

Modelling, Simulation and Analysis of Full Power Converter Wind Turbine with Permanent Synchronous Generator

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This paper focuses on PSS/E modelling and simulation of wind farms of full scale converter wind turbine with permanent magnet synchronous generator and their impact on issues of Kosovo power system operation. The proper modelling of wind farm projects in systems studies is becoming increasingly important to system operators. In the past decade, wind power has evolved into a significant renewable energy source which continues to grow rapidly. The increased size of wind power projects and the development of large wind parks bring about a number of opportunities and challenges. Wind grid code currently require wind turbine to have high immunity against grid faults. In addition, wind turbines that are able to provide more reactive power support are increasingly preferred. This feature can be found in a full converter wind turbines with permanent synchronous generator.

1. Introduction

During a long period of the historical development of the humankind, renewable sources of energy were the only sources at disposal. Energy from wind activity is one of the renewable sources of energy. Modern turbines, using advanced technologies, are capable to produce electric energy with a reasonable cost. Continuing development of the design of new turbines is helping in reduction of the production costs of electric energy, and making this branch of technology economically reasonable in many countries in the world. Capacity of the installed wind turbines worldwide has increased from 17.4 GW in 2000 to about 237 GW at the end of 2011 – an incredible increment, which still continues relentlessly nowadays (GWEC, 2012). In Figure 1 the development of wind power capacities installed worldwide for the time period 1995-2011 is presented.

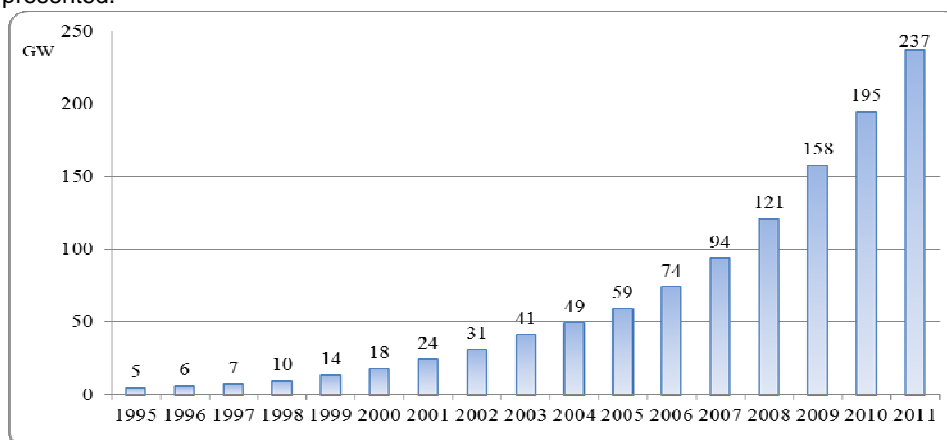


Figure 1: Development of global wind power capacities (GWEC, 2012)

In all countries of Europe, including Kosovo, there is a growing tendency of investors applying for the rights to connect in transmission or distribution grid of various powers capacities of wind generating stations. Approval of new feeding tariffs from ERO (Kosovo Energy Regulatory Office) for the energy producers from renewable sources, such as wind parks, has created very favourable conditions for potential investors. In Kosovo, since the beginning of 2009, for connection on the transmission grid has applied several foreign investors, who projected a total capacity of 157 MW "Transmission Network Development Plan" 2012-2021). Up to now, at the Kosovo Transmission System Operator (KOSTT, 2013) three applications for connection of wind turbines into the transmission grid have been submitted. Study of the impact of wind farm projects on the operating performance of the transmission system, requires adequate software, with which complex systems with a great number of power elements could be modelled. Transmission System Operator possesses a software platform PSS/E (PSS, 2013), known as the most usable software for analysing and projecting of large scale power systems. In this paper the method of modelling a Wind Generating Station is elaborated.

