VOLTAGE PROFILE ANALYSIS IN 30 KV NETWORK AFTER CONNECTION OF WIND POWER PLANT

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ABSTRACT

Maintaining voltage level within permitted range is one of the most important factors regarding power supply quality and normal power system operation. Integration of highly variable power sources such as wind power plants (WPP) into distribution network emphasizes the voltage regulation issues. In this paper, voltage profile in 30 kV network after connection of wind power plant was analyzed regarding different WPP reactive power regulation strategies. A brief description of analyzed system based on the measurements and computer simulations is given.

1. INTRODUCTION

Last decade was period of a relatively high growth of distributed power sources, with significant amount of power plants connected to the distribution network. General cause for such a trend can be found in:

- formation of electric power market, fallowed with laws regulating access to the grid, allowing independent investors to finance and build power plants suitable for connection to distribution network,
- stimulating prices of electrical energy (feed-in tariffs, green certificates, other forms of incentives) also proscribed trough legislation acts related to renewable energy sources and cogeneration,
- technical development, resulting with efficient and relatively low-priced smaller power plants.

These factors made small-scale power plants attractive for investors, motivating them to invest into the further research and development of such projects. Growth of renewable sources was especially intensive in wind power sector.

WPP connection to the distribution network regardless of power plant's capacity usually results with significant changes in network operation. WPP can have both positive and negative effects on distribution network, depending on the distributed source operating mode and technical characteristics of the distribution network and load.

2. IMPACT OF WIND POWER PLANT OPERATION ON STEADY STATE VOLTAGES

Impacts of WPP grid connection can be grouped in steady state and dynamical impacts. Main steady state impacts are [1]:

- change of voltage profile along the radial distribution feeder,
- impact on power and energy losses.

In so called "passive" distribution network (one-way supplied) active and reactive power flows are determined only by network technical parameters and network load. Consequently, node voltages on radial feeder decrease from power supply point towards the end of the feeder. In such network, voltage is mainly regulated using under-load-tap-changers transformers (ULTC), usually at HV/MV transformer stations regardless of load variations. Such voltage regulation practice usually is not able to compensate voltage drop on very long feeders.

If power plant is connected to the network it will generate active power and generate/consume reactive power depending on its technical parameters. In such a case we are speaking of so called "active" distribution network given that a part of distribution network is two ways supplied.

Steady state voltage variations depend on the active and reactive power injection at certain points of the network as well as on the technical parameters of the network. Approximate expression determining voltage rise [2] in power plant point of common coupling - PCC (ΔU) as a function of injected active power (+), consumed reactive power (-) and network parameters (R/X – line resistance/inductance) is given as (1). In case when power plant produces reactive power both augends are positive resulting with even higher voltage increase.

$$\Delta U(t) = R\frac{P_G(t)}{U_n} - X\frac{Q_G(t)}{U_n} \quad (1)$$

Hence, wind power plant operation impact on distribution feeder voltage profile (assuming operation with power factor cosφ=1) manifests itself through increase of voltage along the radial feeder. Furthermore, connection of WPP does not only increase amplitude of possible voltage variations, but also, due to wind stochastic nature, increases frequency of such variations [3-6]. Voltage decrease at the PCC is possible only with WPP consuming a significant amount of reactive power, assuming that WPP technical parameters allow such operation.

In following chapters, parallel operation of WPP (operating with different reactive power control strategies) and distribution network were analyzed along with the impact on voltage profile. Preliminary results were first obtained by computer simulation and afterwards validated by operational measurements.

3. WPP ORLICE GRID CONNECTION AND REACTIVE POWER CONTROL STRATEGIES

Analysis carried out in this article examines impact of WPP Orlice on voltage profile of 30 kV feeder. PCC is situated on 30 kV radial power line Bilice-Primošten-Rogoznica, 15 km from substation 110/30 kV Bilice (Fig.1.). WPP connection to power line is realized with new 30 kV cable. WPP consists of 11 wind turbines with synchronous generators, eight units with 900kW nominal power (ENERCON-44) and three units with 800kW (ENERCON-48), making total WPP capacity of 9.6 MW. Wind generators are connected to grid through inverter allowing reactive power regulation within technical limits and 0.4/30 kV transformer to transform low voltage to grid voltage.
Distribution network 30 kV is supplied through substation 220/110/30 kV Bilice. Each of two 30 kV busbars is powered by individual transformer with rated tap ratio 110/31.5/10.5 kV and nominal power of 63 MVA. Transformer has under-load voltage regulating range of ±16(8x2)%. Still, due to the long distance of 30 kV feeder, voltage drop and variations are significant.
Following WPP reactive power control strategies are most common:

- fixed power factor regime(e.g. cosφ=1),
- voltage control regime (cosφ=f(U)) regulating:
  - generator bus voltage,
  - voltage at PCC (Fig.1.).

