Simulation of Impact of a Wind Farm on the Grid Stability Using PowerWorld Simulator

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Abstract: The paper presents impact of wind turbines on the grid stability. Simulation is carried out using PowerWorld Simulator 15. The stability of the transmission network Osijek has been analyzed, due to the outage of the wind farm Tovarnik. Two cases are simulated. The first presents disconnection of the wind farm Tovarnik with an output power of 44 MW before disconnecting from the grid. The second presents the same, but with the output power of 100 MW before disconnection.

Key-Words: wind turbines, power system dynamics, grid stability, wind power generation, PowerWorld Simulator, GENROU model

1 Introduction

In most countries, the amount of wind power generation integrated into large-scale electrical power systems covers only a small part of the total power system load. However, the amount of electricity generated by wind turbines is increasing continuously. Therefore, wind power penetration in electrical power systems will increase in the future and will start to replace the output of conventional synchronous generators [1]. As a result, it may also begin to influence overall power system behavior. Thus, the impact of wind power on the dynamics of power systems should be studied thoroughly in order to identify potential problems and develop measures to mitigate those problems.

The dynamic behavior of a power system is determined mainly by the generators. Until now, nearly all power has been generated with conventional directly grid-coupled synchronous generators. The behavior of those generators under various circumstances has been studied for decades. Although this generator type used to be applied in wind turbines in the past, this is no longer the case. Instead, the wind turbines use other types of generators, such as squirrel cage induction generators or generators that are grid-coupled via power electronic converters. The interaction of these generator types with power system is different from that of a conventional synchronous generator. As a consequence, wind turbines affect the dynamic behavior of the power system in a way that might be different from that of conventional synchronous generators. Furthermore, there are also differences in the interaction with the power system between the various wind turbine types presently applied, so that the various wind turbine types must be treated separately [2]. This also applies to various wind park connection schemes that can be found discussed in the literature [3, 4].

2 Power System Dynamics

Power system dynamics investigates how a power system responds to disturbances that change the operating point of a system. Examples of such disturbances are frequency changes due to generator trips or if a load is switched in or disconnected; voltage drops due to a fault; changes in prime mover mechanical power or exciter voltage, etc. A disturbance triggers a response in power system, which means that various properties of the power system start to change, such as node voltages, branch currents, machine speeds, etc.

The power system is considered to be stable if the system reaches a new steady state and all generators and loads that were connected to the system before the disturbance remain connected. The original power system is considered to be unstable if loads or generators are disconnected in a new steady state.

Two remarks must be made at this point. Firstly, when a system is stable, the new steady state can either be identical or different from the steady state in which the system resided before the disturbance occurred. This depends on the type of disturbance, the topology of the system and the controllers of the generators. Secondly, an unstable power system does not necessarily lead to a complete blackout of the system. Rather, the topology of a system is changed by protection devices that disconnect branches, loads and/or generators during the transient phenomenon, in order to protect these. In most cases the changed system will be able to reach a new steady state, thus preventing a complete blackout. Although the "new" system was stable after the resulted changes happened, the "old" system was unstable and its stability has been retained by changing the topology of a system.

3 Model in PowerWorld Simulator

PowerWorld Simulator is an interactive power systems simulation package designed to simulate high voltage power systems operation on a time frame ranging from several minutes to several days. The software contains a highly effective power flow analysis package capable of efficiently solving systems with up to 100,000 buses. Simulations described in this paper are carried out using PowerWorld Simulator 15 Beta, with Transient Stability add-on [5].

Wind farm Tovarnik is not built yet, but the project is finished and it has a preliminary approval for construction. The project includes a 44 MW wind farm with 44 Končar KO-VA 57/1 wind turbines [6].

Model of Transmission area Osijek with future wind farm Tovarnik is shown on Fig. 1. Wind farm Tovarnik is marked with a red circle. Red lines present 400 kV lines, blue lines present 220 kV lines, and black ones present 110 kV lines.

