Specifics of Integration of Wind Power Plants into the Croatian Transmission Network

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ABSTRACT

Increasing number and power of wind turbines that form wind power plant have overgrown connection to the distribution network a long time ago. Because of their considerable installed capacity, connection of wind power plants to the transmission network is a common practice today. However, large wind power plants require increased capacity of the transmission network. The problem with investments into the transmission network capacity is that it will be fully utilized only on rare occasions. This makes the investments in power lines reinforcement economically questionable. The transmission network capacity problems get worse when several large wind power plants are connected to the transmission network in the same node and have almost simultaneous peaks in production.

The objective of this paper is to provide an insight in the issues of large-scale wind power plant connection to the transmission grid in Croatia. An accurate and detailed model for assessing power flows and voltage levels has been developed as a result of many projects involving wind power plant connections to the Croatian transmission network. It addresses problems of large-scale wind power plants integration into the Croatian transmission network and proposes solutions acceptable for both the investors and the Transmission System Operator.

INTRODUCTION

In the last two decades wind power is experiencing an almost exponential growth. In 2009 the global installed wind power capacity reached 159 GW, and it showed a growth rate of 31,7%, which is even more than the growth rate of 28,7% from the previous year [1]. China and USA have established themselves as the leaders in wind power technology, with installed capacity of 35 and 26 GW respectively. Leading European country is Germany with over 25 GW of wind power capacity installed [2].

The installed capacity of wind power plants operating in Croatia is 88 MW, most of which is connected to the distribution grid. This makes around 2% of overall installed capacity in Croatia, which is approximately 4000 MW. Therefore, the wind penetration in Croatia is much lower than in most developed European countries. For instance, Denmark had 3124 MW of installed capacity in wind power plants in 2007, which makes more than 24% of overall installed capacity of 12969 MW [3].

Extensive wind power utilization causes problems in power systems which have not been thoroughly prepared for large wind power plants integration. Since the permits for wind power plants locations are not issued centrally and unanimously, the transmission system planning is facing new uncertainties. Private investors are generally not interested in the transmission system stability and other problems in the TSO domain [4].

This paper recognizes several problems and proposes solutions for higher wind power plant penetration into Croatian electric power system. The contributions of the paper are following:

- feasibility assessment of the connection cost for the wind power plant projects,
- detailed and accurate analysis of technical requirements for wind power integration, definition of worst-case scenarios and recognizing specifics for WPP integration in Croatia,
- inclusion of energy buffer, e.g. reversible hydro power plant, as a potential wind energy storage,

The rest of the paper is organized as follows. In Section II, a regulative policy considering connection for wind power plants in Croatia is presented, as well as the specifics of the Croatian transmission network. Problems in realization of these projects are noted, and the solutions are proposed. Section III describes the model used for calculations. The results of both current situation and proposed solution are presented in Section IV. Finally, concluding remarks are drawn in Section V.

WIND POWER PLANT CONNECTION

Current electricity production and consumption facts

Croatian transmission system has a rather unique and distinctive topology which sometimes makes the power flow control demanding. Thermal power units make almost half of the installed capacity in Croatia and majority of them is located in the central north part of the country. In contrast, almost all hydro power plants are situated in the southern part of the country, near the Adriatic Sea.

Besides modelling electricity generation, it is important to distinguish details on electricity consumption. The existing industry is located mainly in the central northern part of Croatia, near the large thermal power plants. In contrary, the coastal part of Croatia is less industrialized, but the tourism is developing in this area and it has a strong potential for further development. The tourism has an unfavourable impact on the Croatian power system since it is a seasonal activity which results in extremely high electricity demand in the summer and extremely low electricity consumption during winter months. The outcome of the extreme electricity consumption during tourist season, as opposed to very low out-of-season electricity consumption is 5 to 6 times lower peak demand in winter periods than during the summer. Such seasonal load curves affect power flows, which are substantially different during tourist season in respect to the winter period. Hence, during the winter, power flows are directed from the south to the north, as opposed to the summer power flows, which are directed from the north to the south of Croatia. Because of relatively small loads, long overhead lines and lack of thermal power plants, the voltage levels in southern Croatia vary a lot. Without any rigor definition this type of network is referred to as the “weak grid” [5].

