Power Stability and Quality Improvement using Ideal DFIG

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ABSTRACT: *The transmission power system has the first DFIG wind farm, and its dynamic characteristics are studied in this paper. We measure it using the MATLAB/SIMULINK tool to study the behaviour. We have designed the wind turbine and power system with real-life data. We intend to improve the power stability and quality for which we find how the DFIG works in various situations. We did simulations for tests with short circuits on voltage level and wind speed changes.*

Keywords: DFIG, Wind Turbine, Dynamic Characteristics, Macedonian Power System

Received: 25 November 2022, Revised 14 February 2023, Accepted 26 February 2023

DOI: 10.6025/jes/2023/13/2/46-55

1. Introduction

The Wind power has widely proved to be one of the most competitive and efficient renewable energy sources with a most favorable technical and economic prospects. This is due to the existence of non-exploited wind resources and to the fact it is a clean energy with a reduced cost of installation and maintenance. Wind turbines, which typically are centralized in wind farms, are constantly planned and commissioned. The produced electrical power from wind is steadily increasing. As a consequence, wind power has reached significant influence on the power production and penetration levels imposing new challenges to the Transmission System Operators (TSO). The process of high wind energy penetration requires the impact analysis of this new technology in power systems. Impact of wind energy on power systems is related to security, stability, power quality and operation of power system.

Among the several wind energy technologies, a generation of variable speed wind turbines present many advantages compare to the fixed speed wind turbines. These wind energy conversion Among the several wind energy technologies, a generation of variable speed wind turbines present many advantages compare to the fixed speed wind turbines. These wind energy conversion doubly fed induction generator (DFIG) wind turbines are nowadays more widely used especially in large wind farms. The main reason for the popularity of the DFIG is their competitve cost and performance and ability to supply power at constant voltage and frequency while rotor speed varies. Following the fact that most country intend to use renewable energy sources in their power systems, our case study came as result of the initial project of implementing wind power energy into the electrical power system of Macedonia [11]. In the initial project, authorities have planned to implement DFIG because of the fact that it will drastically decrease the costs for invertors, it will enable control of the torque and as last, it will increase the efficiency of wind extraction. An electromagnetic transient model is developed on the widely used simulation platform MATLAB/SIMULINK utilizing its SimPowerSystem toolbox. The model is applied for a study of a grid-connected wind farm interacting with varying wind speed and grid fault. Because the turbine is a set of many sub models that are working as one, proper explanation for every sub model will be given. Thanks to the unlimited possibilities of MATLAB, modeling the wind turbine was easy.

2. Wind Turbine Model Description

Several generator types are in use for wind power applications today. The main distinction can be made between fixed speed and variable speed wind generator types. The most widely used variable speed wind generator concepts are double fed induction generator.

The DFIG is a wound rotor induction generator with a voltage source converter connected to the slip rings of the rotor [9]. The stator winding is coupled directly to the grid and the rotor winding is connected to the grid via AC/DC/AC converter. Wind turbine is coupled to the induction generator through a mechanical shaft system, which consists of a low-speed and high-speed shafts and gearbox between. In order to produce electrical power at constant voltage and frequency to the utility grid over a wide operation range, the power flow between the rotor winding and the grid must be controlled both in magnitude and in direction. Therefore, there are two IGBT PWM converters: a rotor side converter (RSC) and a grid side converter (GSC) connected back-to-back by a dc link capacitor. The crowbar circuit is used to short circuit the rotor side convertor in order to protect it from over current in the rotor during transient disturbances.

The operation of the DFIG wind turbine is regulated by a control system, which generally consists of two parts: the electrical control of the DFIG and the mechanical control of the wind turbine blade pitch angle. Control of the DFIG is achieved by controlling the RSC and GSC, as shown in Figure 1.

