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Optimal grid integration of wind power plants in Croatian 110 kV network

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Abstract—**Wind power projects in Croatia are demanded on a larger scale in the recent few years. However, Croatian Transmission System Operator (TSO) has many problems with the quantity of capacity asked for grid connection resulting in many places with large scale line congestion. Transmission network is not ready for such big penetration of real power with stochastic nature produced by a large number of wind power units which was proven with many load flow analysis carried by system operator. In this paper one example of two different developers asking for grid connection on the same 110 kV line is presented. Also, current and future states of network are analyzed. Main problems are detected and measures for grid integration of both wind power plants are suggested.**

***Index Terms*— line congestion, load flow, grid integration, system operator, wind power.**

I. Introduction

Wind power plants projects in Croatia are still not so numerous like in other European countries. There are only two wind power plants (WPP) installed in Croatian power system with total installed capacity of 17 MW. Croatian transmission power system operator has issued new set of regulations and standards concerning WPP grid connection.

Each project must prove the possibility of load evacuation, short circuit current calculation and compliance with N-1 security criteria. Concerning WPP projects in northern Adriatics, in the vicinity of the city of Senj, there is one wind power plant Vratarusa being built with 14 turbines, 3 MW each, giving totally 42 MW of installed capacity. It will be grid connected to 110 kV Senj-Crikvenica line over 110/33 kV substation located near the wind farm.

About 15 km northern from this spot, there is another potential wind farm location Breze which is supposed to be grid connected on the same 110 kV line. Since the grid connection permit has already been issued for the owner of WPP Vratarusa, the developer of WPP Breze must prove the possibility of connection to the same 110 kV line. There are two large hydro power plants (HPPs) in the close vicinity of the WPP locations, as well as one smaller HPP.

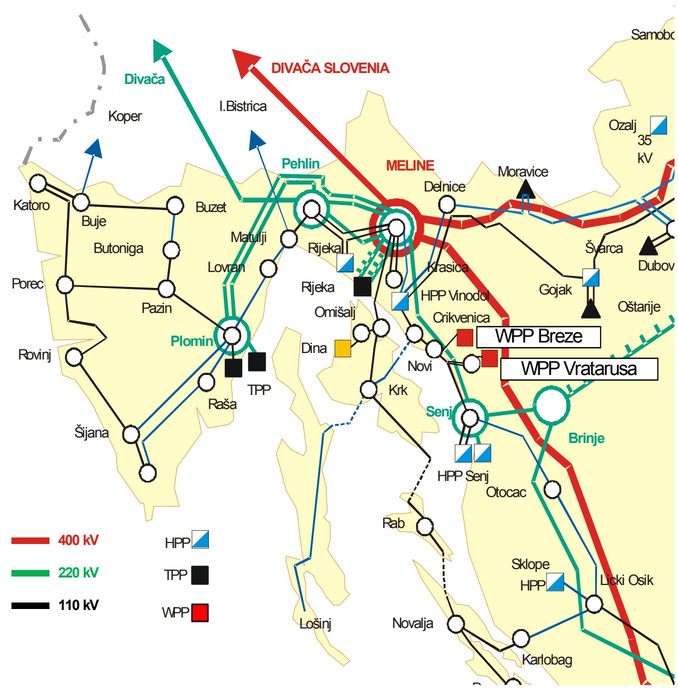

Fig. 1. Croatian power system in northern Adriatic area

Figure 1 shows the Croatian power system in its northern-western part, meaning the northern Adriatic area. Two large HPPs are also serving as regulation power plants bringing necessary rotating reserve to the Croatian power system making this topic even more delicate. Even without any WPP connected on the grid, in the so called "zero case" the situation with load flows in this part of the power system is not brilliant. There is large congestion of 110 kV network.

This already unsuitable situation is being worsened during high hydrology meaning high production from surrounding hydro power plants. During this "high hydrology" period even for the "zero case" the security criteria N-1 is not fulfilled, thus making a large problem for the developers of any kind of power plants to fulfill the necessary conditions and standards for the grid connection in this area. Also it is necessary to point to possible congestion problems on submarine cable line (SCL) to island Krk. However, WPP Vratarusa is being given a grid connection permit for installed capacity 42 MW, although the proposed installing capacity was 66 MW. This "shrinkage" of permitted maximal production power is a consequence of bad network conditions and large congestions in this area.