In the future, it is expected that the difference in winter and summer loads will be even greater. In the coastal (southern) part of Croatia, electricity is still used for household heating but currents trend suggests that the majority of households will use gas for heating in the future. This will even more increase the gap between the winter and summer electricity consumption.

Wind power plant connection problems

The locations suitable for wind energy exploitations in Croatia are exclusively located in the southern part of Croatia, as indicated in Figure 1, which lays the problem of evacuating large amounts of electricity from southern to the northern part of Croatia. In addition, if large river inflows in southern Croatia coincide with favourable wind speeds, which keep the output of wind power plants at maximal level, the problem of power evacuation is even more emphasised [6].

Figure 1. Potential locations for future WPP

Investors have recognized incentives of approximately 0,088 €/kWh guaranteed over a 12 years period [7] and several studies have shown this guarantees a return rate for the wind power plant projects in the period of 5 to 7 years. Croatian National Energy Strategy therefore relies on wind energy to be the driving force in achieving EU set goals for renewable energy targets with projected 1200 MW of installed wind capacity by the year 2020 [8]. The Strategy however does not specify how or where those wind power plants should be connected to the transmission grid. To achieve this goal, a great deal of high-end organization and planning is required having in mind the conditions of non-discriminatory access to the transmission network to all potential investors.

An important element in the 2001/77/EC Directive [9] is the requirement of transparent, non-discriminating connection tariffs. At the moment, mainly two types of connection costs are used, i.e. shallow and deep connection costs. With shallow costs the investor only finances the physical connection to the grid while the possible grid reinforcements financing is attributed to the system operator. The system operator then includes these investments in the transmission network tariffs. The lack of this system is the necessity to establish some sort of use-of-system tariff by which the system operator would then charge the usage of the grid to power producers. This can be categorized as flat rate or flow based [10].

With deep connection cost, on the other hand, the investor is obliged to pay for the connection costs plus all the grid investments determined by an independent preliminary analysis. This is the connecting policy applied in Croatia [**7**]. This means that if a wind power plant did not cause any disturbances and reinforcements were not needed, the next investor whose plant is causing congestion is obligated to pay for the full investment even though its load flow share through a congested line is modest. This way a connected generator pays a proportional cost based on its own power rating. Despite the fact deep connection cost is generally considered as more discriminatory; only four EU member states have implemented the shallow connection cost policy (Belgium, the Netherlands, Germany and Denmark) [11-14]. An alternative which preserves transparency and is non-discriminating is the use of mixed charges [15].

Wind power plant connection case study

The case study presents the connection costs of five wind power plants (WPP) in case of deep connection cost policy and in case of the proposed mixed connection cost policy. In order to connect all five WPPs to the existing transmission network, new transmission lines have to be constructed, with additional reinforcement of some of the existing transmission lines, as shown in Figure 2. Table 1 provides grid reinforcement cost for each WPP. The first WPP being connected to the transmission network is ZD-6 and its owners must finance the line ZD-6 – Gračac. Other WPPs owners, ZD-6 2, Otrić 1 and Otrić 2 have to finance only their connection cost to the existing network, which now includes the ZD-6 bus. These costs can be neglected because of the vicinity of these four WPPs. The last WPP which should be connected to the transmission network is WPP Vučipolje. Its transmission network connection point is in the middle of overhead line ZD-6 – Gračac. Because of its significant capacity, the overhead line Vučipolje – Gračac is congested if all WPPs operate near its installed capacity. Therefore, the line Vučipolje – Gračac needs to be reinforced with additional power line and the owner of WPP Vučipolje should finance this reinforcement. Additionally, after connection of WPP Vučipolje, the line Gračac – Obrovac is also congested during favourable wind speeds and the owner of WPP Vučipolje should finance this reinforcement as well.

