditi računa o osiguravanju dovoljne rezerve primarne *P/f* regulacije u svakom trenutku.

U sustav automatske sekundarne *P/f* regulacije unutar EES–a RH uključene su tri hidroelektrane:

— HE Zakučac,
— HE Senj, te
— HE Vinodol.

Tablica 9 prikazuje ukupan raspon teoretski moguće snage sekundarne regulacije unutar EES-a Hrvatske ukoliko bi sve tri hidroelektrane uključene u sustav sekundarne regulacije bile u pogonu.

are sufficient reserves of primary *P/f* control to correct the fluctuations in wind velocity at one-second intervals and the power outputs of wind power plants (which are very low, according to experience in other countries). Nonetheless, the transmission system operator will have to take the securing of sufficient reserves of primary *P/f* control into account at every moment.

In the system of automatic secondary *P/f* control within the electric power system of the Republic of Croatia, there are three hydroelectric power plants:

— the Zakučac Hydroelectric Power Plant,
— the Senj Hydroelectric Power Plant, and
— the Vinodol Hydroelectric Power Plant.

Table 9 presents the total range of the theoretically feasible secondary control power within the Croatian electric power system, if all three hydroelectric power plants included in the secondary control system are in operation.

Tablica 9 — Raspon sekundarne P/f regulacije u EES—u RH
Table 9 — Range of secondary P/f control in the EPS of the Republic of Croatia

Elektrana / Power Plant	Raspon sekundarne *P/f* regulacije / Range of secondary *P/f* control	
	po agregatu / per generating unit [MW]	po elektrani / per power plant [MW]
HE / HPP Zakučac	40	160
HE / HPP Senj	37	111
HE / HPP Vinodol	30	90
Ukupno / Total	361	

Tablica 10 prikazuje procjenu ukupnog raspona snage sekundarne regulacije unutar EES-a RH ovisno o godišnjem dobu, a tablica 11 ovisno o dobu dana.

Table 10 presents an estimate of the total range of secondary control power within the electric power system of the Republic of Croatia, depending on the season of the year. Table 11 presents an estimate of the total power range of secondary control within the electric power system of the Republic of Croatia, depending on the time of day.

Tablica 10 — Procjena raspona sekundarne P/f regulacije u EES—u RH ovisno o godišnjem dobu
Table 10 — Estimate of the range of secondary P/f control in the Croatian electric power system, depending upon the season of the year

Elektrana / Power Plant	Raspon sekundarne *P/f* regulacije / Range of secondary *P/f* control			
	Zima / Winter		Ljeto / Summer	
	po agregatu / per generating unit [MW]	po elektrani / per power plant [MW]	po agregatu / per generating unit [MW]	po elektrani / per power plant [MW]
HE / HPP Zakučac	40	160	40	80
HE / HPP Senj	—	—	37	111
HE / HPP Vinodol	30	90	30	90
Ukupno / Total	150		281	

Tablica 11 — Procjena raspona sekundarne P/f regulacije u EES—u RH ovisno o dobu dana
Table 11 — Estimate of the range of secondary P/f control in the Croatian electric power system, depending on the time of day

Elektrana / Power Plant	Raspon sekundarne *P/f* regulacije / Range of secondary *P/f* control			
	Zima / Winter		Ljeto / Summer	
	Dan / Day [MW]	Noć / Night [MW]	Dan / Day [MW]	Noć / Night [MW]
HE / HPP Zakučac	160	—	80	—
HE / HPP Senj	—	—	37	—
HE / HPP Vinodol	90	90	90	90
Ukupno / Total	150 MW dan / day / 90 MW noć / night		207 MW dan / day / 90 MW noć / night	