2. Fully rated converter wind turbine with permanent magnet synchronous generator

Development of modern wind turbine generators has evolved through the years, in the aspects of output power, dimensions, and the technology used. Conceptual scheme of wind turbines with full scale power converter; with variable speed with a synchronous generator, is shown in Figure 2. This type of turbines nowadays may or may not include a gearbox and wide range electrical generators types can be employed, for example, induction, wound-rotor synchronous or multi-pole permanent magnet synchronous. All the power generated by the generator passes through the converter, thus isolating the dynamic operation of the generator from the grid. Electric frequency of the generator can vary following the change in the wind's speed; otherwise power frequency injected in the grid remains unchanged; thus allowing variable speed operation of the wind turbine. The power converters can be arranged in different ways. Whereas the generator side converter can be a diode rectifier or a PWM (Pulse Width Modulation) voltage source converter, the grid side converter is typically a PWM source converter. The control strategy of the generator operation and active and reactive power flow to the grid depends on the type of power converter arrangement. The rotor side converter ensures the rotational speed being adjusted within a large range, whereas its grid side converter transfers the active power to the grid and attempts to cancel the reactive power consumption. (Bin Wu at all, 2011)

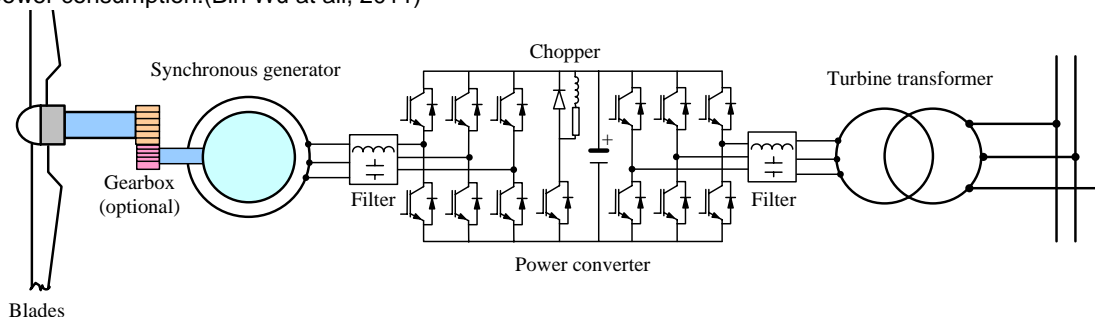


Figure 2. Schematic of a full scale converter wind turbine

3. Study Case – Simulation of the impact of the 30 MW wind park “Kitka”

In this paper the project of the wind park with 30 MW installed capacity is analysed. So called “Kitka” wind park will have 15 installed wind turbine generators, with maximal power of $15 \times 2 \text{ MW} = 30 \text{ MW}$, which will be collected through 20 kV underground cables and connected to the 20/110 kV wind park substation. The wind park substation will be interconnected to the transmission grid through 110 kV line to the nearest 110 kV transmission grid, as shown in Figure 3.

3.1 Computer modelling of the wind park

The modelling approach of wind farms is based on Wind Grid Code (2011) requirements. The aim of Wind Grid Code is to provide a self-contained description of the technical and operational requirements that are to be met by the developers and operators of Wind-Powered Generating Stations (WPGS) that wish to connect to the Kosovo electricity grid and participate in the Kosovo electricity market (Wind Grid Code, 2011). The Wind Code applies to all WPGS's that are or have applied to be connected to the transmission grid, with installed capacity of more than 10 MW. Developers of WPGS-s intending to apply for connection to the transmission grid should be aware that they are required to provide project planning data at this

level of detail at the time of filing the application in order for the Transmission System Operator to carry out the relevant connection design and impact studies. Upon receiving the Connection Application, planning engineers will perform the impact and design study which cover:

- Impact of the Wind Farm connection on the power system security, reliability and quality of supply.
- Design of the appropriate direct assets from the commercial boundary (110 kV grid).
- Design of the necessary Infrastructure reinforcement of the Transmission System, if is required.