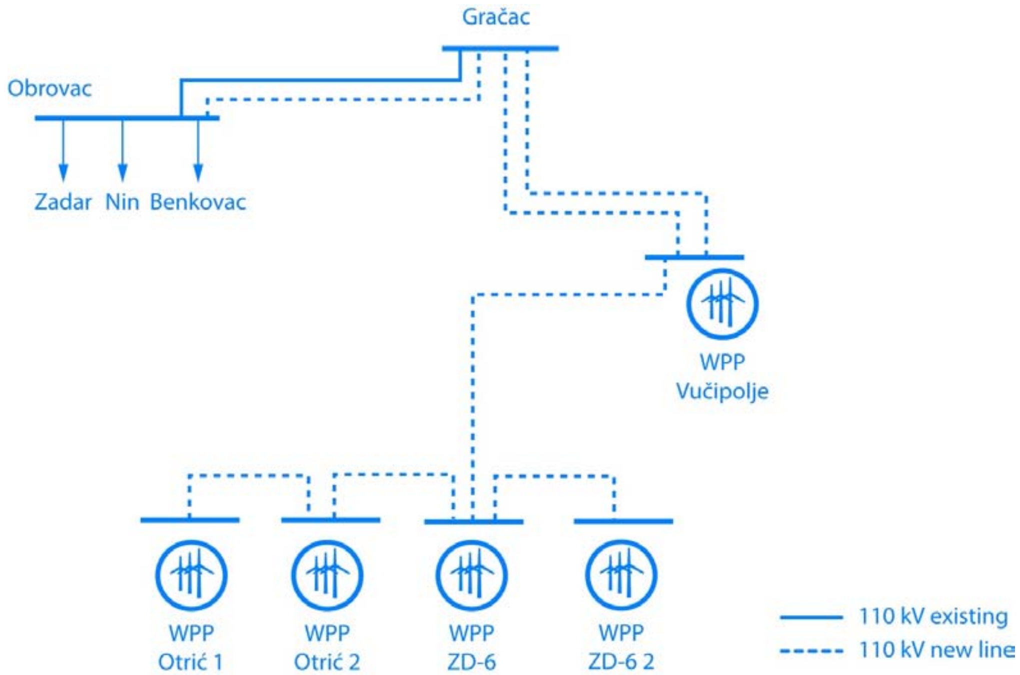

Figure 2. Reinforced part of the 110 kV transmission network

Table 1. Connection cost for each investor under current connection cost policy in Croatia

WPP	Capacity (MW)	Action	Cost (€)
ZD-6	9	110 kV overhead line Velika Popina – Gračac (17,8 km x 90.000 €/km)	1.600.000
		Overall	**1.600.000**
ZD-6 2	39	**Overall**	**0**
Otrić 1	40	**Overall**	**0**
Otrić 2	20,7	**Overall**	**0**
Vučipolje	82	2 x 110 kV overhead line Vučipolje – Gračac (reinforcement of existing 110 kV line 8,8 km x 110 €/km)	968.000
		2 x 110 kV overhead line Gračac – Obrovac (reinforcement of existing 110 kV line 21,3 km x 110 €/km)	2.343.000
		Overall	**3.311.000**

If mixed connection cost policy is applied all the necessary transmission network reinforcements are proportionally financed by all WPPs that use it. In this case study, the overall transmission network reinforcement cost is issued to 4.911.000 €, which should be divided among investors according to their installed capacity, as shown in the Table 2. It is important to note that the cost of 110/X kV transformer station is not taken into consideration in both tables. Comparison of connection costs for each WPP in both cases is shown in Figure 3. Figure 3 shows that implementing a new connection policy, mixed connection cost, would be less discriminatory for investors. By applying the proposed policy, investors are stimulated to merge and make joint investments. The authors believe this would stimulate potential projects and speed up the grid integration process.