Teoretski je moguće u hrvatskom EES-u osigurati ukupno maksimalno 361 MW snage sekundarne regulacije ukoliko bi sve tri hidroelektrane uključene u sustav sekundarne regulacije bile u pogonu, s dovoljnim količinama vode. Realno mogući iznos snage sekundarne regulacije u praksi odstupa od maksimalne vrijednosti ovisno o tome koje su elektrane u pogonu i radnoj točki svakog agregata. Pogon razmatranih hidroelektrana ovisi i o dobu dana, pa su HE Zakučac i HE Senj noću uglavnom izvan pogona, što znači da u sekundarnoj regulaciji tada može sudjelovati samo HE Vinodol što ograničava snagu sekundarne regulacije noću samo na maksimalnih 90 MW. Trenutačna snaga sekundarne regulacije ovisi i o hidrologiji, odnosno promatranom godišnjem dobu. Zbog velikih dotoka vode HE Senj zimi radi u baznom režimu rada te ne sudjeluje u sekundarnoj regulaciji, koju tad osiguravaju samo HE Zakučac i HE Vinodol. Ljeti u situaciji loših hidroloških okolnosti raspoloživa snaga sekundarne regulacije može biti izrazito niska ukoliko nema dovoljno vode za pogon agregata HE Zakučac.

Područje regulacije HE Zakučac nalazi se između 55 MW i 95 MW snage agregata, što znači da je po agregatu teoretski moguće osigurati 40 MW snage sekundarne regulacije, odnosno ukupno 160 MW za elektranu u cjelini. Dispečeri izbjegavaju regulaciju sa sva četiri agregata zbog velikog naprezanja hidromehaničkih sustava tako da regulaciju vrše koristeći dva agregata u rasponu od ±40 MW (ukupan raspon regulacije 80 MW). Važan faktor u određivanju raspoložive snage sekundarne regulacije HE Zakučac su hidrološke okolnosti, budući da je u situacijama bez dovoljno vode (posebno tijekom ljetnih mjeseci) raspoloživa snaga sekundarne regulacije značajno manja (maksimalno ±40 MW ljeti). Osim toga, vodi koja služi za pogon agregata HE Zakučac treba oko 7 sati od akumulacijskog jezera Peruča, odnosno 2 sata iz HE Orlovac da bi došla do agregata HE Zakučac.

In the electric power system of the Republic of Croatia, it is theoretically possible to secure a total maximum of 361 MW of secondary control power if all three hydroelectric power plants included in the secondary control system are in operation, with sufficient amounts of water. The realistically feasible amount of secondary control power deviates in practice from the maximum values, depending on which power plants are in operation and the operating point of each generating unit. The operation of the hydroelectric power plants considered also depends upon the time of day, so that the Zakučac and Senj Hydroelectric Power Plants are usually not in operation during the night, which means that only the Vinodol Hydroelectric Power Plant can participate in secondary control then, which limits the secondary control power at night to only a maximum of 90 MW. The instantaneous secondary control power also depends upon hydrology, i.e. the season of the year considered. Due to great inflows of water, in winter the Senj Hydroelectric Power Plant operates under a basic operating regime and does not participate in secondary control, which then leaves only the Zakučac and Vinodol Hydroelectric Power Plants. In the summer, under poorer hydrological conditions, the available secondary control power can be markedly low if there is not enough water for the operation of the generating unit of the Zakučac Hydroelectric Power Plant.

The control range of the Zakučac Hydroelectric Power Plant is between 55 MW and 95 MW of the power of the generating unit, which means that per generating unit it is theoretically possible to secure 40 MW of secondary control power, or a total of 160 MW for the power plant as a whole. Dispatchers avoid using all four generating units for control at the same time due to great strain upon the hydromechanical systems. Therefore, control is performed using two generating units at a time in a range of ±40 MW (the total control range is 80 MW). An important factor in determining the available secondary control power of the Zakučac Hydroelectric Power Plant is the hydrological conditions, since in situations without sufficient water (especially during the summer months) the available secondary control power is significantly lower (maximum ±40 MW during the summer). Moreover, the water that serves for the operation of the generating units of the Zakučac