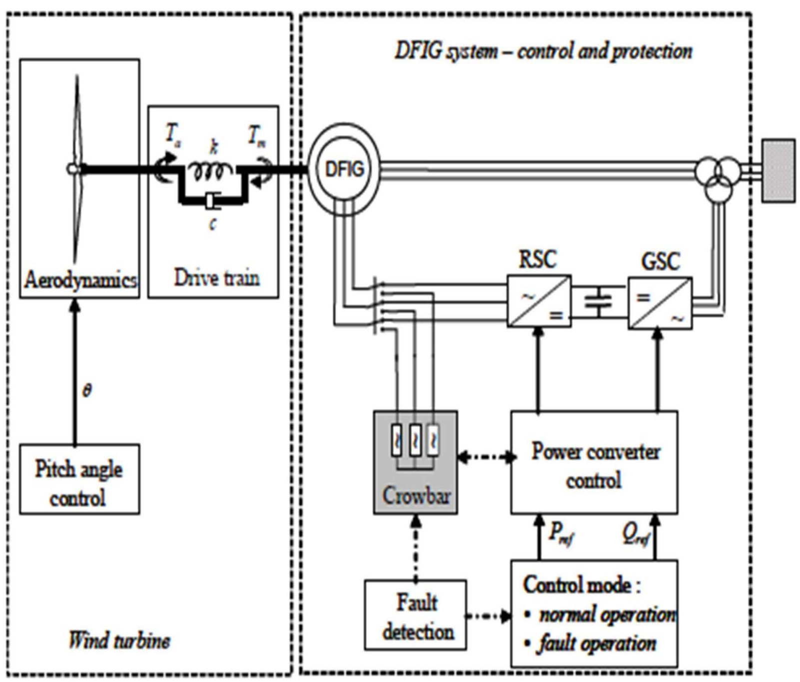


Figure 1.DFIG wind turbine configuration and control

3. Model of the Generator

It would be of interest to describe the basics of the DFIG according to electrical machines theory. The generator is modeled according the dq component system [6]. At start, a brief mathematical explanation is provided. The mathematical model needs mathematical constants according equivalent circuit presented on Figure 2.

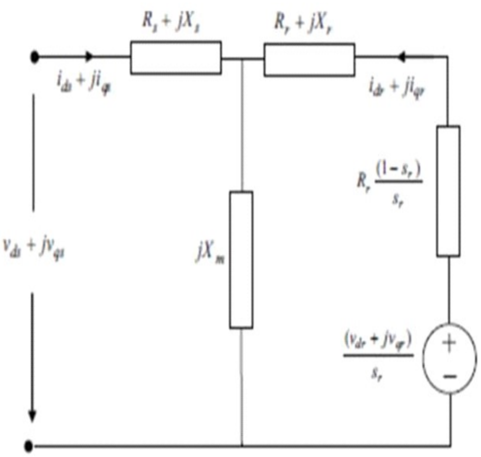


Figure 2. Equivalent circuit of DFIG

$$E_d' = -\frac{\omega_s L_m}{L_{rr}} \psi_{qr} \tag{1}$$

$$E_q' = \frac{\omega_s L_m}{L_{rr}} \psi_{dr} \tag{2}$$

$$X_s = \omega_s L_{ss} \tag{3}$$

$$X_s' = \omega_s \left(L_{ss} - \frac{L_m^2}{L_{rr}}\right), \quad T_0' = \frac{L_{rr}}{R_r} \tag{4}$$

in order to explain the model properly

$$\frac{X_s'}{\omega_s}\frac{di_{qs}}{dt} = v_{qs} - \left[R_s + \frac{1}{\omega_s T_0'}(X_s - X_s')\right] i_{qs} - (1 - s_r)E_q' - \frac{L_m}{L_{rr}} v_{qr} - \frac{1}{\omega_s T_0'} E_d' - X_s' i_{ds} \tag{5}$$

$$\frac{X_s'}{\omega_s}\frac{di_{ds}}{dt} = v_{ds} - \left[R_s + \frac{1}{\omega_s T_0'}(X_s - X_s')\right] i_{ds} - (1 - s_r)E_d' - \frac{L_m}{L_{rr}} v_{dr} - \frac{1}{\omega_s T_0'} E_q' - X_s' i_{qs} \tag{6}$$

$$\frac{dE_d'}{dt} = s_r \omega_s E_q' - \omega_s \frac{L_m}{L_{rr}} v_{qr} - \frac{1}{T_0'}\left[E_d' + (X_s - X_s') i_{qs}\right] \tag{7}$$

$$\frac{dE_q'}{dt} = -s_r \omega_s E_d' - \omega_s \frac{L_m}{L_{rr}} v_{dr} - \frac{1}{T_0'}\left[E_q' + (X_s - X_s') i_{ds}\right] \tag{8}$$

4. Model of the Drive Train

The drive train is the mechanical part of the system that consists of gearbox, shafts, turbine and other important mechanical parts. In this study, the two mass drive train model is used [7] and is presented on Figure 3. The two mass drive train model is used because of the fact that the turbine model is represented as one mass, while the generator is the other mass. Both masses are connected with a mechanical shaft that possesses certain damping and stiffness value. In the expression, T represents the torque, Ω is the angular speed and J is the inertia moment. In the expressions, subscripts t and g represent the generator and turbine side respectively.