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Transmission system operator (TSO) came in even bigger problems after the request of another developer for the grid connection of WPP Breze in the same 110 kV line. The denial of request leads to a "walking on thin ice" of favouring one developer in front of the other. Therefore, it was the urgent time to make analysis of possible grid connection of these two WPPs on the same 110 kV line. Therefore it was necessary to recommend measures for grid connection enabling of both WPPs. In this paper, two measures are proposed for grid connection enabling of both WPPs. Also, detailed load flow analysis, short circuit calculation and dynamic simulation are presented for each case.

II. Technical Description and Calculations

As it was already mentioned, WPP Vratarusa is currently being built and it will be grid connected through 110 /33 kV substation on a 110 kV network. Only few kilometers away, WPP Breze is supposed to be grid connected through another 110/35 kV substation.

110 kV network scheme is presented in Figure 2. It can be seen that HPPs are grid connected in the vicinity of planned WPPs making this situation very delicate.

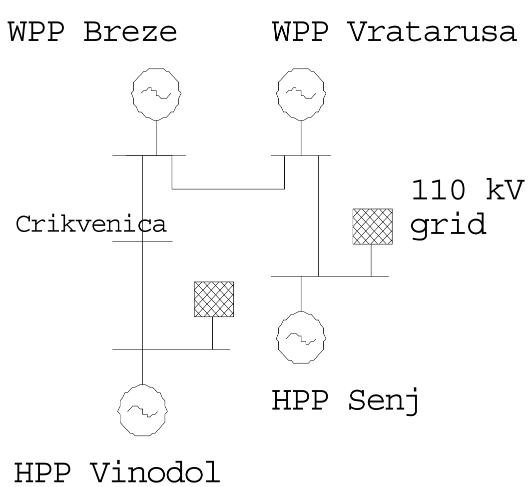

Fig. 2. 110 kV network scheme in the vicinity of wind power plant projects

A. HPP description

HPP Senj is high pressure derivation hydro power plant with 3 machines, 72 MW each. Total installed real power is 216 MW. Recent studies showed that with the reconstruction of the subject HPP, installed capacity can be increased till 5%. Grid connection for two machines is via 110 kV network and for one machine via 220 kV network.

HPP Senj is regulation power plant in croatian power system and a supplier of necessary rotating reserve into the system which makes any connection in its vicinity very delicate and sensible subject. Grid connection scheme is shown in following picture.

HPP Vinodol is high pressure derivation hydro power plant with 3 machines, 28 MW each. Total installed real power is 84 MW. Grid connection for all machines is made via 110 kV network as shown in fig. 1. HPP Vinodol is also regulation power plant in croatian power system and a supplier of necessary rotating reserve into the system which makes any connection in its vicinity even more delicate.

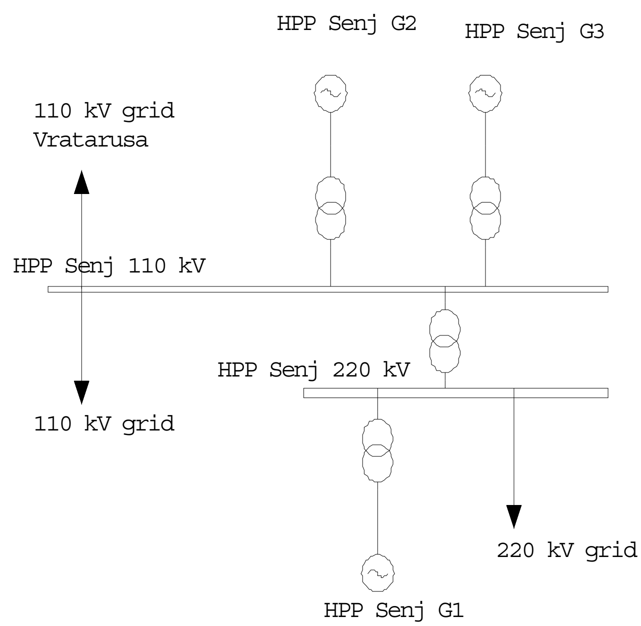

Fig. 3. Grid connection scheme in the vicinity of HPP Senj

B. Zero case

In zero case, load flow analysis was carried out in order to determine circumstances in network without any plant connected to grid. According to results, load flow in the 110 kV overhead line (OHL) Senj – Crikvenica is 48% of the line thermal rating (S_{term}) .