Područje regulacije HE Senj nalazi se između 35 MW i 72 MW, što daje ukupan raspon snage sekundarne regulacije od 37 MW po agregatu, odnosno 111 MW ukupno. Turbinski regulatori i sekundarni regulator su ugrađeni prije dvije godine, te su vrlo brzi tako da snaga agregata često prelazi gornju i donju granicu limitera snage (snaga se ponekad kreće između 27 MW i 80 MW po agregatu). Radi toga je namjera osoblja elektrane da raspon sekundarne regulacije ograniči na 40 MW do 66 MW po agregatu. HE Senj je najviše uključena u sekundarnu regulaciju tijekom proljeća i jeseni, te ograničeno tijekom ljeta radi nedostatka vode. Dosadašnja praksa je takva da HE Senj nije stalno uključena u sustav sekundarne regulacije već nalog za uključenje dobiva telefonski iz CDU Pehlin. Zbog bujičastog karaktera voda koje pogone HE Senj ona povremeno radi u baznom režimu rada, a u situacijama lošijih hidroloških prilika uglavnom se koristi za pokrivanje dnevnih maksimuma potrošnje (od 12 do 14 h, te od 18 do 22 h) dok je noću izvan pogona. Voda od akumulacijskog jezera Kosinj do HE Senj putuje oko 3 sata.

Područje regulacije HE Vinodol nalazi se između 0 MW i 30 MW po agregatu (ukupno 90 MW), a elektrana je stalno uključena u sustav sekundarne regulacije ili se koristi kao rotirajuća rezerva (radi u praznom hodu). Turbinski regulatori su ugrađeni 2003. godine. Bazna snaga iznosi 5 MW. HE Vinodol je u pogonu oko 7 500 h godišnje, ali proizvodnja električne energije je vrlo mala. Zahtjevi za pokrivanjem baznog opterećenja stižu iznimno rijetko. HE Vinodol je u pogonu tijekom dana i noći, a u 7. mjesecu kad su najmanje vode obično se obavlja remont hidroelektrane.

Na temelju svega izloženog možemo zaključiti da raspon sekundarne regulacije u EES-u RH ovisi o više faktora:

- dobu dana,
- godišnjem dobu,
- hidrologiji i voznom redu elektrana,
- radnoj točci i režimima rada generatora HE Senj i HE Zakučac.

Prema trenutačnoj dispečerskoj praksi moguće je osigurati u EES-u između 90 MW i 280 MW snage sekundarne regulacije, ovisno o gornjim faktorima.

Hydroelectric Power Plant requires approximately 7 hours from the Peruča Reservoir, respectively 2 hours from the Orlovac Hydroelectric Power Plant, in order to arrive at the Zakučac Hydroelectric Power Plant generating units.

The control range of the Senj Hydroelectric Power Pant is between 35 MW and 72 MW, which yields a total secondary control power range of 37 MW per generating unit, or a total of 111 MW. The speed governors and secondary regulators were installed two years ago, and are very fast so that the generating unit power often exceeds the upper and lower levels of the power limiter (the power sometimes ranges between 27 MW and 80 MW per generating unit). Therefore, it is the intention of the power plant personnel to limit the range of the secondary control at 40 MW to 66 MW per generating unit. The Senj Hydroelectric Power Plant is mostly included in secondary control during the spring and autumn, and is limited during the summer due to a shortage of water. The practice to date has been that the Senj Hydroelectric Power Plant is not constantly included in the secondary control system but the order for inclusion is obtained by telephone from the Pehlin Remote Control Center. Due to the turbulent character of the water that supplies the Senj Hydroelectric Power Plant, it occasionally operates in the basic operating regime Under poor hydrological conditions, it is mainly used for covering the maximum daily consumption (from 12 noon to 2 p.m., and from 6 to 10 p.m.), while it is not in operation during the night. Water from the Kosinj Reservoir flows approximately 3 hours to the Senj Hydroelectric Power Plant.