Figure 2 displays WPP Orlice reactive power management capability diagram (PQ diagram) at PCC. Slight shift of the characteristic to the left (reactive power generation area) is caused by internal cable network capacitance. Reactive power (voltage) regulation range is determined by distribution system operator (DSO) requests. In case of WPP Orlice, regulation range is allowed from 0.88ind - 0.86cap according to DSO grid connection approval. Possible regulation range (Fig. 2. - shaded area) refers to normal operating conditions, among others voltage within ±10%U_n and considers technical constrains as well as DSO requirements.

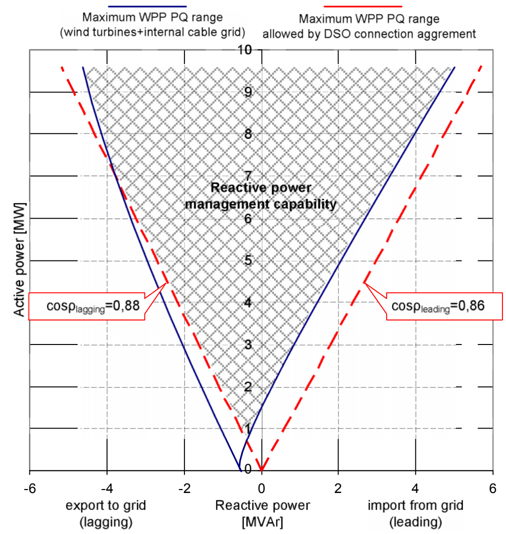

Fig. 2. WPP Orlice reactive power capability at PCC

4. VOLTAGE PROFILE ANALYSIS IN 30 KV NETWORK

Main objective of analysis is to understand impact of WPP Orlice on voltage profile of surrounding network, with emphasis on voltage raise during minimal consumption in network and maximal production of WPP.
Besides WPP output power and surrounding network technical parameters, very important parameter effecting voltage profile is ULTC's voltage regulation regime.
Voltage on 30 kV side of 220/110/30 kV transformer is regulated according to reference value of:

- 30.7 kV during highest consumption in summer
- 30.2 during rest of the year, when consumption is lower.

Voltage reference values selected in this manner assure compensation of voltage drop during summer period with high consumption and limits voltage raise in 10 kV network during periods when consumption is lower.
Load flow analysis is made for four characteristic states considering WPP Orlice power output and distribution network consumption.