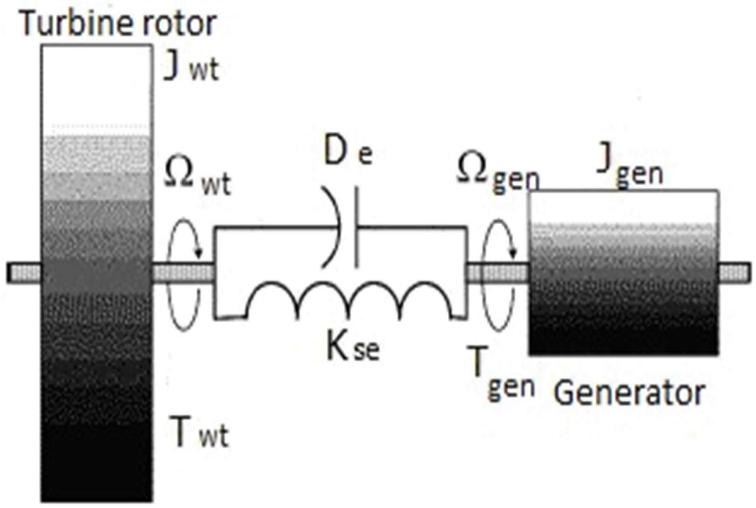


Figure 3. Two mass drive train model

$$T_{wt} = J_{wt} \frac{d\Omega_{wt}}{dt} + D_e(\Omega_{wt} - \Omega_{gen}) + k_{se}(\Theta_{wt} - \Theta_{gen}) \frac{d\Theta_{wt}}{dt} = \Omega_{wt} \tag{9}$$

$$-T_{gen} = J_{gen} \frac{d\Omega_{gen}}{dt} + D_e(\Omega_{gen} - \Omega_{wt}) + k_{se}(\Theta_{gen} - \Theta_{et}) \frac{d\Theta_{gen}}{dt} = \Omega_{gen} \tag{10}$$

where equivalent stiffness and equivalent moment of inertia for the rotor is given by:

$$\frac{1}{k_{se}} = \frac{1}{\frac{k_{wt}}{k^2_{gearbox}}} + \frac{1}{k_{gen}} \tag{11}$$

$$J_{wt} = \frac{1}{k^2_{gearbox}} \cdot J'_{wt} \tag{12}$$

5. Rotor Side Controller

The main purpose of using the rotor side controller is to measure and control the voltage and energy on the output of the turbine. The logic that is used is PI controllers. By using PI controllers, the overall energy is added to the overall loss of energy, and that sum is compared to the reference value from the characteristic. When the controller works in voltage regulation mode, the PI control is performed through the UI characteristic. The PI controller is actually used to decrease the error of the power to zero. The simplified block diagram of the rotor side converter is presented on Figure 4.