Transmission area Osijek has connections with Transmission area Zagreb (400 kV transmission line Ernestinovo-Žerjavinec), Republic of Serbia (400 kV transmission line Ernestinovo-Mladost), and Bosnia and Herzegovina (400 kV transmission line Ernestinovo-Ugljevik and two 220 kV transmission lines, Đakovo-Tuzla and Đakovo-Gradačac). In a real system, at the ends of those transmission lines are also substations. However, model of Transmission area Osijek is presented as a detached part of power system. Therefore, in the model, the ends of transmission lines of Transmission area Osijek are modeled as generators and loads, respectively.

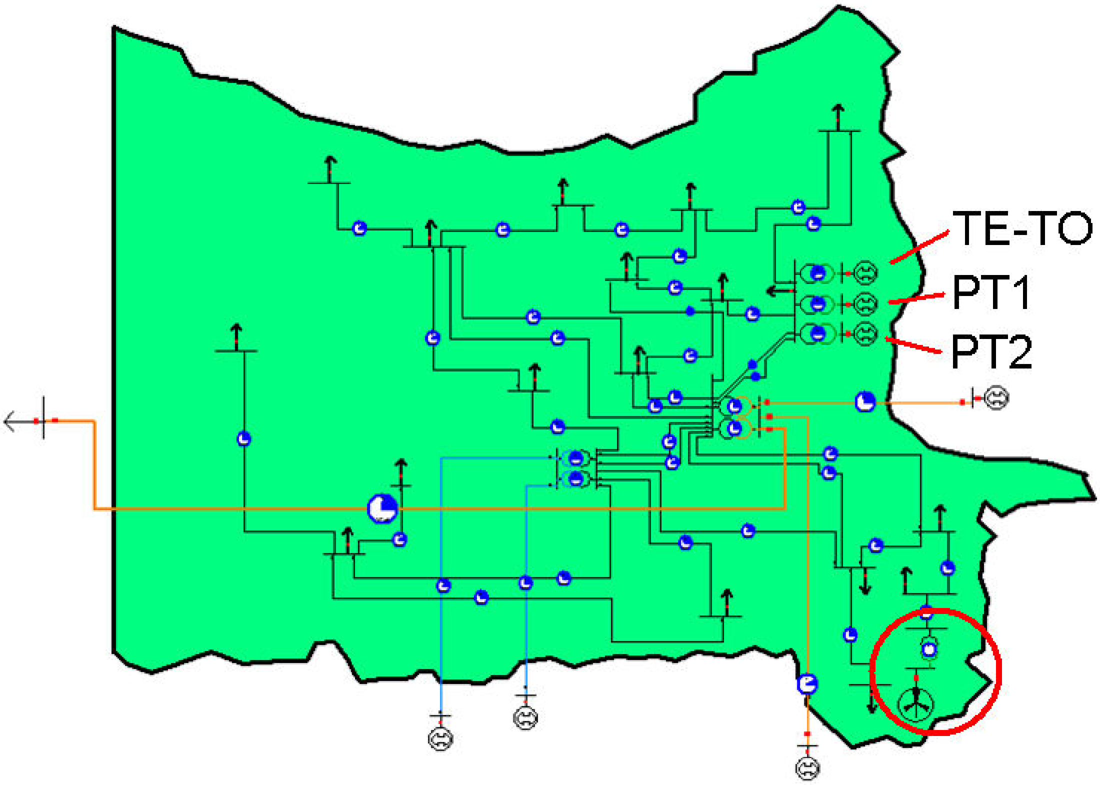

Fig. 1 Model in PowerWorld Simulator

For transient stability simulation, a more precise model of generators is needed than for a power flow simulation. Model includes power and voltage control parameters (MW Output, Min. MW Output, Max. MW Output, Mvar Output, Min. Mvar Output, Max. Mvar Output), as well as stability parameters (Machine Model, Exciter Model, Governor Model, etc.). The most important is the machine model. PowerWorld has several machine models included. The Machine Model GENROU is used for modeling three generators in power plant in Osijek (TE-TO, PT1, PT2), as it is usual for solid rotor generator represented by equal mutual inductance rotor modeling [7]. Block diagram of GENROU model is shown in Fig. 2. Definitions and values of parameters of GENROU model are shown in Table 1.