The control range of the Vinodol Hydroelectric Power Plant is between 0 MW and 30 MW per generating unit (a total of 90 MW), and the power plant is constantly included in the secondary control system or is used as a spinning reserve (no—load operation). The speed governors were installed in the year 2003. The base power is 5 MW. The Vinodol Hydroelectric Power Plant is in operation for approximately 7 500 h/year, but its generation of electrical energy is very low. Orders for coverage of the base load arrive very rarely. The Vinodol Hydroelectric Power Plant is in operation during the day and night, and in the month of July when there is the least water, the plant is usually overhauled.

On the basis of everything that has been presented, we can conclude that the range of secondary control in the electric power system of the Republic of Croatia depends upon several factors:

- the time of day,
- the season of the year,
- the hydrology and schedule of the power plant,
- the operating points and operating regimes of the generators of the Senj Hydroelectric

Power Plant and the Zakučac Hydroelectric Power Plant.

Raspoloživa snaga tercijarne regulacije ovisi prvenstveno o voznom redu elektrana i radnim točkama agregata. Na temelju podataka o angažmanima agregata tijekom 2005. godine zaključujemo da je moguće osigurati određenu snagu tercijarne regulacije u iznosu od nekoliko stotina megavati (ovisno o voznom redu elektrana) prvenstveno u sljedećim elektranama:

— sve hidroelektrane ukoliko ima dovoljno vode,
— TE Rijeka ako je u pogonu,
— TE Sisak ako je u pogonu,
— KTE Jertovec,
— PTE Osijek.

5.3 Procjena mogućnosti prihvata vjetroelektrana s aspekta *P/f* regulacije

Na temelju prethodnih analiza karakteristika vjetra na najvjerojatnijim lokacijama VE i procijenjenih regulacijskih sposobnosti EES-a možemo zaključiti sljedeće:

— ne očekuju se velike promjene kretanja snage VE u sekundnom i minutnom području, ali operator prijenosnog sustava mora pri izradi voznog reda osigurati dovoljnu snagu primarne regulacije da pokriva te promjene,
— u 15-minutnoj i satnoj vremenskoj domeni moguće su rijetke promjene izlazne snage VE do najviše 50 % instalirane snage u svim VE, pa operator prijenosnog sustava mora osigurati adekvatnu snagu sekundarne i tercijarne regulacije radi pokrivanja tih promjena,
— unutar hrvatskog EES-a trenutačno se može maksimalno osigurati između 90 MW i 280 MW snage sekundarne regulacije. Od toga je potrebno 78 MW rezervirati kao ispomoć UCTE–u, pa preostaje maksimalno 200 MW raspoložive regulacije. S obzirom da je prema dostupnim podacima i provedenim analizama satna promjena proizvodnje VE varira do 50 % njihove instalirane snage, očito je da 200 MW regulacijske snage može podržati 400 MW instalirane snage VE. Međutim, potrebno je uzeti u obzir i odstupanja ostvarenih od planiranih vrijednosti opterećenja. Prema dosadašnjem iskustvu ta odstupanja iznose do 40 MW (ili 2 % od trenutačnog opterećenja). Ako uzimamo u obzir i grešku pri prognozi opterećenja, jasno je da ukupna raspoloživa regulacijska snaga iznosi okvirno između 150 MW i 200 MW,

According to the current dispatcher's practice, it is possible to secure between 90 MW and 280 MW of secondary control power in the electric power system, depending on the above factors.

The power available for tertiary control depends primarily on the power plant schedule and the operating points of the generating units. Based upon data on generating units operation during the year 2005, we conclude that it is possible to secure tertiary control power in the amount of several hundred MW (depending on the power plant schedule), primarily at the following power plants:

— all the hydroelectric power plants, if there is sufficient water,
— the Rijeka Thermal Power Plant, if it is in operation,
— the Sisak Thermal Power Plant, if it is in operation,
— the Jertovec Combined Cycle Unit,
— the Osijek Combined Cycle Gas Unit.