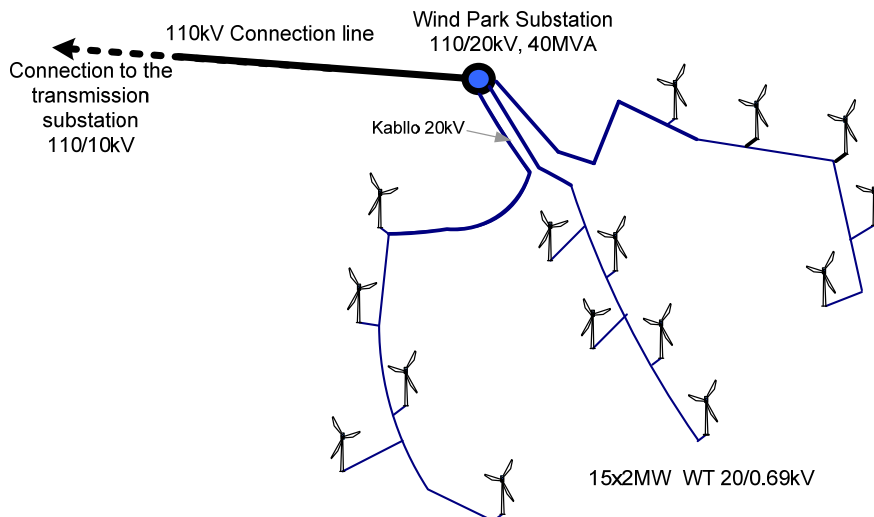


Figure 3. Connection of 30 MW wind park project "Kitka" in transmission grid

Based on grid code and wind grid code requirements a new connection (a generator or load) could be connected into the transmission network if the following conditions are fulfilled:

- System operation security after the connection shall not be negatively affected.
- The quality and reliability of demand supply shall comply with grid code requirements
- The steady state and transient stability of power system should have sufficient security margin. (Kabashi et al., 2011).

In order to come to the conclusion whether the project could be connected into the transmission network, first a computer model of the system must be prepared, which contains the detailed wind park components (wind turbines, cables, transformers, bus bars etc.). Modelling has to be carried out in two aspects: steady state modelling and dynamic modelling (Gashi at al, 2012) using the guidelines of the PSS/E manual version 33 (PSS, 2012). In this case three common calculations are essential for assessing the impact of Wind Farms on security and reliability of power systems: power flow calculation, short circuit calculation and dynamic calculations.

3.2 Modelling of the wind park for steady state

Steady state modelling of power system in the software platform PSS/E is simple and is based on the modelling of transformers, cables and generators, which contains respective models that must be fed with correct parameters regarding to the specific project (Fox at all, 2007). A power flow calculation is to determine the power flows on transmission lines and transformers and the voltage profile of system bus bars. This calculation is fundamentally important for the planning and design of the connection of wind farms to the transmission grid. N-1 Security criterion is essential for the proper design of transmission networks to ensure the security and reliability of power supply. System performance is compared to operating limits and criteria. Short Circuit calculations also play a very significant role for the proper selection of high voltage equipment and the setting of protection relays (Slootweg, 2003). In Figure 4, a detailed model of 30 MW Wind Park connected to the transmission network is shown. In Figure 4 it can be seen that the wind park, from the point of view of reactive power, is completely compensated and there is no need for additional compensation due to the technology of the turbine with full converter with a synchronous generator. From the steady state point of view, connection of the wind park of capacity 30 MW does not expose to risk the security and reliability of the operation of the transmission system (KOSTT, 2013).

3.3 Dynamic modelling of the wind park

In order to analyze the dynamic processes, the system is mode led based on the dynamic parameters of electric machines (synchronous and induction machines) and regulatory accessory equipment (turbine,

speed governors, exciters, etc.). Wind park which contains the wind turbines is similarly modeled. Library of PSS/E software contains all kinds of generic models of turbines mentioned earlier in this paper. In its special platform, PSS/E software uses numerical methods of integration with a timescale of 8 ms. Dynamic calculations in PSS/E, first require calculation of initial conditions of the system, which the software imports from the model of stationary state (Akhmatov, 2003).