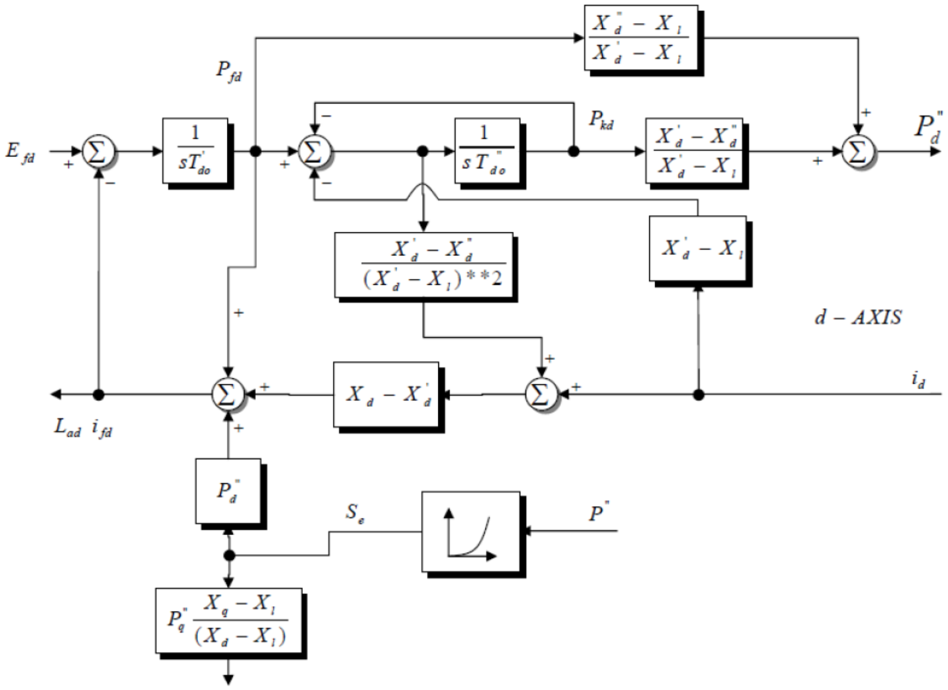

Fig. 2 Block diagram of GENROU model

Table 1: Parameters of GENROU model

Parameter	Description	Value for generator TE-TO Osijek	Value for generators PT1 and PT2
H	Inertia constant, sec	1.00	0.80
D	Damping factor, pu	0.00	0.00
Ra	Stator resistance, pu	0.00	0.00
Xd	D-axis synchronous reactance	2.10	2.10
Xq	Q-axis synchronous reactance	2.37	2.50
Xdp	D-axis transient reactance	0.20	0.18
Xqp	Q-axis transient reactance	0.24	0.20
Xdpp=Xqpp	subtransient reactance	0.15	0.13
X1	Stator leakage reactance, pu	0.10	0.08
Tdop	D-axis transient rotor time constant	10.00	11.00
Tqop	Q-axis transient rotor time constant	3.00	3.75
Tdopp	D-axis subtransient rotor time constant	0.05	0.06
Tqopp	Q-axis subtransient rotor time constant	0.05	0.06
S (1.0)	Saturation factor at 1 pu flux	0.152	0.152
S (1.2)	Saturation factor at 1.2 pu flux	0.537	0.152
Rcomp	Compounding resistance for voltage control, pu	0.00	0.00
Xcomp	Compounding reactance for voltage control, pu	0.00	0.00

4 Simulation Results

Two cases are simulated. The first presents disconnection of Wind Farm Tovarnik with the output power of 44 MW before disconnecting from the grid due to a fault. The second presents the same, but with the output power of 100 MW before disconnection. The output power of 100 MW is taken because that is approximately the maximum output power for a specified location. In both cases output power of generator in cogeneration plant (TE-TO), voltage and frequency at buses of the power plant Osijek and rotor angle of that generator will be investigated. Simulation duration time is set to 8 seconds, time of a fault is set to 1 second, and frequency of the system is set to 50 Hz. The results of the simulation show the stability of the system after a disconnection of Wind Farm Tovarnik in both cases.