5.3 Assessment of the possibilities for integrating wind power plants from the aspect of *P/f* control

Based upon the previous analyses of the characteristics of the wind at the most likely locations for wind power plants and the assessed control capabilities of the electric power system, we can conclude the following:

— major changes are not expected in the power fluctuations of the WPPs at second and minute intervals. However, the transmission system operator must secure sufficient primary control power to cover these changes when preparing the schedule,
— in 15-minute and hourly temporal domains, infrequent fluctuations in the power output of WPPs are possible of up to a maximum of 50 % of the installed capacity in all the wind power plants, so that the transmission system operator must secure adequate secondary and tertiary control power to cover these changes,
— within the Croatian electric power system, it is currently possible to secure a maximum of between 90 MW and 280 MW of secondary control power. Of this, 78 MW must be reserved for the UCTE, and thus a maximum of 200 MW of available control remain. Since the hourly fluctuations in the generation of WPPs vary by up to 50 % of their installed capacity according to the available data and analyses conducted, it is evident that 200 MW of control power can support 400 MW of WPP installed capacity. However, it is necessary to take deviations from the planned load values into account. According to past experience, this deviation is up to 40 MW (or 2 % of the instantaneous load). If we take the error in load forecasting into account, it is clear that the total available

odnosno da dozvoljena instalirana snaga VE trenutačno iznosi između 300 MW i 400 MW,

- budući da su velike 15-minutne i satne varijacije snaga VE rijetki događaji, te s obzirom da sustav ne raspolaže dovoljnom rezervom sekundarne regulacije u svakom trenutku tijekom godine, nužno je HEP OPS zakonski dati ovlasti da isključuje ili smanjuje angažman VE kada je ugrožena pogonska sigurnost,
- kritični pogonski događaji vezani za prihvat proizvodnje VE očekuju se u ljetnim noćnim satima kada je opterećenje EES-a nisko, hidrološke okolnosti loše, a angažman i raspoloživost konvencionalnih elektrana smanjena,
- budući da je moguće tehnički ograničiti maksimalnu promjenu snage VE naviše, dok nije moguće regulirati snagu VE pri smanjenju brzine vjetra, radne točke agregata koji sudjeluju u sekundarnoj regulaciji potrebno je postavljati u blizinu minimalnih vrijednosti područja sekundarne regulacije (HE Zakučac 55 MW za svaki agregat u pogonu, HE Senj 35 MW po agregatu, HE Vinodol 5 MW po svakom agregatu), kako bi se osiguralo dovoljno povećanje proizvodnje hidroelektrana kod istodobnog smanjenja proizvodnje VE,
- u dnevnoj domeni moguće su promjene snage VE u iznosu od 0 MW do $P_{\mathrm{WPP\ ins}}$, što znači da HEP OPS mora imati na raspolaganju odgovarajuću snagu u proizvodnim jedinicama koje mogu relativno brzo ući ili izaći iz pogona,
- regulacija snage i frekvencije unutar elektroenergetskog sustava zbog priključka VE na sustav izaziva povećanje troškova vođenja sustava, pa je potrebno odrediti načine pokrivanja tih troškova.

5.4 Procjena mogućnosti prihvata vjetroelektrana s aspekta *Q/U* regulacije

Regulacija napona i jalove snage unutar EES-a Hrvatske obavlja se koristeći sinkrone generatore, mrežne transformatore s automatskom regulacijom prijenosnog omjera, te kondenzatorske baterije i prigušnice najčešće priključene na tercijare mrežnih transformatora. Dosadašnja višegodišnja iskustva govore da su mogućnosti regulacije napona i jalove snage u EES vrlo ograničene. Veći problemi postoje s previsokim naponima u mreži, kada zbog slabo opterećenih dugačkih dalekovoda 400 kV pri nižim opterećenjima u sustavu dolazi do povišenja napona u mreži 400 kV i 220 kV. Smanjenje

control power is roughly between 150 MW and 200 MW, i.e. the allowed installed capacity of the wind power plants is currently between 300 MW and 400 MW,