Table 2. Connection cost for each investor if mixed connection cost policy is applied

WPP	Capacity (MW)	Action	Cost (€)
ZD-6	9	Allocated transmission network reinforcement cost	231.770
		Overall	**231.770**
ZD-6-2	39	Allocated transmission network reinforcement cost	1.004.350
		Overall	**1.004.350**
Otrić 1	40	Allocated transmission network reinforcement cost	1.030.100
		Overall	**1.030.100**
Otrić 2	20,7	Allocated transmission network reinforcement cost	533.080
		Overall	**533.080**
Vučipolje	82	Allocated transmission network reinforcement cost	2.111.700
		Overall	**2.111.700**

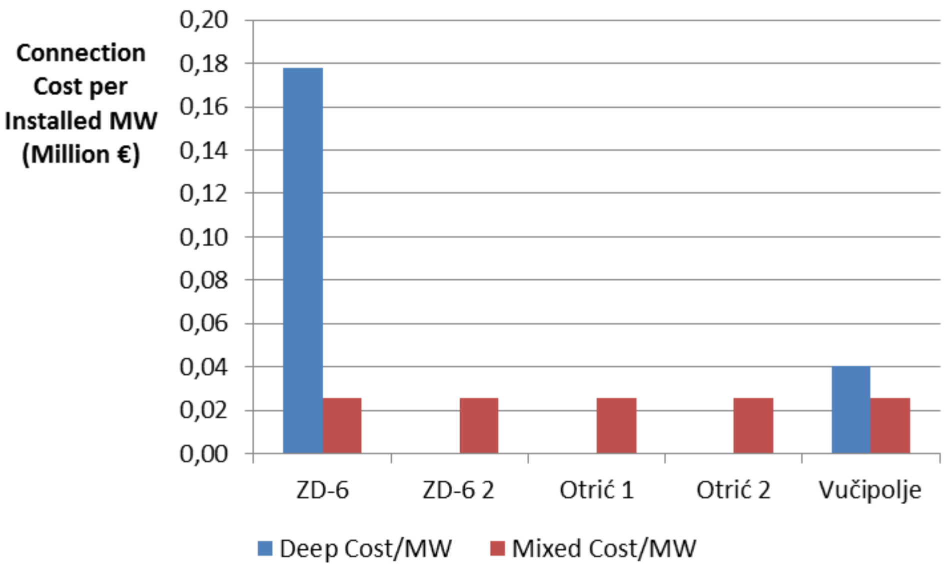

Figure 3. Comparison of connection costs in both cases

WPP connection analysis procedure

In Croatia, common practice was to analyse the influence of the future power plant on the transmission grid, without the impact of other power plants which might be built in the vicinity. Since the required analyses are obligatory for wind power investors, they have no direct interest to include other wind power plants in the assessments, besides their own. Furthermore, by not including other influential power plants in the assessments, preliminary studies will show no problems with the new wind farms connection to the grid. Since they are all not connected at the same time, the one connecting later would often face unpredicted expenses (caused by the congestion or short circuit problems in the grid).

The proposed model for connecting new wind power plants is taking into account all the potential WPPs in the surrounding transmission grid. With all the potential capacities included, both TSO and the investors gain more accurate perspective of potential future problems and investments. As stated in [2]: “In order to properly assess the scope of integration of wind power, a system-wide approach should be adopted. Wind cannot be analysed in isolation from other parts of the power system - and all systems differ. The size and inherent flexibility of the power system are crucial aspects in determining the system’s ability to accommodate a high share of wind power”. The proposed model and conclusions from analyses are presented in Section III.

The Croatian National Energy Strategy proposes several different scenarios for future generation mix, and in each of the scenarios, the goal of 1200 MW of installed wind power in Croatia is emphasised [8].

The most relevant document for wind power plant integration into the Croatian electric system is [16]. A detailed research presented in that project also sets several targets for future analyses:

- The presented study makes analyses for each connection node separately, not taking into account other power plants in vicinity.
- The project does not make any future transmission grid planning. It examines the current state of the transmission grid and investigates how much electric power can be injected into the current Croatian transmission grid in each node.

- The study concludes that total wind power which can be integrated into present Croatian transmission system is 923 MW. On the other hand, it raises the question of variable production from wind and makes a conclusion that, due to limited possibilities or secondary regulation, maximal power from wind in the year 2006is between 300 and 400 MW. Croatian TSO, referencing itself on the mentioned project, does not issue permits for new wind power plants after the 360 MW limit has been reached.