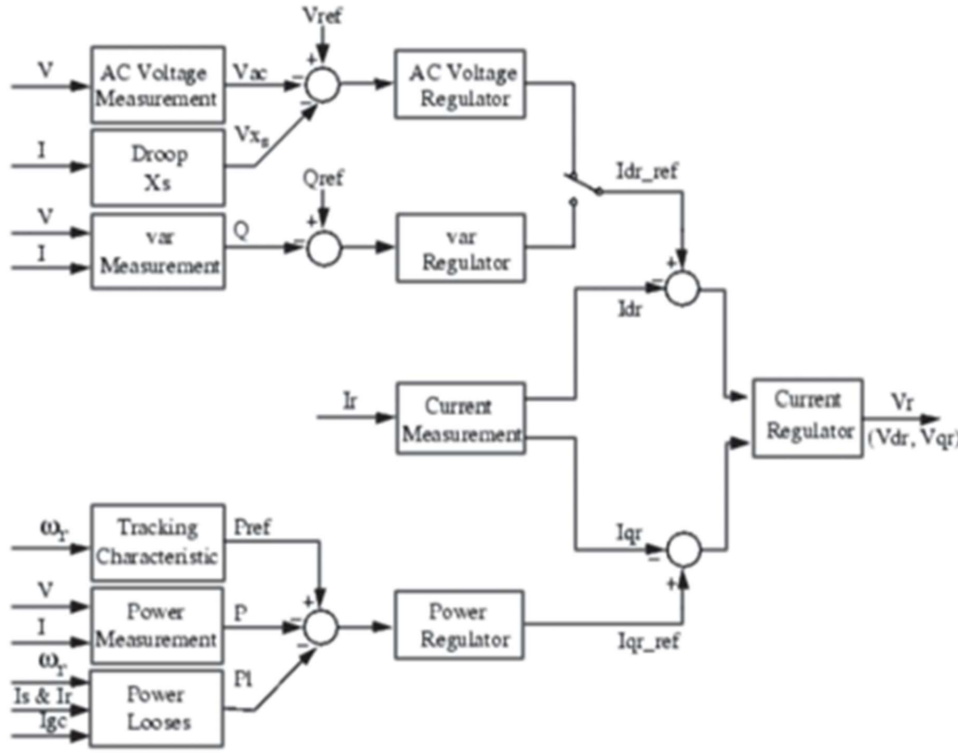


Figure 4. Rotor side controller

5.1. Wind turbine model

For the wind turbine model that is used here, first we must start from the basic concept of wind turbines. Every wind turbine uses the kinetic energy that is present in the wind and transforms it into mechanical energy. The power that is developed by the turbine is represented with the following equation:

$$P = \frac{1}{2} C_p \rho A V^3 \tag{13}$$

where C_p denotes the power coefficient, ρ is the air density, V is the wind velocity and A is the area of the turbine blades. If we insert another variable, called tip speed ratio, which is a ratio between turbine blade linear speed and the wind speed. The mathematical expression is

$$\lambda = \frac{R\omega}{V} \tag{14}$$

If in the expression (13) we substitute the expression (14), we get the simplified expression for the power from the wind turbine

$$P = \frac{1}{2} C_p(\lambda) \rho A (\frac{R}{\lambda})^3 \omega^3 \tag{15}$$

In this study case we have used the mechanical characteristic that is presented on Figure 5.

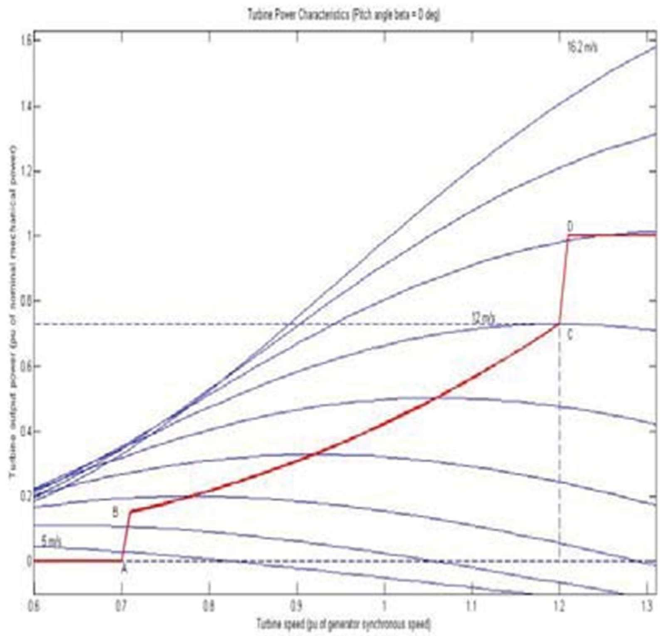


Figure 5. Mechanical characteristic of the used wind turbine

On Fig. 5 on the horizontal axis we have assigned the parameters for the turbine speed and on the vertical axis we have presented the output power of the turbine.

6. Pitch Angle Controller

On Fig. 5 on the horizontal axis we have assigned the parameters for the turbine speed and on the vertical axis we have presented the output power of the turbine.