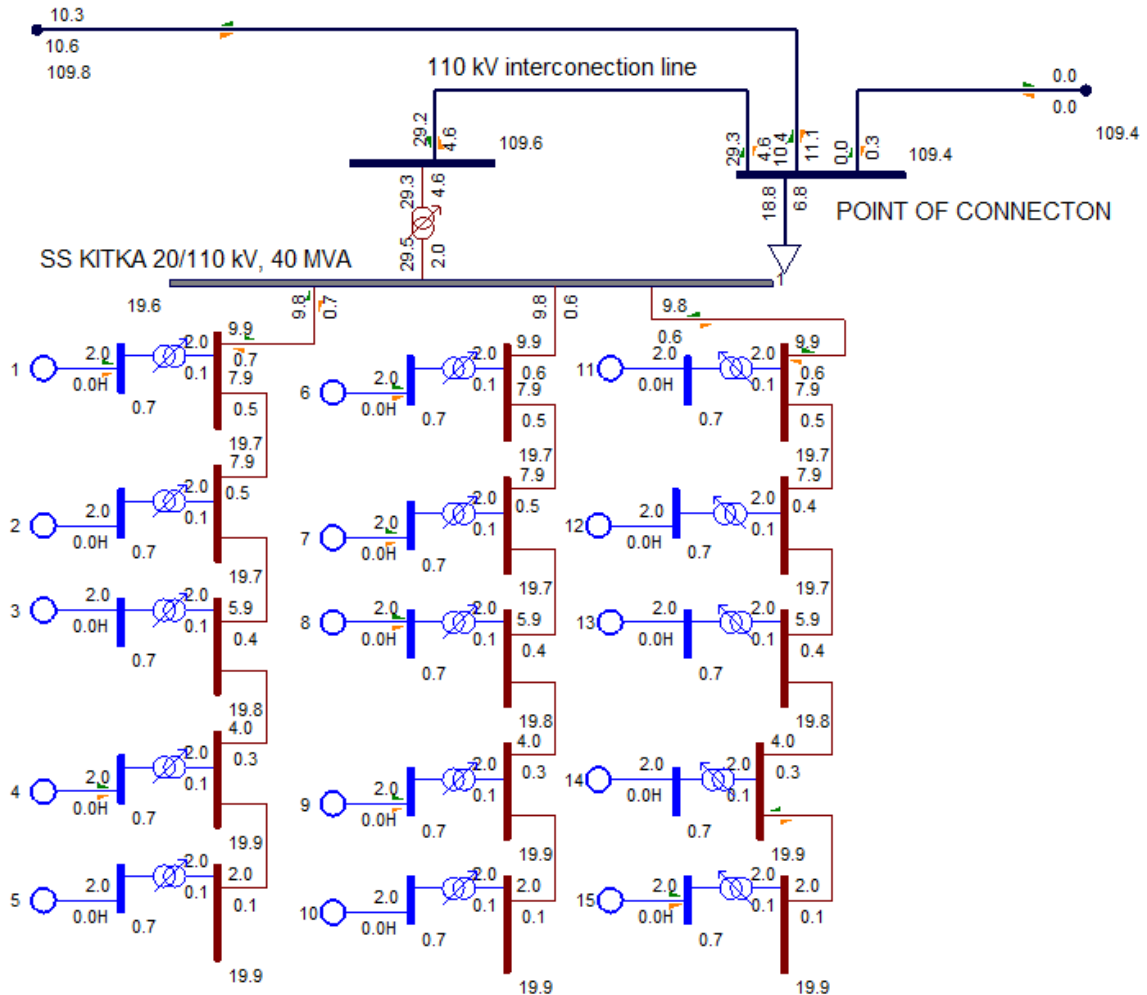


Figure 4. Detailed model of 30 MW Wind Park on PSS/E

In this paper, wind park is modelled in detail. 15 generators of type with full converter with a synchronous generator 2 MW of power are modelled. The rest part of the system represents the large scale model of south-east European power system. PSS/E software is well-known for calculation of large scale complex power systems, which exhibits much more realistic pattern of real characteristics of the system than the simplified models. On the other hand, the more complex and the greater the number of elements in the model, the more time is needed for simulation, especially during the simulation of dynamic processes (Perdana, 2008). This complex model is used to identify more realistically the impacts caused by the connection of the wind park of capacity 30 MW into the transmission system of Kosovo.

4. Dynamic simulations – results and discussion

For all simulations carried out, following conditions are imposed: Fault caused in connection terminals of the energetic wind park at the voltage level 110 kV is a bolted symmetrical three-phase applied one second after the start of the simulation. The fault clearing time is 9 cycles and the simulation time is 20 seconds.

4.1 Response of voltage during the fault at the connection point