LARGE WIND INTEGRATION IN THE CROATIAN TRANSMISSION GRID

For the purpose of the analysis, the entire Croatian transmission network is simulated and analysed. Croatian transmission system consists of six 400/X kV substations, thirteen 220/X kV substations and 106 110/X kV substations. Transmission grid consists of 1159 km of 400 kV lines, 1144 km of 220 kV line and 4634 km of 110 kV lines. To model the transmission grid adequately the latest data from Croatian TSO annual report was used. Several static states were selected to check the accuracy of the created model, ranging from maximum winter load peak in 2009, maximal winter load peak in 2010 and high hydrology case based on real scenario in the spring of 2010. Data on all power plants, thermal and hydro, and all concurrent load data at 110 kV level were exported from Croatian TSOs Energy Management System. The load flows calculation results obtained from the calculation were compared to the real ones. The model was found to be extremely accurate. Short circuit calculation was also conducted and the results were compared to the measured short circuit currents and to an independent study [17]. High accuracy of the model was confirmed again**.**

Predicting and evaluating connection points for wind power plants has been a research topic in [18, 19]. These two papers present a multi-objective approach to assessing value and influence of connecting wind power plants to specific nodes in the grid. In [18] a potential influence and benefits of connecting wind power plants to a specific node is calculated, resulting in optimal connection nodes. On the other hand, [19] focuses on nodes where connecting wind power plants will not cause congestion and maximization of wind connection to those nodes.

Investors interested in building wind parks will usually make requests for permits regardless of the connection point characteristics (possibilities for power evacuation). Integrating large amount of wind power plants is a dynamic process and both the transmission system and the generation profile will change before any larger penetration of wind occurs.

As mentioned in Section I, certain specifics in Croatian power system need to be taken into consideration when analysing the transmission grid. For this reason, several scenarios that accurately present the system state have been pre-determined, in collaboration with Croatian TSO. :

- default scenario, set as winter maximum in 2009,
- maximum generation and maximum consumption scenario – congestion scenario,
- maximum hydrology and low consumption scenario – congestion and voltage scenario.

These scenarios were named A, B and C respectively. Each of these scenarios was then analysed over 5 different states and accordingly they were named. State of each scenario 1 describes the Croatian transmission system state at the moment, with 88 MW of wind power plants installed. State 2 of each scenario includes all the future wind power plants that have been issued permits for connection to the transmission grid. These account for total of 360

MW. These are predicted to be online and operational by 2015 (that's how long permits issued to the investors are valid). States 3 to 5 of each scenario are all the wind power plants with finished and accepted preliminary analyses in which their impact on transmission grid has been analyzed. In state 3 these wind power plants produce their installed power. State 4 has them working at 50%. The final state demonstrates the potential of storage in reversible hydro power plant. All these scenarios and states are named accordingly (A1-A5, B1-B5, C1-C5).

Wind power plants taken into consideration are listed in Table 3, with their respective capacities. The overall demanded wind capacity is 890,4 MW, which is still less than the wind capacity projected in [8] by the year 2020. The authors consider this estimate to be very optimistic and the one stated in [8] very questionable, especially considering current trends and time frame set for achieving that.

Table 3. Wind power plants considered in the calculations

Wind Power Plant	Number of Turbines	Single Turbine Capacity (MW)	Installed Capacity (MW)
Bruvno	18	2,5	45
Bubrig	10	1,5	15
Crni Vrh	5	2	10
Crno Brdo	7	2,3	16,1
Glunča	10	2,3	22
Jelinak	20	1,5	30
Krš Pađene	40	2,5	100
Mazin 2	7	2,3	16,1
Mazin Bruvno 2A	21	3	63
Obrovac - Zelengrad	14	3	42
Ogorje	25	3	75
Orlice	12	0,8	9,6
Otrić 1	16	2,5	40
Otrić 2	9	2,3	20,7
Pometeno brdo	20	1	20
Ponikve	17	2	34
Rudine	12	3	35
ST1-1 Voštane	7	2,3	15
ST1-2 Kamensko	7	2,3	15
Trtar Krtolin	14	0,8	11,2
Velika Glava	10	1,8	18
Voštane	9	2,3	20,7
Vrataruša	14	3	42
Vučipolje	41	2	82
ZD2	6	3	18
ZD3	6	3	18
ZD4	3	3	9
ZD6	4	2,3	9
ZD6-2	13	3	39
Overall			**890,4**