- since major 15-minute and hourly fluctuations in the output of WPPs are rare events, and since the system does not have sufficient secondary control available at every moment during the year, the HEP Transmission System Operator should be given legal authorization to stop or reduce the operation of WPPs when system security is threatened,
- critical operational events connected with the integration of wind power plant generation are anticipated during the summer night hours, when the electric power system load is low, the hydrological conditions are poor, and the operation and availability of conventional electric power plants is reduced,
- since it is possible to limit the maximum fluctuation in the power of WPPs upward, while it is not possible to control the power of WPPs when wind velocity is low, the operating points of the generating units that participate in secondary control must be set in the vicinity of the minimum values of the area of secondary control (the Zakučac Hydroelectric Power Plant – 55 MW per generating unit in operation, the Senj Hydroelectric Power Plant – 35 MW per generating unit and the Vinodol Hydroelectric Power Plant – 5 MW per generating unit), in order to secure a sufficient increase in the generation of the hydroelectric power plants with the simultaneous reduction in the generation of the wind power plants,
- in the daily domain, fluctuations in the power of a WPP in the amount of from 0 MW to $P_{\mathrm{WPP\ ins}}$ are possible, which means that the HEP Transmission System Operator must have the corresponding power available at the generating units that can go in or out of operation relatively quickly,
- due to the integration of WPPs into the system, the control of power and frequency within the power system causes the costs of ancillary system services to rise. Therefore, it is necessary to determine ways to cover these costs.

5.4 Assessment of the possibilities for integrating wind power plants from the aspect of *Q/U* control

Control of the voltage and reactive power within the electric power system of Croatia is performed using synchronous generators, network transformers with automatic control of the turns ratio, shunt capacitors and inductors most frequently connected to the tertiary windings of network transformers. Many years of experience indicate that the possibilities for the control of voltage and reactive power in electric power systems are very limited. There is a greater problem with exnapona se ograničeno može postići koristeći generator NE Krško u poduzbudi, te generatore RHE Velebit u kompenzacijskom režimu rada.

Priključkom VE na mrežu 110 kV ne bi se smjelo nepovoljno odraziti na naponske prilike u njoj. Nepovoljna okolnost je što će se većina VE iz razmatranog scenarija njihove izgradnje sagraditi unutar južnog dijela EES—a gdje je problem previsokih napona najizraženiji. Zato je potrebno da VE imaju mogućnost proizvodnje jalove snage i automatske regulacije napona na priključnim 110 kV sabirnicama VE u određenom opsegu od kapacitivnog do induktivnog područja (barem od 0,95 kap. do 0,95 ind.).

Ispitivanja na modelu pokazuju da ukoliko bi VE bile angažirane s nultom proizvodnjom jalove snage naponi u priključnim čvorištima bi u analiziranim pogonskim stanjima rasli od 0,3 kV do 4,4 kV, što je nepovoljno u situacijama kada su naponi u mreži visoki i bez VE, pa njihov priključak dodatno može povisiti napone iznad dozvoljenih granica.

6 PROCJENA MOGUĆNOSTI PRIHVATA VJETROELEKTRANA U EES-u HRVATSKE U KRATKOROČNOM RAZDOBLJU

Na temelju analiza opisanih u prethodnim poglavljima možemo procijeniti ukupnu instaliranu snagu VE koju današnji elektroenergetski sustav može prihvatiti bez većih posljedica po sigurnost pogona i napajanje potrošača. Ta je snaga određena polazeći od današnjih spoznaja o lokacijama i snagama VE planiranih za izgradnju, evakuacijskih sposobnosti prijenosne mreže, procijenjenim karakteristikama kretanja snage VE, te regulacijskih sposobnosti EES-a. Procjena iznosi:

— instalirana snaga VE u najvjerojatnijem scenariju izgradnje: 1 560,5 MW,
— dozvoljena snaga VE s obzirom na izgrađenost i evakuacijske sposobnosti prijenosne mreže: 923,5 MW,
— dozvoljena snaga VE s obzirom na regulacijske sposobnosti postojećih elektrana unutar EES—a: 300 MW do 400 MW.