After the occurrence of the three-phase short circuit at the 110 kV bus bar of the collector substation Kitka 20/110 kV, the voltage drop occurs almost in the entire transmission system. More precisely, the closer the location of the fault, the greater will the voltage drop be. This transient voltage drop lasts as long as the time of activity of protective relays in order to isolate the fault. In Figure 5, is shown the impact of short circuit for three monitored bus bars: lead at short circuit 110 kV that represents the point of connection of the collector substation with the transmission network, lead in the secondary side 20 kV of the collector substation, and terminals 0.69 kV of one of the 15 wind turbine generators.

In Figure 5 is shown the voltage diagram of for the lead at the short circuit dropping to the zero value, whereas at two other leads the minimal voltage is above 0.2 p.u. (per unit). It could be noticed the transient process at the voltage of the terminals of the generator, where the voltage starts increasing even as long as the short circuits lasts. At the instant when the fault is eliminated, the voltage is very rapidly reversed at the initial value before the fault. Capability of the wind turbine generator to stay in operation after the occurrence of fault in the system, under certain conditions, is a basic requirement of the Wind Grid Code. From the voltage point of view, wind turbine with full rated convertor fulfils the requirements of the above mentioned wind code.

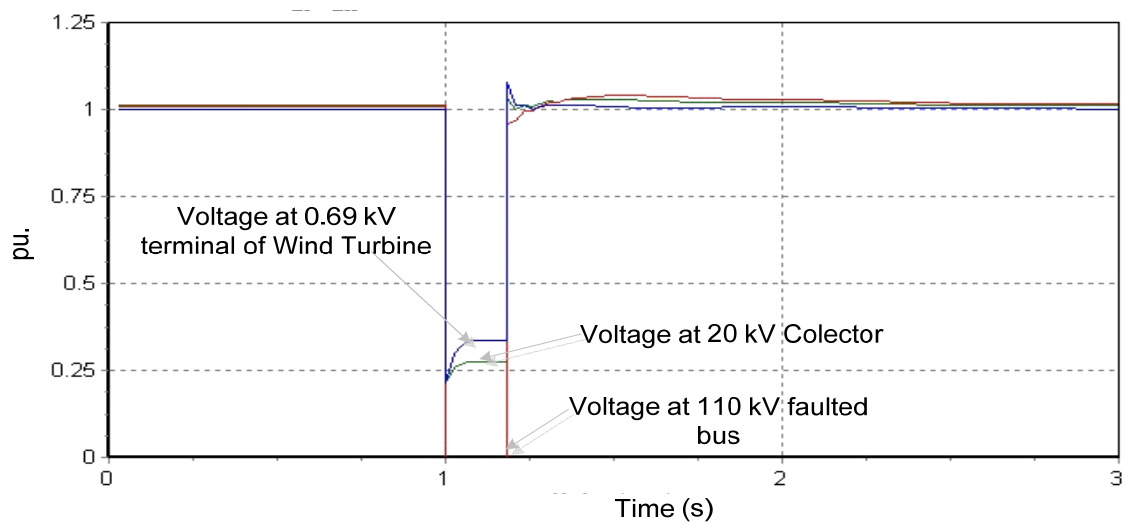


Figure 5. Voltage response after fault occur in the 110 kV connection point of wind farm