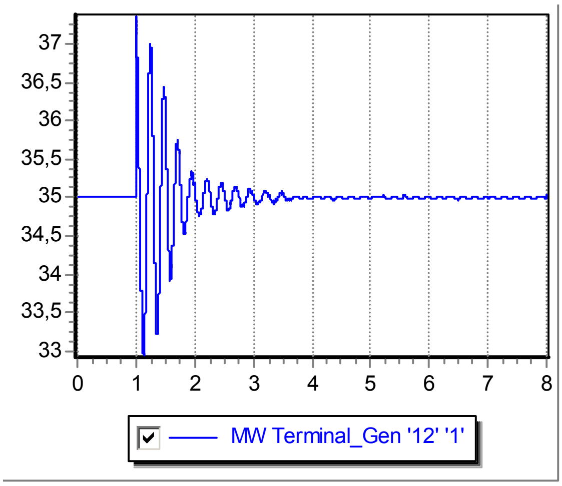

Fig. 3 Output power of TE-TO generator

Fig. 3 indicates that the output power of TE-TO generator has damped oscillations which last about 2,5 seconds. The maximum amplitude of those oscillations is about 2 MW. Important to notice is that the output power of TE-TO generator after transient process has the same value as the output power before fault, meaning that the power shortage caused by disconnection of wind farm is not compensated by TE-TO generator. After short analysis in the software, it can also be seen that the power shortage is compensated by generators that are models for substations from Serbia and BIH.

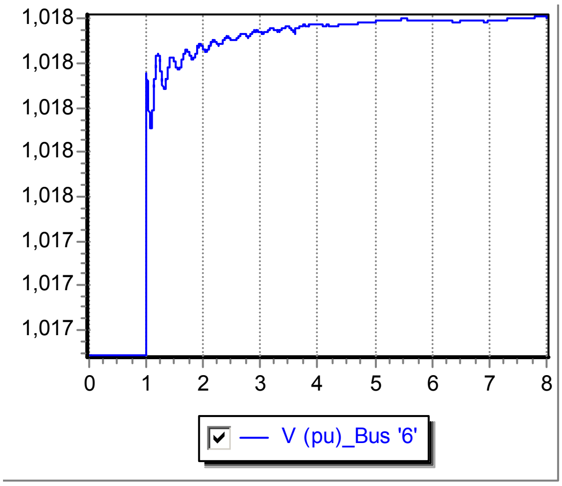

Fig. 4 Voltage at the cogeneration plant bus

Fig. 4 indicates voltage increase for approximately 0.001 pu, with small damped oscillations. That small variation of voltage is caused by change of reactive power flow at the bus.

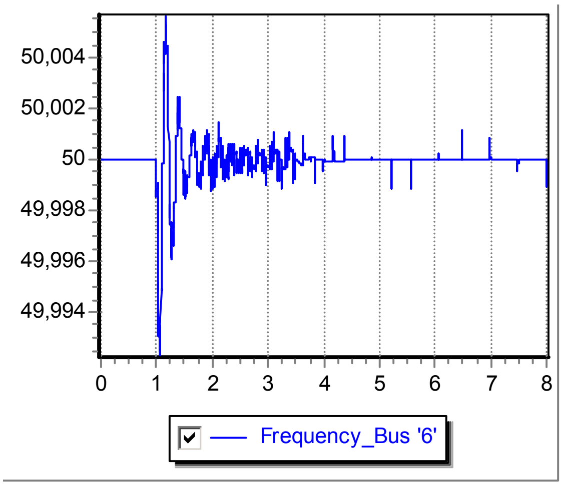

Fig. 5 Frequency at the cogeneration plant bus

Fig. 5 indicates that frequency in the system also has small damped oscillations which were caused by disconnection of the wind farm from the grid. The oscillations last about 3 seconds, and their maximum amplitude is 0.008 Hz. Small disagreement of the frequency after transient process is caused by the imperfection of a mathematical model of the system, i.e. in the real system this disagreement should not exist.