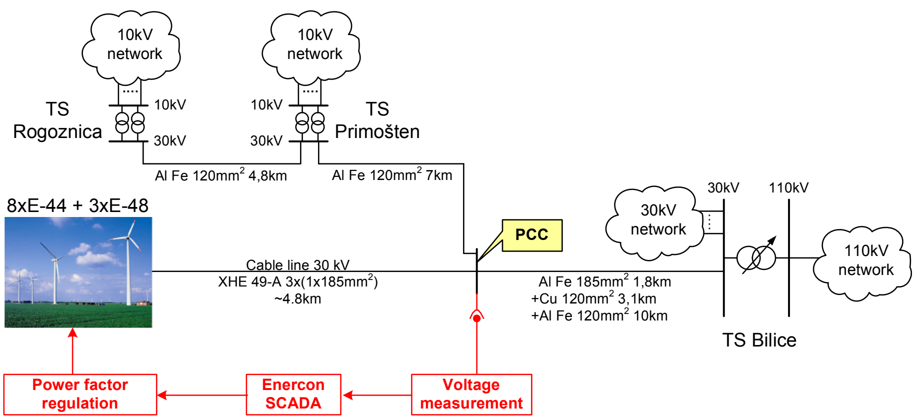

Fig. 1. WPP connection (voltage control at PCC) and surrounding 30 kV network

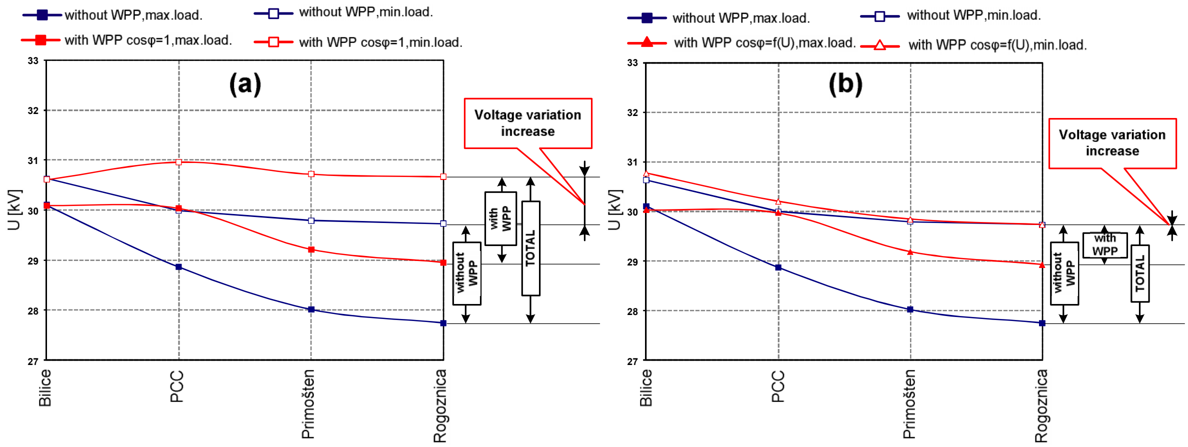

Fig. 3. Voltage profile along 30 kV feeder with WPP Orlice: working with constant power factor (a), voltage control at PCC (b)

Furthermore, both WPP Orlice reactive power control strategies are considered in this analysis:

- constant power factor regime (cosφ=1),
- voltage control regime (cosφ=f(U)) - voltage at PCC is regulated to setting value considering WPP reactive power management capability (Fig. 2).

Figures 3a and 3b display voltage profile together with partial and total voltage variations along the 30 kV power line Bilice-PCC-Primošten-Rogoznica, as a result of load flow calculations.

Analysis shows that in case of minimal consumption and WPP operating with constant power factor (cosφ=1) generating maximal output power, voltage profile exceeds admissible voltage limits. All other system operation states especially those with WPP working in voltage control regime, result with voltage profile within admissible limits.

Furthermore, voltage profile analysis before and after connection of WPP shows that voltage variations at PCC doubles after connection of WPP while operating with constant power factor. On the other hand voltage variations, with WPP operating in voltage control regime, remain practically the same.

Based on acquired operational measurements, simulation results are further validated. Measurements are delivered by DSO and include 15-min average values of active/reactive power and voltage in substation Bilice and PCC of WPP Orlice. Available measurements refer to period July 2009 - January 2010. Figure 4 displays TS Bilice and WPP Orlice voltage duration curve.

For needs of validation, this period is divided into two subperiods as follows:

- Summer (July 2009 – September 2009) – presenting maximal consumption period. During this period, voltage regulation at TS Bilice maintained voltage level at 30.7 kV and WPP Orlice operated at constant power factor regime (cosφ=1).
- Winter (October 2009 - January 2010) – presenting lower consumption period. During this period , voltage regulation at TS Bilice maintained voltage level at 30.2 kV and WPP Orlice operated at voltage regulation regime (cosφ=f(U)) regulating voltage at PCC.

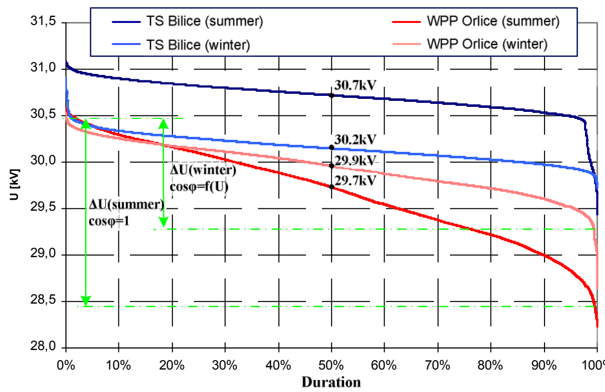

Fig.4. TS Bilice and WPP Orlice voltage duration curve

Results in fig 4 indicate rather small voltage variations in substation Bilice in relation to voltage at WPP Orlice PCC during both periods (±0.25 kV regarding maintained voltage). Smaller voltage variations, despite WPP production and distribution load variations are result of successful automatic voltage regulation at TS Bilice.