The line loading results for each of the mentioned scenarios are presented in Table 4-6. In case it is not stated differently, the results are for 110 kV lines.

The reversible hydro power plants, often referred to as hydro pump storage systems, are not highly dependent on water inflow and are already stipulated in literature as a practical and feasible way of storing energy from wind [20]. State 5 of each scenario examines the potential benefits that energy storage could have on high wind power integration and production. Reversible hydro power plant (RHPP) Velebit was originally constructed as a storage with the vision of harvesting extra energy from future nuclear power plant which was suppose to be built on island Vir. Since this plan was never realized RHPP Velebit has been working very rarely in its motor regime. With the high integration of wind energy into the Croatian transmission system the advantages of two generators, capable of working with 130 MW in motor regime each, gain on its importance again. More on RHPP Velebit can be found in [21].

In the presented cases in Table 4-6 in state 5 of each scenario, the reversible hydro power plant Velebit is working in the pumping regime. Its upper basing capacity allows it to pump the water for six hours at its maximal capacity before the upper tank reaches its limit. In those six hours it can store almost 1000 MWh of wind energy. These numbers and simulations stipulate future usage of reversible hydro power plants as a way of storing wind energy in the Croatian power system.

Table 4. Power lines loading in Scenario A – referent scenario

Line	A1	A2	A3	A4	A5
Bruška - Benkovac	17,73	24,54	12,64	5,97	10,09
Gračac - Obrovac (new)	----	----	65,45	35,09	72,83
Gracac - Obrovac (exisitng)	11,51	10,38	85,45	45,81	95,08
Licki osik - Karlobag	12,06	12,38	19,19	16,28	20,67
Gracac - Licki Osik	12,08	32,14	85,79	43,77	67,06
Velebit - Melina (400 kV)	32,14	44,17	66,69	44,04	37,74
Bruška - Obrovac	17,68	64,78	45,48	19,44	43,79
Obrovac - Nin	28,86	36,45	57,72	41,76	46,54
Obrovac - Zadar	21,1	23,98	36,19	28,9	30,72
Licki osik - Otocac	8,02	35,96	98,85	47,53	72,87
Otocac - Senj	4,64	32,32	95,13	44,07	69,19
Lički osik - Sklope	26,51	26,72	27,51	25,97	27,04
Obrovac - Velebit	18,06	10,13	70,83	27,3	86,09
Velebit - Konjsko (400kV)	17,61	22,71	29,65	19,43	35,51

In the presented scenario it is visible that currently wind power plants do not cause congestion or require investments into the transmission lines for the sole purpose of evacuating energy from WPP. Even if all the wind power plants with valid licences are to be connected to the grid, there would be no need for new power lines. State A3 shows that in case of higher wind penetration there is a necessity for new power lines. The basic idea is to evacuate the produced energy to the nearest 400 kV node. To achieve that a new power line between nodes Gračac and Obrovac is suggested, evacuating the energy from Gračac to Obrovac and Velebit and then into the 400 kV grid.

