Wind Turbine Fault Ride Through in Weak Power System

Blagoja Stevanoski[1] Nikola Acevski[2] and Metodija Atanasovski[3]

Abstract – **This paper deals with dynamic characteristics of the first DFIG wind farm which is connected to the transmission power system of Republic of Macedonia. Matlab/Simulink software is used to present the fault ride-through ability of the wind farm. The DFIG wind turbine and the power system are modelled with real characteristics, like in the initial project. Results from tests short circuit on 110 kV voltage level buses will be simulated in order to define how the DFIG will react under these circumstances and which actions should be undertaken in the power system to improve power system stability.**

Keywords – **DFIG, wind turbine, dynamic characteristics, fault ride-through, grid code, Macedonian power system**

I. INTRODUCTION

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 and large wind generation units have capacities comparable to conventional power plants. 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) [11]. 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. As a consequence grid operators require them to participate in grid voltage support in steady state as well as during faults. Many grid codes contain dynamic requirements like the fault ride through (FRT) ability of generating units. Additionally, voltage support during grid fault due to the injection of short time reactive current is requested in certain grid codes. FRT capability and voltage support allow a secure operation of the 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 systems are connected to the grid through voltage source converters to make variable-speed operation possible. The 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 competitive 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 Republic of Macedonia [13]. In the initial project, authorities have planned to implement DFIG because of the fact that it will drastically decrease the costs for investors, it will enable control of the torque and as last, it will increase the efficiency of wind extraction. Therefore, the paper includes dynamic simulation results of DFIG-based wind farm connected to a weak power system (the installed capacity of the Macedonian power system is about 1350 MW) during grid disturbances. The simulations are made by using the simulation platform Matlab/Simulink utilizing its SimPowerSystem toolbox.

II. 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 concept is doubly fed induction generator. DFIG can combine fast control due to the high switching frequency of the power electronics and moderate costs of converter system [2].

The DFIG is a wound rotor induction generator with a voltage source converter connected to the slip rings of the rotor [10]. The number of pole pairs varies between two and three. Therefore slow speed 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. The stator winding is coupled directly to the grid and the rotor winding is connected to the grid via AC/DC/AC converter. The mechanical power generated by the wind turbine drives the DFIG, which feeds electrical power into the grid through the stator and rotor windings. 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. Therefore, there are two PWM converters: a rotor side converter (RSC) and a grid side converter (GSC) connected back-to-back by a dc link capacitor. The converters allows controlling the amplitude, frequency and phase angle of the rotor voltage. This enable variable speed operation of the DFIG, which can be used to adopt the generator speed according wind speed to increase the wind power utilization . The speed range of the generator is about ± 30% of the synchronous speed. Thus the speed of the generator is

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decoupled from grid frequency [5].

The voltage source converters are usually equipped with Insulated Gate Bipolar Transistors (IGBT) in a standard three-phase bridge configuration. The IGBT are controlled by pulse width modulation signals from a digital signal processor. The rotor circuit and so the converter circuit can be dimensioned for 20-30% nominal active power of wind turbine. The power flow through the rotor can be bidirectional. The power flows into the rotor when the wind turbine operates at sub synchronous speed, with low mechanical input power. The rotor power flow reverses at super-synchronous speed. Thus, with high mechanical input power, part of power is fed to the grid through the stator and part through the back-to-back converter. For protecting the components against overvoltage's and overcurrent's a DC-link chopper and a rotor crowbar are included. 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 chopper protects the DC-link against excessive voltage following grid faults.

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 Fig. 1.

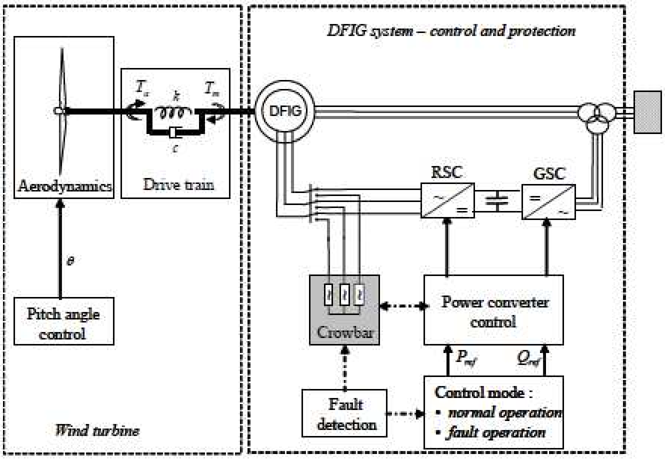

Fig. 1. DFIG wind turbine configuration and control

A. Wind turbine during grid fault

At the occurrence of a fault in the network, high currents are induced in a DFIG. Therefore, the RSC switches must be blocked to avoid their damage and at the same time DFIG wind turbine can be protected by using a different methods. A standard solution is short-circuiting the rotor circuit through an external resistance called crowbar resistance. Modern DFIG wind turbine can also be protected with a DC chopper. At the event of a short-circuit, the RSC switches are blocked and the rotor current is led into the DC-link capacitor through anti-parallel diodes of the RSC. In this way the rotor circuit is rapidly demagnetized and the RSC can be restarted when the rotor current and DC-link voltage decrease below a certain value.