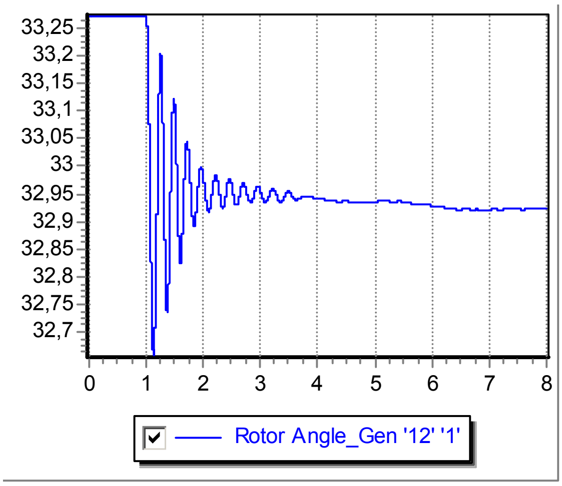

Fig. 6 Rotor angle of TE-TO generator

Fig. 6 indicates that the rotor angle also has damped oscillations, but its value has decreased after transient process, which can be explained using transient stability equation for generators:

$$P_e = \frac{E' \cdot V}{X} \sin\delta \qquad (1)$$

where P_e is electric power, E' is generator voltage behind transient reactance, V is voltage at substation bus, X is total reactance between generator and grid, and δ is rotor angle of synchronous generator. All variables remain the same, except voltage (V) at substation bus. That voltage increases, which leads to decreasing of $\sin\delta$, which implies decreasing of δ, i.e. generator rotor angle.

Diagrams for the second case, where output power of the wind farm before disconnection was 100 MW, are shown in Figures 7-10.

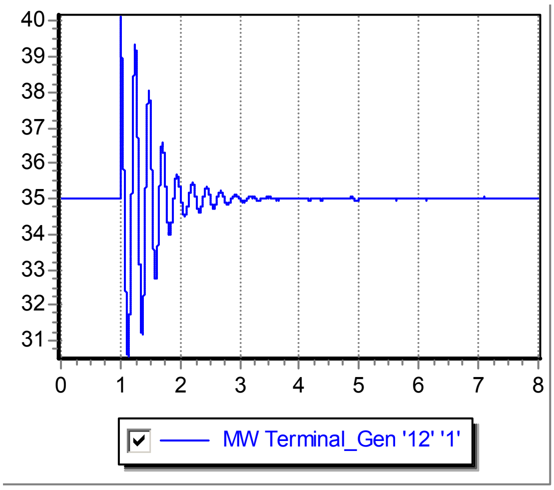

Fig. 7 Output power of TE-TO generator

Fig. 7 indicates that the output power of TE-TO generator in the second case is very similar to the one from the first case shown in Fig. 3, but with one major difference - the maximum amplitude of damped oscillations is now 5 MW, instead of 2 MW.

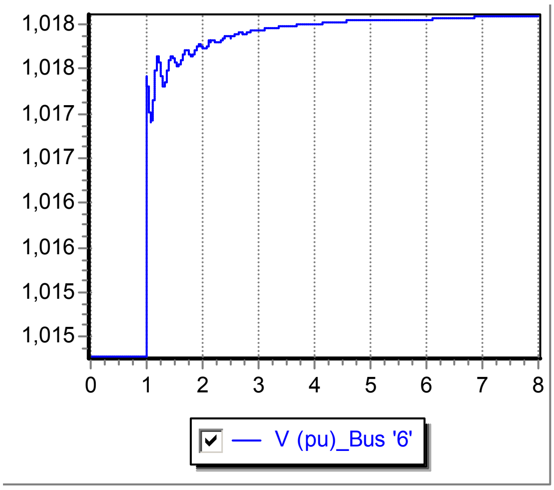

Fig. 8 Voltage at the cogeneration plant bus

Voltage in the second case also has small damped oscillations, but in the second case it increases its value for approximately 0.003 pu, Fig. 8, which is three times more than in the first case, Fig. 4.