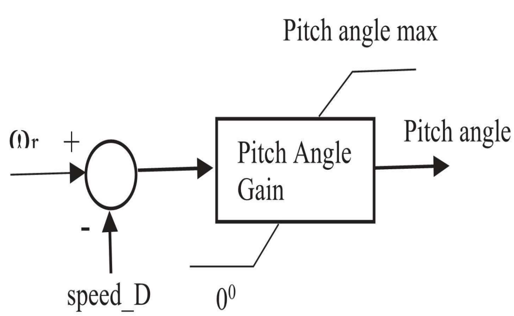


Figure 6. Pitch angle controller

The pitch angle controller tracks the speed that is defined in the speed tracking characteristic.

7. Simulation

We investigate dynamic model of wind farm which will located in southeastern town of Bogdanci [11]. The wind farm is planned to be connected through transformers followed by a single set of transmission lines to a grid. Power generation in the grid is dominated by synchronous generators, so the grid is treated as an infinite bus. In this study case we have made a simplified MATLAB Simulink model of the transmission power system of Macedonia. In that power system there is a wind farm of 50 MW that has to be installed. The number of used wind turbines is 22, each one of them with installed power of 2,3 MW. All turbines are DFIG. In the initial MATLAB model of the study case, we implemented all 22 turbines in one system, and thus we received one system with 50 MW of power. A block diagram of the model used in this study case is presented on Figure 7.

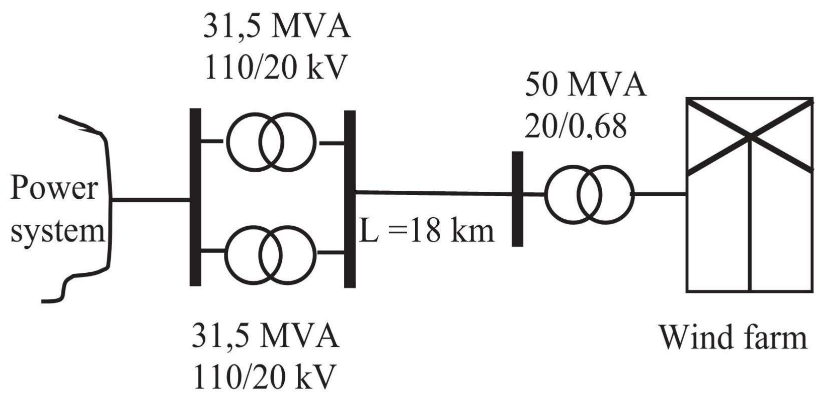
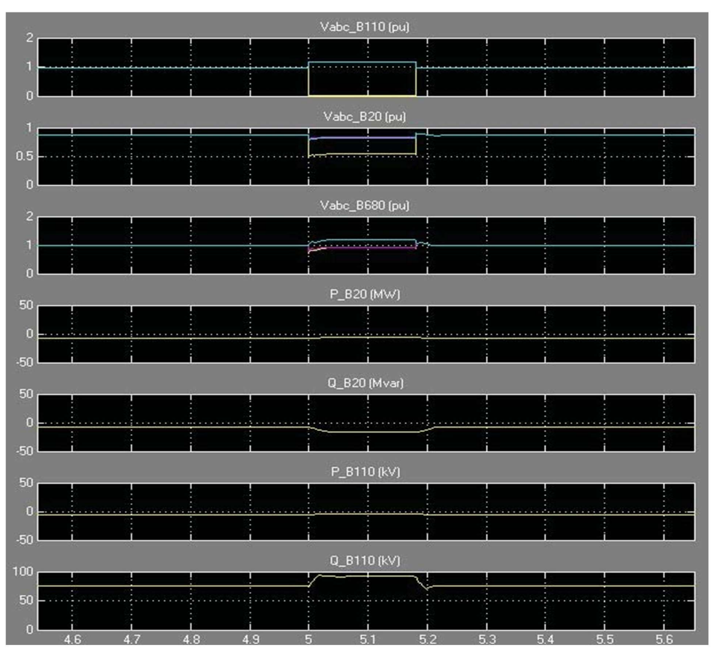


Figure 7 Wind farm connection on power system

Two tests have been performed. The first test was made under short circuit on the 110 kV bus near the wind farm, or to be more specific, on the place where the wind farm is connected to the transmission power system. At the second test we assumed that on the wind farm there was a sudden change on the wind speed. The turbine works in two modes. The first mode is VAR Regulation while the other mode is the Voltage regulation. It is in everyone's interest to perform simulations under these two working modes. At first we will start by assuming that we have single phase short circuit on the 110 kV bus.