Procjenjuje se da je u sadašnjem trenutku moguće na sustav priključiti VE u rasponu od 300 MW do 400 MW ukupne instalirane snage. Procjena se temelji na pretpostavci da

cessively high voltages in the network when the 400 kV transmission—lines loading and the system load are low, leading to voltage increases in the networks 400 kV and 220 kV. It is possible to achieve a limited reduction in voltage by using the generator of the Krško Nuclear Power Plant in the under excitation regime and the generators of the Velebit Reversible Hydroelectric Power Plant in a compensatory regime.

The integration of wind power plants into a network 110 kV should not have an unfavorable effect on its voltage conditions. Unfortunately, the majority of the WPPs from the scenario being studied will be constructed within the southern part of the electric power system, where the problem of excessively high voltage is the most marked. Therefore, it is necessary for the WPPs to be able to produce reactive power and automatic voltage control at the connections to the 110 kV busbars of the wind power plants in a specific range from the capacitive to the inductive region (at least 0,95 cap. to 0,95 ind.).

Studies on the model show that if WPPs were operating at a power factor of 1, the voltages at the connection nodes in the analyzed operational states would increase from 0,3 kV to 4,4 kV, which is undesirable in situations when the voltages in the network are even high without the WPPs, so that their integration could additionally increase the voltages over the allowed limits.

6 ASSESSMENT OF THE POSSIBILITIES FOR INTEGRATING WIND POWER PLANTS INTO THE CROATIAN ELECTRIC POWER SYSTEM IN THE NEAR FUTURE

Based upon the analyses described in the previous chapters, we can estimate the total installed capacity of the WPPs that the present power system can integrate without major consequences to the security of operations and customer supply. This power is determined according to present knowledge of the locations and the power of the planned WPPs, the transmission network capacity, the assessed power fluctuations characteristics of the WPPs and the control capabilities of the electric power system, as follows:

— installed capacity of the wind power plants in the most likely construction scenario: 1 560,5 MW
— the allowed power of the WPPs, regarding the level of construction and capacity of the transmission network: 923,5 MW
— the allowed power of WPPs, regarding the control capabilities of the existing power plants within the EPS: 300 MW – 400 MW.

It is estimated that at the moment it is possible to integrate WPPs into the system in a range of from 300 MW će iste biti prostorno disperzirane, što znači veći broj manjih jedinica. U slučaju izgradnje dvije ili tri VE velikih snaga (>100 MW) sigurnost pogona mogla bi biti narušena radi velikih oscilacija u izlaznoj snazi VE.

7 ZAKLJUČAK

Na temelju provedenih analiza može se zaključiti sljedeće:

- sustav mora biti u svakom trenutku sposoban omogućiti sekundarnu i tercijarnu *P/f* regulaciju u najmanjem iznosu od oko 50 % instalirane snage svih VE (ne uzimajući ovom procjenom u obzir potrebnu rezervu radi varijacija opterećenja u sustavu i obveza prema UCTE),
- sustav mora biti sposoban pružiti dnevnu (24 h), međudnevnu (48 h) i mjesečnu rezervu do pune instalirane snage VE,
- velike oscilacije snage proizvodnje VE izrazito su stohastičkog karaktera i događaju se rijetko, tako da će iskorištenje snage sekundarne i tercijarne regulacije u sustavu radi varijacija proizvodnje VE biti malo,
- potrebe za primarnom regulacijom unutar sustava nije moguće ovom prilikom procijeniti jer nisu poznate promjene brzine vjetra i kretanja snaga VE u sekundnom i minutnom području.

Na temelju svega izloženog može se zaključiti da raspon sekundarne regulacije u EES-u RH ovisi o više faktora:

- dobu dana,
- godišnjem dobu,
- hidrologiji i voznom redu elektrana,
- radnoj točci i režimima rada generatora HE Senj i HE Zakučac.