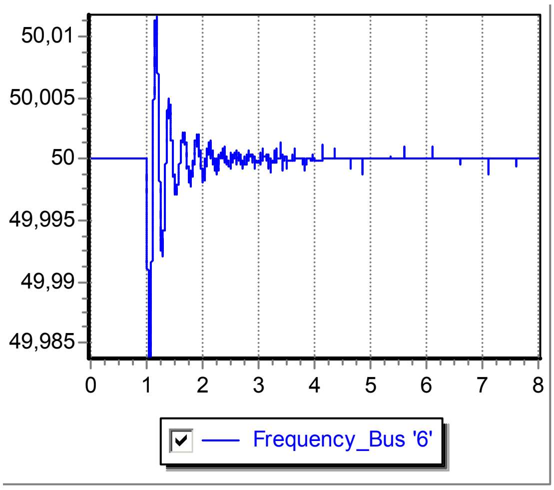

Fig. 9 Frequency at the cogeneration plant bus

Frequency of the system also has small damped oscillations, but their maximum amplitude is now 0.016 Hz, Fig. 9, instead of 0.008 Hz as it was in the first case, Fig. 5.

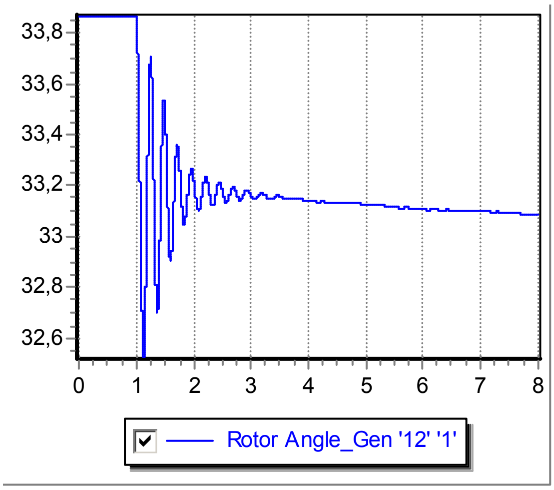

Fig. 10 Rotor angle of TE-TO generator

The rotor angle also decreased its value, Fig. 10, but this time the change was bigger than in the first case, Fig. 6. This can be explained by the voltage at the substation bus which increased more than in the first case. To fulfill transient stability equation (1), rotor angle had to decrease more than in the first case.

5 Conclusion

PowerWorld Simulator enables quick and comprehensive analysis of the grid stability. In this paper, the stability of the transmission network Osijek has been analyzed, due to the outage of the wind farm Tovarnik.

By observing the simulation results, it can be seen that the system will stay stable in both cases. Electrical power consumption in Transmission area Osijek is about 500 MW. Rated power of wind farm Tovarnik of 44 MW does not exceed 10% of consumption power in that area. When installing a wind farm with nominal output power below 10% of consumption power in some area, there should not be any problems with integration of that wind farm in the system [3, 4].

Nominal output power of wind farm in the second analyzed case was 100 MW, which is 20% of consumption power in that area. The system was also stable, but there were larger disturbances than previously seen.

System remained stable in both cases because Transmission area Osijek presents a strong grid which is very well connected with neighboring systems with 400 kV and 220 kV lines. However, neighboring systems were modeled as generators and loads, respectively. Therefore, the future work will address more detailed model of neighboring systems as well as more detailed models of particular elements of observed system (generators, transformers, lines, etc.).

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