As first test we decided that we will use the case where the wind farm works in Voltage regulation mode. The single phase short circuit starts at 5 sec and lasts until 5.18 sec. For this purpose we present the following screenshots for the Network parameters and Turbine parameters, accordingly. As first diagram we will present the Network parameters on Fig. 8, while the Turbine parameters are presented on Figure 9.



Figuee 8 Network parameters (VAR regulation mode)

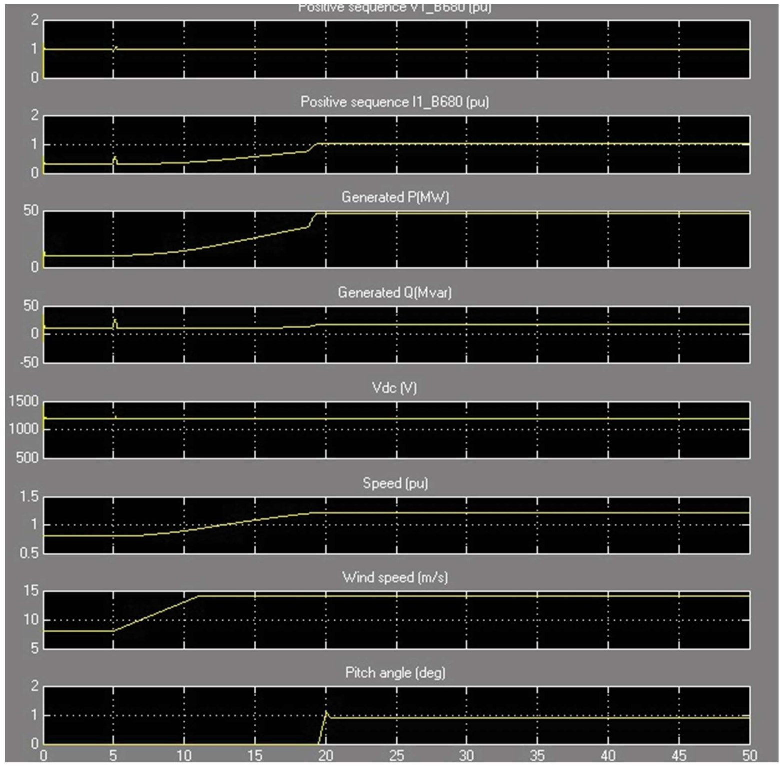


Figure 9. Turbine parameters (VAR regulation mode)

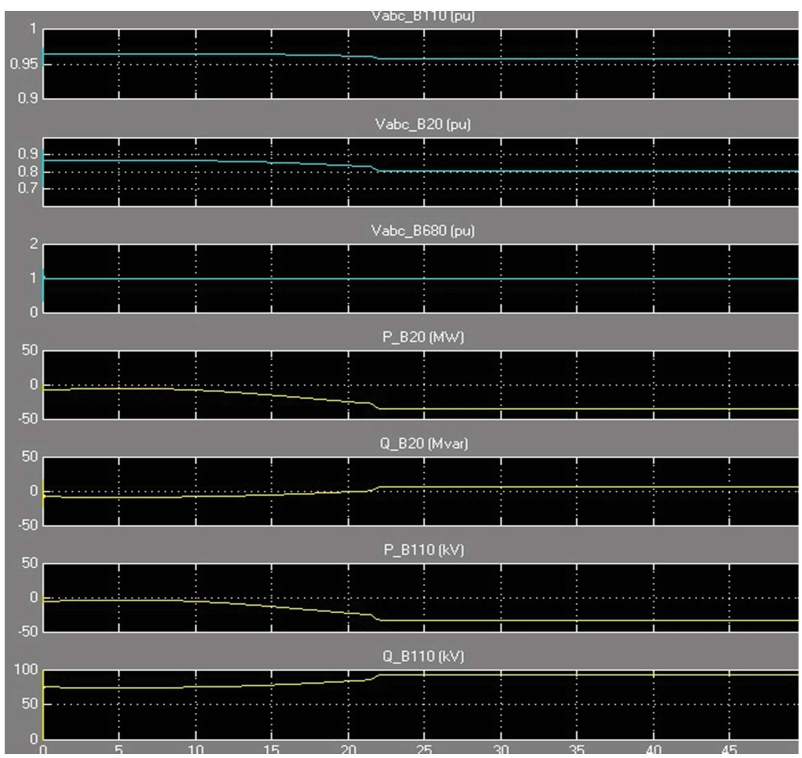


Figure 10. Network parameters (Voltage regulation mode)

In the second experiment we assume that the wind turbine worked in Voltage regulation mode. The turbine works during the whole period that is given in the simulation parameters. On Figure 10 we present the Network parameters and the results from the simulation.