In the case of high hydrology same line is loaded with 80% of the line thermal rating. Results are as follows:

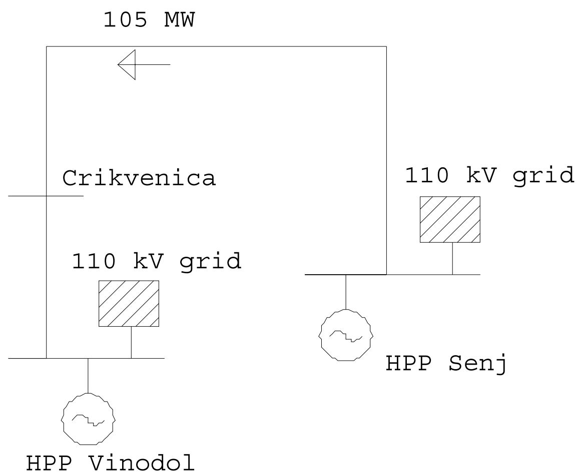

Fig. 4. Load flow analysis for zero case in the N-1 situation

According to results, load flow in the 110 kV overhead line (OHL) Senj – Crikvenica is 48% of the line thermal rating. In the case of high hydrology same line is loaded with 80% of the line thermal rating. The problem appears in the case N-1 when transformer 220/110 kV in the HPP Senj is out of operation. Load flow is then 90% of thermal rating which makes possible dangerous operation. This makes even zero case unsuitable for permanent operation.

Table 1. N-1 security analysis – zero case

N-1 element	Overloaded element	S_{term} (MVA)	Rating (%)
OHL 220 kV HPP Senj - Melina	OHL 110 kV HPP Senj - Crikvenica	120	79
Transformer 220/110 kV HPP Senj	OHL 110 kV HPP Senj - Crikvenica	120	88

Therefore, it was already in the plans for a long period of time to build a new 110 kV line between substations Senj and Crikvenica. This new line was in some earlier development plans planned as double circuit line which would be even better option and would boost power system stability in this area. On the other hand it is very expensive solution, especially considering low possibilities for acquiring new line corridor in this very touristic area. For this reason, this solution was postponed but it was unavoidable after grid connection requests for future WPPs.

C. Case A

In the case A, one WPP is grid connected and that is namely WPP Vratarusa because this project was much further in developing phase. WPP Vratarusa with planned capacity 42 MW is grid connected via substation 110/33 kV. Load flow analysis defines again possible operation of 110 kV network in the close vicinity but only in the case of totally "healthy" grid. This situation is described in the following figure where case A in the healthy network is shown.

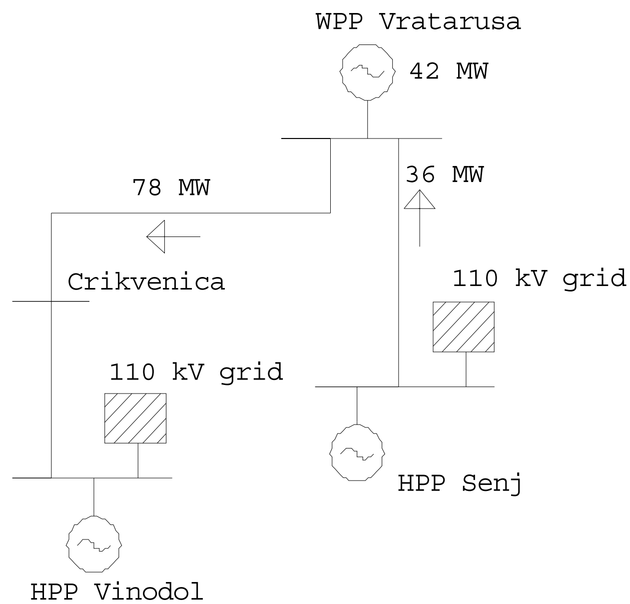

Fig. 5. Load flow analysis for case A in the healthy network situation

N-1 security analysis gives overload of 110 kV lines and possible regional blackouts or brownouts in the area, depending on the protecting devices coordination.

Some elements are overloaded over their thermal ratings which gives possible condition for larger system failures. After the relay functioning, most probably parts of the system would remain without power supply.

In the table 2. results for N-1 security analysis in the case A are given. It can be seen how some elements are overloaded. These results confirm the necessity for network upgrade in this part of the system. If this upgrade would consist from building of new lines it would most probably represent expenditure which would largely influence the feasibility of wind power plant projects.

Table 2. N-1 security analysis – case A

N-1 element	Overloaded element	S_{term} (MVA)	Rating (%)
Transformer 220/110 kV HPP Senj	OHL 110 kV Novi - Crikvenica	120	112
Transformer 220/110 kV HPP Senj	OHL 110 kV VE Vratarusa - Novi	120	118
OHL 220 kV HE Senj - Melina	OHL 110 kV Novi - Crikvenica	120	92
OHL 220 kV HE Senj - Melina	OHL 110 kV VE Vratarusa - Novi	120	99

D. Case B

In the case B, both WPPs are grid connected. With the experiences from previous case A, it can be expected that N-1 situation will not give satisfactory results. In the normal operation of case B, OHL Breze – Crikvenica is loaded 70% of thermal line rating.