Prema trenutačnoj dispečerskoj praksi moguće je osigurati u EES-u između 90 MW i 280 MW snage sekundarne regulacije, ovisno o gornjim faktorima.

Usprkos ograničenju u instaliranoj snazi VE koju sustav može u ovom trenutku prihvatiti, nužno je zakonski dati HEP OPS-u ovlasti da trenutačno isključuje VE kada je pogonska sigurnost ugrožena.

Predloženih 300 MW do 400 MW podrazumijeva instaliranu snagu VE koju hrvatski elektroenergetski sustav može danas prihvatiti, a da sigurnost pogona sustava bude zadovoljavajuća. Međutim, jasno je da razvoj,

to 400 MW of total installed capacity. This estimate is based upon the assumptions that the WPPs will be spatially dispersed, i.e. a large number of small units. In the event of the construction of two or three wind power plants with high installed capacities (>100 MW), operational security can be endangered due to great fluctuations in the power output of the WPPs.

7 CONCLUSION

Based upon the analyses performed, the following can be concluded:

- at every moment, the system must be capable of facilitating a minimum secondary and tertiary *P/f* control of approximately 50 % of the installed capacity of all the WPPs (not taking into account the necessary reserve due to load variations in the system and obligations toward the UCTE),
- the system must be capable of providing 24-hour, 48-hour and monthly reserves up to the full installed capacity of the WPPs,
- great fluctuations in the output of WPPs are of a markedly stochastic character and rarely occur, so that the utilization of secondary and tertiary control power in the system due to fluctuations in the wind power plant output will be low,
- the requirements for primary control within the system cannot be evaluated on this occasion because the fluctuations in wind velocity and the power output of the WPPs at second and minute intervals are unknown.

On the basis of everything that has been presented, it can be concluded that the range of secondary control in the electric power system of the Republic of Croatia depends upon several factors:

- the time of day,
- the season of the year,
- the hydrology and the power plant schedule, and
- the operating points and operating regimes of the generators of the Senj and Zakučac Hydroelectric Power Plants.

According to current dispatcher practice, it is possible to secure between 90 MW and 280 MW of secondary control power in the EPS, depending upon the above factors.

Despite the limited installed capacity of the WPPs that the system can accept at the moment, it is necessary for the HEP Transmission System Operator (HEP OPS) to be given legal authorization to disconnect WPPs instantaneously when operating security is endangered.

The proposed 300 MW to 400 MW are understood as the installed capacity of the WPPs that the Croatian electric power system can integrate today, while mainizgradnja i revitalizacija prijenosne mreže, te proizvodnih objekata mogu značajno utjecati na rezultate ovakve analize.

Na temelju svega navedenog jasno je da će se u srednjoročnom razdoblju javiti potreba za ponovnom detaljnom analizom i revizijom dobivenih rezultata. Do tada autori preporučuju sljedeće aktivnosti koje mogu utjecati na lakšu integraciju VE u sustav:

— uvođenje kvalitetne prognoze proizvodnje VE za razdoblje do barem 48 sati,
— uvođenje naknada za pružanje pomoćnih usluga sustavu,
— uključivanje većeg broja elektrana u sekundarnu *P/f* regulaciju,
— modernizaciju sustava vođenja,
— edukaciju i obuku ljudi uključenih u integraciju VE u sustav.

taining a satisfactory level of operating security. However, it is clear that the development, construction and revitalization of the transmission network and generation facilities can significantly affect the results of such analysis.

On the basis of the aforementioned, it is clear that the need will arise in the medium-range period for repeated detailed analyses and revisions of the results obtained. Until then, the authors recommend the following activities that can facilitate the integration of WPPs into the system:

— the introduction of quality forecasts of the generation output of wind power plants for a period of at least 48 hours,
— the introduction of financial compensation for providing ancillary system services,
— the integration of a larger number of power plants into secondary *P/f* control,
— the modernization of the dispatching center, and
— the education and training of the personnel involved in the integration of WPPs into the system.

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