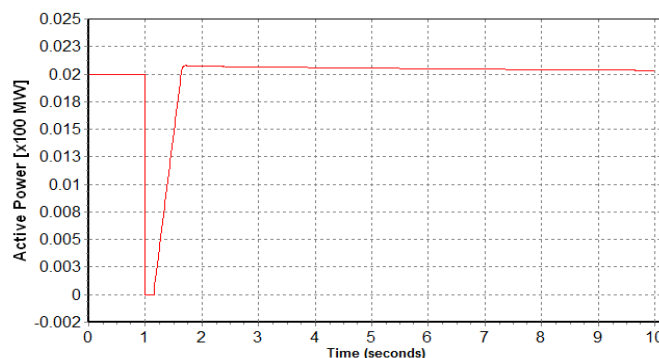


Figure 6. Active power response of wind turbine generator after fault

4.2 Response of active and reactive power during fault at connection point

Figure 6 shows that during the fault the wind turbine generator (WTG) electrical power output for selected wind turbine generator WTG1, suddenly decreases to a very low close to zero, after the fault occurs.

After the fault is cleared, the power output recovers very quickly to pre-fault value of 2 MW. Total power of the wind park behaves in the same manner, so that the initial power of 29.5 MW injected into the net before the occurrence of the fault, drops very rapidly to a value close to zero during the fault, and recovers for a short time to the initial value after the elimination of the fault. The reactive power output from selected

wind turbine generator is shown in Figure 7. Before the fault occurs, the generated reactive power is zero and the wind farm operates at unity power factor. Each WTG units during the fault provide reactive power support to the grid ($0.05 \times 100 \text{ MVAR} = 0.5 \text{ MVAR}$), as is required by the Wind Grid Code. In total the wind farm during the fault, inject around 7.5 MVAR reactive power to the grid.

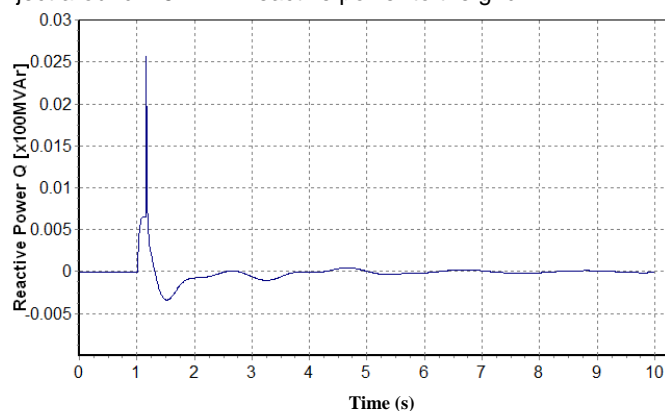


Figure 7. Reactive power response of wind turbine generator after fault

5. Conclusion

By continuing build up of large capacities of wind power, problems began to arise for Transmission Operators world wide. System Operators has modified the own Grid Codes, imposing special technical criteria for wind turbine generators. Turbine manufacturers have been complying very rapidly with new requirements, passing from the concept of turbines with constant speed to those with variable speed. In these paper simulations of the power flows, short circuits and dynamics are carried out in the complex computer model using simulating platform PSS/E, with the purpose to analyse the impact of connection of the 30 MW Wind Park in the transmission network. As the penetration of wind power onto the Kosovo power system increases, the dynamic behaviour of the power system is increasingly affected. The overall conclusion of these analyses is that the wind farm does have an influence on the transmission system but all of the requirements of the Grid Code relating to the wind farm connection were satisfied. New technologies of wind turbines, i.e., the concept of the turbine with variable speed with full convertor, allow integration of considerable capacities into the transmission network.

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