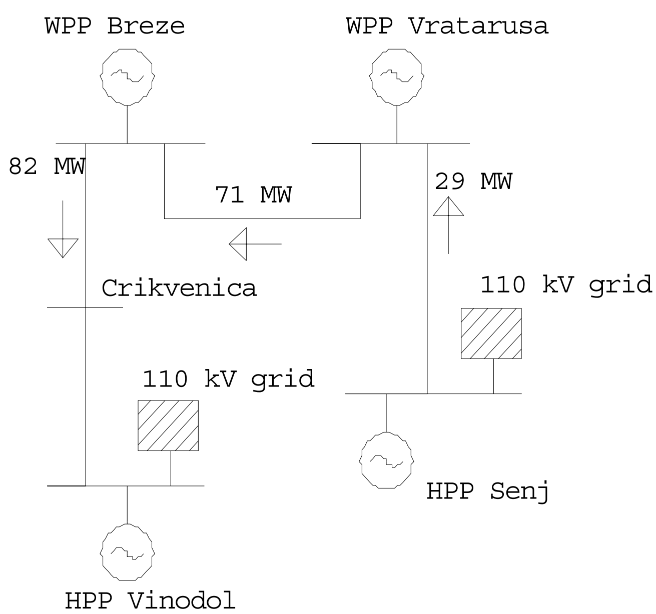

Fig. 6. Load flow analysis for case B in the healthy network situation

From the other results it can be concluded that grid connection and operation of WPP Breze doesn't change the bad situation in the network. There is still same level of congestion in the 110 kV network.

Very interesting thing is that OHL loadings in healthy network can still operate in normal operating conditions. But in the situation N-1, almost each element is overloaded. Complete blackout of this part of the system is unavoidable. Therefore it is necessary to find suitable solution for network strengthening.

Table 3. N-1 security analysis – case B

N-1 element	Overloaded element	S_{term} (MVA)	Rating (%)
Transformer 220/110 kV HPP Senj	OHL 110 kV Novi - Crikvenica	120	126
Transformer 220/110 kV HPP Senj	OHL 110 kV WPP Vratarusa - Novi	120	116
Transformer 220/110 kV HPP Senj	SCL 110 kV Crikvenica - Krk	70	98
OHL 220 kV HPP Senj - Melina	OHL 110 kV Novi - Crikvenica	120	104

It can be seen that three elements would be overloaded after contingency on transformer in substation 220/110 kV in HPP Senj. Blackout, or at least brownout of this part of the system is unavoidable. Therefore it is necessary to find suitable solution for network strengthening in order to make suitable conditions for enabling grid connection of both WPPs.

Results from table 2 suggest that it is necessary to build a new overhead line, or new double circuit line, on the corridor from HPP Senj till substation Crikvenica, more precisely on the route HPP Senj – WPP Vratarusa – WPP Breze (substation Novi) – substation Crikvenica. In this way, very good practice of congestion management is achieved, but it represents also a very expensive solution which would cause negative values for Internal Rate of Return (IRR) and Net Present Value (NPV) of all future WPP projects in the vicinity.

Therefore, it was necessary to make a suitable solution of this problem which would not endanger feasibility of future power production projects.

E. Case C

Network strengthening is always an expensive and painful process for system operator. Building of new lines is always long term and expensive project which opens many questions with line corridors and investment portfolios. In this case following measure was proposed: - reconstruction of HPP Senj and refurbishment of 3 machines and their grid connection on 220 kV grid. In this case following results occur.

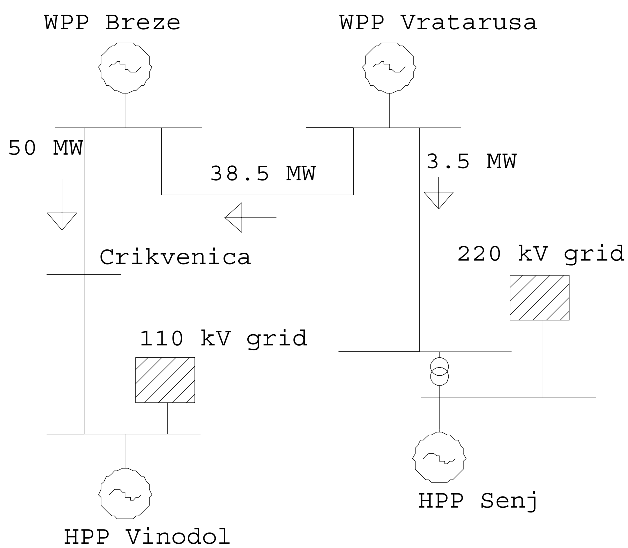

Fig. 7. Load flow analysis for case C in the healthy network situation

Load flow analysis shows that in the normal operating conditions every OHL is loaded less than 50% of thermal rating. Following table shows N-1 security analysis results.