Table 5. Power lines loading in Scenario B – maximal production, maximal consumption

Line	B1	B2	B3	B4	B5
Bruška - Benkovac	13,42	7,4	31,76	32,43	31,54
Gračac - Obrovac (new)	----	-----	65,1	35,03	70,13
Gracac - Obrovac (exisitng)	4,1	45,35	85	45,74	91,57
Licki osik - Karlobag	9,67	10,26	17,24	14,05	17,87
Gracac - Licki Osik	10,87	28,15	73,53	40,19	57,85
Velebit - Melina (400 kV)	10,91	23,95	47,06	23,61	13,96
Bruška - Obrovac	13,82	33,86	22,23	19,7	22,88
Obrovac - Nin	32,92	39,09	56,5	45,07	47,04
Obrovac - Zadar	27,79	30,42	40,44	35,5	35,83
Licki osik - Otocac	11,38	32,87	86,09	44,74	64,36
Otocac - Senj	8,93	28,9	82,92	41,02	61,2
Lički osik - Sklope	26,95	26,01	26,77	26,21	26,77
Obrovac - Velebit	7,8	12,24	60,37	19,8	72,27
Velebit - Konjsko (400kV)	18,13	6,73	11,53	6,38	16,12

Table 6. Power lines loading in Scenario C – maximal hydro, minimum consumption

Line	C1	C2	C3	C4	C5
Bruška - Benkovac	40,82	61,14	31	27,81	31,33
Gračac - Obrovac (new)	----	----	70,54	34,35	69,49
Gracac - Obrovac (exisitng)	13,46	32,73	92,09	44,85	90,72
Licki osik - Karlobag	4,96	6,53	17,84	10,16	16,42
Gracac - Licki Osik	13,92	29,49	74,88	43,32	59,14
Velebit - Melina (400 kV)	46,24	63,48	87,13	60,79	46,35
Bruška - Obrovac	40,84	85,48	60,79	42,08	58,52
Obrovac - Nin	14,48	19	39,26	25,73	29,17
Obrovac - Zadar	4,8	5,13	18,08	11,64	12,96
Licki osik - Otocac	28,33	49,46	95,42	63,31	75,49
Otocac - Senj	26,98	48,04	93,9	61,93	73,99
Lički osik - Sklope	26,16	26,29	28,87	25,68	27,28
Obrovac - Velebit	12,45	33,14	98,55	52,36	97,81
Velebit - Konjsko (400kV)	23,79	34,24	40,51	26,43	42,72

Due to the specifics of Croatian electric system, high hydrology scenario should be taken as a reference scenario for all the subsequent analyses. Wind and hydro power plants are highly concentrated in the same geographical area, i.e. the southern part of Croatia. Both technologies have a specific stochastic power generation dependant on several environmental factors. In this case, those factors coincide and result in simultaneous high production from both wind power plants and hydro power plants, usually in spring and autumn seasons. Furthermore, those high generations overlap during early mornings which are known as a low consumption periods.

Because of the huge amount of busses and lines it is impossible to present the results of the power flow and voltage levels calculations for the whole Croatian transmission system in this paper. The calculations and models have been analyzed in power system tool NEPLAN version 5.4.3, research licence [22].

CONCLUSION

Wind power is often stipulated as the future of energy systems. Presented as a substitute for traditional power plants, including fossil fuel and nuclear fuel powered ones, it creates negativity and brings resistance with most system operators. Variability of the wind, and consequently wind power plant stochastic output, presents a challenge for, up until now, stable and reasonably secure power systems. System operators face the ongoing pressure to integrate higher amount of wind power into the transmission system. On the other hand, they have to be able to plan operation and development of the system under new and very unpredictable circumstances.

This paper presents a static analysis of the Croatian electric systems and brings several proposals and solutions for the large wind power integration. A detailed model of the Croatian electric system is presented. The model is tested on several scenarios and its high accuracy was proven. To support that, Croatian TSO has acknowledged the accuracy by accepting several analyses for the transmission system state made on the presented model.

Several specific scenarios have been presented to establish transmission system state after large wind power plants integration. These scenarios have been chosen in agreement with the Croatian system operator. It can be concluded that, due to its specifics, relevant scenario for future wind power integration is the high hydrology scenario. It presents the most relevant view on potential congestion states in the transmission grid. The presented model emphasises the importance of reversible hydro power plants as potential energy storage for wind energy. For a more detailed conclusion a dynamic analysis should be conducted including specifics of each generator and wind turbine to be installed in the future.