On the other hand, voltage variations at PCC are rather high, especially during summer period (WPP operating with constant power factor) when voltage variations are twice higher than in winter period (WPP controlling voltage at PCC). Based on previous examination following conclusions can be made:

- voltage regulation regime results with far better voltage conditions in distribution network(in relation to constant power factor) and presents better option from distribution network point of view.
- constant power factor regime results with lower reactive power flows and therefore lower active power losses in internal cable network. This option presents

better solution from WPP point of view [7].

Figures 5 and 6 display chronological active/reactive power curves for analyzed feeder and chronological voltage curves at substation Bilice and WPP Orlice PCC

Figure 5, referring to summer period 04.08.2009 – 06.08.2009, show smaller voltage variations around regulated value of 30.7 kV in TS Bilice. Voltage variations at PCC are higher and follow variations in feeder consumption. Although individual wind turbines operate with power factor *cosφ=1*, most of the time WPP Orlice operates in inductive area, injecting reactive power into network due to MV cable grid reactive power production.

Figure 6, referring to winter period 11.12.2009 – 13.12.2009, also show small voltage variations around regulated value of 30.2 kV in substation Bilice. Unlike previous period, voltage variations at WPP Orlice PCC are significantly lower. Such conditions are induced due to lower variations in feeder consumption and WPP operating with voltage regulation regime (note capacitive operation during higher production and lower consumption).

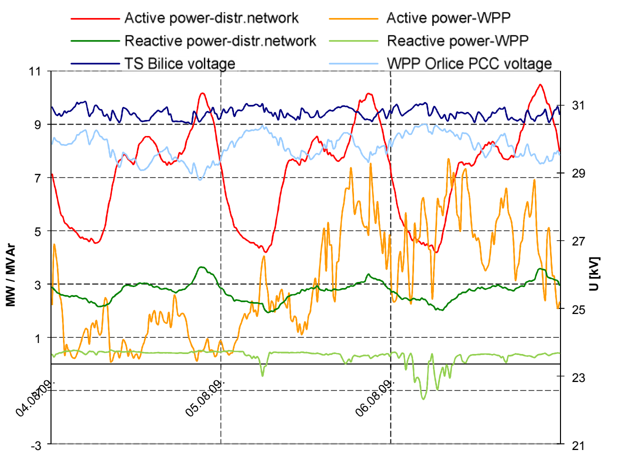

Fig.5. Chronological curves for the period 04.08.09 -06.08.09: WPP Orlice operating with constant power factor cosφ=1

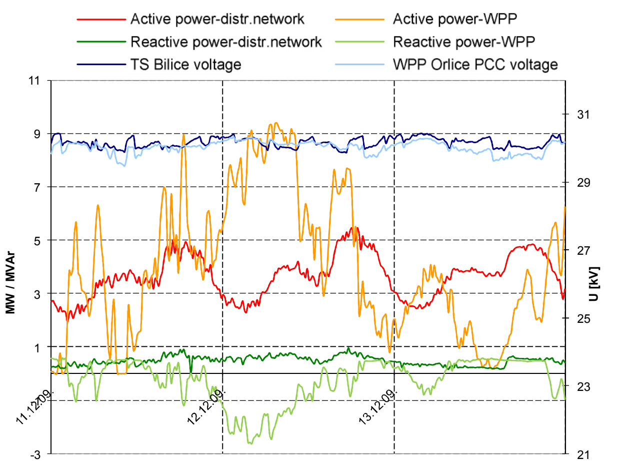

Fig.6. Chronological curves for the period 11.12.09 -13.12.09: WPP Orlice regulating voltage at PCC cosφ=f(U)

5. CONCLUSION

Last decade presents period of higher integration of distributed power sources especially wind power. WPP operation results with significant changes of distribution network voltage profile, particularly when WPP capacity and load are at same order of magnitude.

This paper analysis one such example through impact of WPP Orlice on surrounding network. Analysis is made using load flow simulations and available measurements. Results conclude that impact of WPP Orlice on voltage profile in distribution network mainly depends on WPP reactive power control strategy. Constant power factor regime considerably increases voltage variations, while voltage control regime with PCC voltage regulation, significantly reduces voltage variations.

Although voltage regulation regime reduces WPP impact on voltage profile, such regime increases reactive power flows in both MV cable network and distribution feeder thereby increasing power losses and decreasing economical benefits for both subjects.

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