Table 4. N-1 security analysis – case C

N-1 element	Overloaded element	S_{term} (MVA)	Rating (%)
OHL 220 kV HPP Senj - Melina	OHL 110 kV Novi - Crikvenica	120	83

In the N-1 situation OHL 110 kV Breze – Crikvenica is the most loaded and is still loaded 83% of thermal rating. This makes case C the most suitable one and also the most economic one, especially comparing to building new lines.

F. Short-Circuit calculations

Faulted network analysis for each case shows that short circuit currents on every node do not exceed circuit breakers rated breaking currents in a given node. Following figure shows short-circuit currents for every given case.

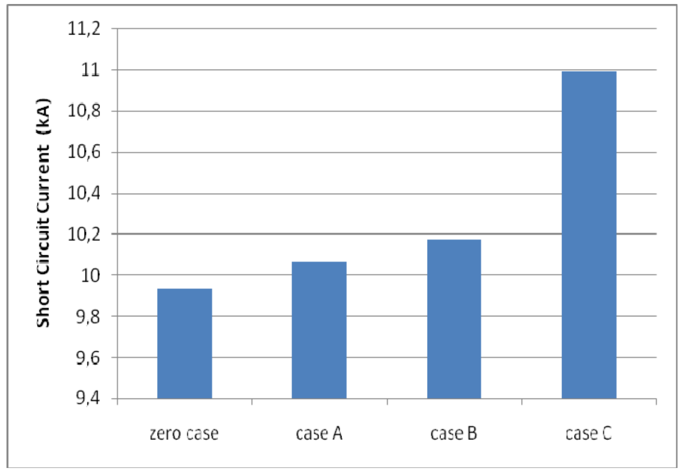

Fig. 8. Short-circuit currents for different cases on 110 kV bus in HPP Senj

Since circuit breakers have suitable characteristics with breaking capacity of 31.5 kA, there is no need to make any additional reconstructions in any of given substations. This analysis only confirms that case C is the most suitable solution.

III. Conclusions

In this paper an analysis of wind power plant grid connection is analyzed. Two wind power plants are supposed to be grid connected on the same 110 kV line. Subject line, together with its surrounding network shows many disadvantages and limitations considering congestions which occur during high hydrology periods and thus corresponding high production from neighbouring hydro power plants.

Four cases of power system operation in the area were analyzed. Zero case represents current condition with none of the WPPs connected to grid. Case A represents situation with WPP Vratarusa connected to grid and case B represents situation with both WPPs (Vratarusa and Breze) connected to grid. Together with previous cases, case C is represented where reconstruction of substation in HPP Senj is analyzed.

Current state in subject substation is that two machines of HPP Senj are connected on 110 kV network and one machine on 220 kV network. This reconstruction comprises installation of new step-up transformers in order to switch generator connection from 110 kV network to 220 kV network. In this way, during high hydrology periods, load flows would be passed through surrounding 220 kV network releasing necessary transmission capacity in 110 kV network and thus giving availability for grid connection of both WPPs.

Considering all analyzed cases, case A and case B point to necessity of building a new line in the congested corridor which initiates many investment costs and also a long time framework especially taking into account environmental requests, building permits and other necessary steps.

Case C imposes as the most suitable solution with many advantages. The biggest advantage is procurement of N-1 security criteria. Also, increased load flows are being transferred to 220 kV network thus releasing necessary transmission capacity in 110 kV network and giving new possibilities for grid access of new electricity sources in this area.

In this paper costs were not calculated but were shortly analyzed. Costs for building a new double circuit line on a given route would initiate many problems with the procurement of line corridors and time framework necessary for this construction. This would bring new uncertainties for wind power project developers and increase costs. Also, reconstruction of HPP Senj substation would initiate lower investment costs and give boost to system security.

Costs and time period for substation reconstruction in HPP Senj are much lower than costs and time period for building a new line. However, in this paper cost allocation was not analyzed which would open many new questions between interested parties.

IV. References

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V. Biographies

Mario Klaric (S’04) was born in Sibenik, Croatia on 1979. He finished his B.Sc. and M.Sc. at the University of Zagreb, where he is currently PhD student as well as MBA student. His area of interest is wind power and grid integration of renewable energy sources. He is a student member of IEEE.

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