Despite the open access policy to all investors, authors find the deep connection policy currently applied in Croatia to be somewhat discriminatory depending on the location of future power plant. Based on European experiences, a mixed connection cost policy has been suggested. This policy clearly shows less discriminatory approach to future investors and increases feasibility of certain future wind projects.

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6th Dubovnik Conference on Sustainable Development of Energy Water and Environment Systems

Specifics of Integration of Wind Power Plants into the Croatian Transmission Network

Dear reviewers,

Thank you for your useful comments and suggestions on the language and the structure of our manuscript. We have modified the manuscript accordingly, and the detailed corrections are listed below point by point:

1) Language revision is needed. There are many errors of diction and missing noun markers ("A", "The").

> We have made the correction to the language and hope this will be sufficient. Several reference are added referring to assumptions or statements made in the paper.

2) Where is the feasibility assessment of future wind power project, which the objectives promise? Only estimates of connection costs are estimated. It would be good to see more results about the energy storage facility. Generally, the result section appears thin relative to the many assumptions made, and no analysis of the sensitivity is part of the paper.

> We did not promise to make a feasibility assessment of the future power plants. The idea was to emphasise the connection cost policy. Despite this policy being implemented in most countries of EU it is found to be somewhat discriminatory. Comparing the results of the proposed mixed connection charge, which requires fewest changes in regulatory, we have demonstrated benefits of such approach.
>
> We have made 3 scenarios and each analysed over 5 different states. We believe this should be sufficient to confirm the accuracy of the model and support the on conclusions brought in the paper. According to your suggestion we added the section describing the reversible hydro power plant and referenced to a paper detail explaining operation of the mention RHPP.

3) The tool NEPLAN needs to be described as a method.

> NEPLAN is a software tool specialized in grid analyses. It consists of electric, gas and water analysis tools. We have made a reference to more information on NEPLAN. Describing a software package might be considered advertising and we were hoping to avoid it in a research paper.

4) Rather than the analysis of the static voltage and the short circuit currents, an analysis of grid stability would require dynamic effects such as cascading effects. At least in the conclusions or perspectives this simplification and its consequences should be addressed.

> We have emphasised the necessity of dynamic analyses to be able to make a more detailed analysis. These analyses are not demanded by the regulator and therefore are very rarely conducted.

5) It would be nice to know the difference, on the national scale, between the deep and the mixed connection costs. A prioritised proposal could be presented for the wind turbine development achievable at least costs.

> According to your suggestion we have made an overview of the connection cost. At the moment in only 4 EU countries shallow connection policy is implemented and only in UK mixed connection. All other EU countries have deep connection cost implemented.

6) Very little is explained about the robustness of the analysis to changes in preconditions such as loads, costs and stochastic variables. It is either "take it or leave it", where the reader has no means of telling whether you are right or not.

Since the whole transmission system is modelled it would be very difficult to show. We have however expanded our results and explanations. In the reviewed version there are 3 scenarios and each analysed in 5 states giving the 15 states all together. We believe these should be sufficient to make an estimate on the robustness. In case the reviewers believe more results should be demonstrated, or the input data should be provided, we are ready to do so at request.

7) Detailed comments:
P.1: What is an "extreme, almost exponential growth"? Growth can be exponential without being extreme. Wind energy in most countries as well as on a global scale has always grown by 20-30%, so this is not extreme in relative terms.
Likewise, what is "extremely extensive wind power utilisation"? Which levels of utilisation do you think this includes?
"Decision for power plants" should read "decisions for wind power plants".
P.2: "Previously mentioned facts": which facts do you refer to?
Can you show the balancing problems by means of some graphic or by some quantitative overview?
P.4: What is the consequence, in terms of the objective of your paper, of a mixed change connection costing?
Which are the sources of the proposed connection case and their costs?
P.6: The first bullet point contains repeated text.
P.7: It is not clear whether the load data used are concurrent.
Table 3: If aiming at a time horizon of 2020, a sensitivity analysis should be made, which includes higher turbine capacities, eventually reduced numbers of turbines.

We have made corrections according to the reviewers' comments and suggestions.

The manuscript has been resubmitted to your conference. We look forward to your positive response.
Tomislav Capuder