As it is presented in Figure 8, on the 5th second there is an active short circuit on the 110 kV buses. During the short circuit period we see that the voltage on one phase on the 110 kV bus drops to 0 and lasts during the short circuit period. It is in our interest to track all the parameters in the wind turbine. We can see from Fig. 9 that the voltage at the wind turbine terminals during the short circuit drops to 0.97. The turbine protection system is set up to react in cases when the voltage drops under 0.95 pu for time greater than 0.1 seconds. The wind farm continues to work and gives full power in the transmission system. In conclusion we can state that the short circuit didn't affect the work of the turbines. In the second working mode which is called VAR regulation mode, the wind turbine trips and stops working from the 5th second.

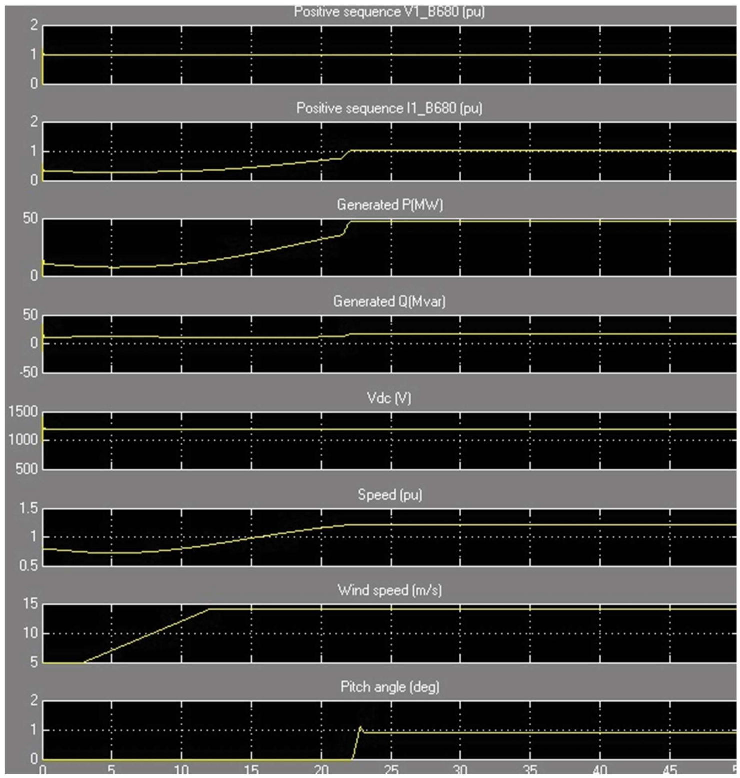


Figure 11. Turbine parameters (Voltage regulation mode)

In the second experiment we assume that the wind turbine worked in Voltage regulation mode. The turbine works during the whole period that is given in the simulation parameters. On Figure 10 we present the Network parameters and the results from the simulation.

As it can be seen from the simulation results in Figure 10 and Figure 11, in this mode, the system continues to work and generates power into the transmission power system.

From Figure 11 that represents the turbine parameters it can be seen that the wind speed increases to 14 m/s starting from the 3rd second of the simulation period. The pitch angle increases up to 1.2 degrees in order to control the mechanical power of the turbine. It is a protection algorithm which is used in the protection of the wind turbine. In the VAR regulation mode, the wind turbine trips and doesn't insert energy into the power system, because of the fact that the protection which is set up to disconnect the turbine from the network in case the voltage on the output of the turbine drops under 0.95 pu, reacts and disconnects the turbine from the network.

7. Conclusions

From the simulation results shown in the previous section of the article a very useful conclusion can be drawn. Because Macedonia is in constant need of electrical energy, our proposal would be to implement the wind turbines into the system, and they should work in Voltage regulation mode. The place where the turbines will be installed is windy, and if the VAR regulation mode is used, then the system won't have great benefit of them. The Voltage regulation mode is more tolerant unlike the other mode, where the turbine trips and disconnects from the network.

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