The high crowbar resistance causes the ac component of the symmetrical short-circuit current to decay more rapidly and after some periods, the short-circuit current of a DFIG is made up predominantly of a dc component. Someone authors have been proposed to calculate the symmetrical short-circuit current in the same manner as done for a SCIG (squirrel cage induction generator), but incrementing the value of the rotor resistance in the expression for the rotor transient time constant by the value of the crowbar resistance. When the RSC is reconnected it control the stator current and DFIG may be looked as a constant current source.

The RSC controls independently the active and reactive power injected by the DFIG into the grid in a stator flux dq-reference frame [10]. The q-axis current component is used to control the active power using a maximum power tracking. The d-axis current component is used to control the reactive power exchanged with the grid, which in normal operation is set to zero. In case of disturbance, if induced current in the rotor circuit is not high enough to activate the over-current protection, the RSC is set to inject reactive power into to grid in order to support the voltage restoration.

The objective of the GSC is to maintain the voltage at the DC link between both converters. In case of disturbance, the GSC is set to inject reactive power into the grid, whether the RSC is blocked or is kept in operation. As for the RSC, the control of the GSC is performed using d and q-axis current, but instead of rotating with the stator flux, the axis rotates with the grid voltage.

III. GRID FAULT RIDE-THROUGH REQUIREMENTS

The fault ride-through requirements has been imposed in order to avoid significant loss of wind turbine production in the event of grid faults. At the beginning, wind turbine were only required to disconnect from the grid when a grid fault was detected. However, with the increased capacity of the wind turbines in the power system, such a disconnection of wind turbines could generate problems in the control of frequency and voltage in the system, and as worst case a system collapse. Therefore, the large increase in the installed wind capacity in transmission systems necessitates that wind generation remains in operation in the case of network disturbances. For avoiding scenarios where generators are disconnected during grid faults, transmission system operators have developed voltage and time duration profiles that define requirements of a generator to "ride through" grid faults without disconnection [18]. Voltage dips following a fault in the system are expected to be above this curve. The duration of the voltage dip is dependent on the speed of the protection system. Since TSO in different countries may have different protection rules, the grid fault ride-though (GFRT) requirements are specific to each national grid code. The voltage-time curves from Macedonian national grid code is shown in Figure 2. A wind turbine is required to remain connected to the grid if the voltage at the point of common coupling (PCC) during fault always remains above the voltage-

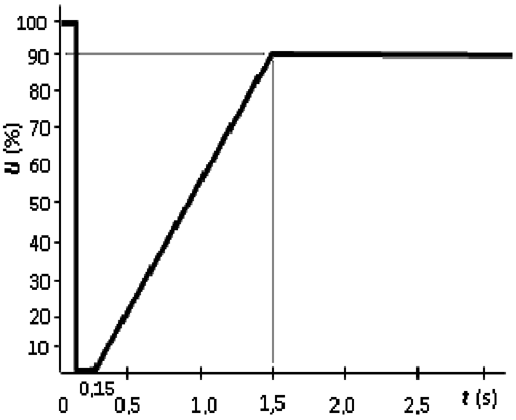

Fig. 2 Voltage requirement at PCC during a fault

time curve given in the grid code. The 150 ms delay shown in the figure accounts for the normal operating time of protection relays. Besides remaining connected, a wind turbine may also be required to provide reactive current support to the grid during voltage dip, to support and faster restore the grid voltage. Wind turbine must support voltage with additional reactive power during voltage collapse. Voltage regulator must, within 40 ms after fault recognition, to deliver reactive power at low voltage side of the block transformer of at least 2% of the rated current for each percent of the voltage dip. If necessary, it should be possible to deliver reactive power to at least 100% of the nominal current [11].

IV. SIMULATION

The simulation performed in this work concern the first wind farm in Macedonia, located near southeastern town of Bogdanci [15]. The rated power capacity of the wind farm is 36,8 MW which is installed at first phase. There are 16 wind turbines (Siemens SWT-2,3-93), each one of them with installed power of 2,3 MW equipped with doubly fed induction generators. The wind farm is connected through step up transformers 20/110 kV followed by a classical 110 kV AC overhead line to a transmission network. For the studies the point of common coupling (PCC) is defined at a busbar of the connected grid. In this study case a simplified Simulink model of the transmission power system is used with appropriate short circuit power. A block diagram of the model used in this simulation is presented on Fig. 3.

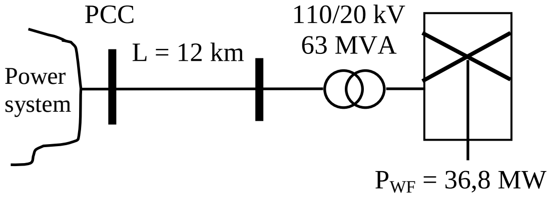

Fig. 3 Wind farm connection on power system

Two scenarios have been performed in order to investigate how wind farm grid ride-through in case of near fault and fault below transmission network.

A. GFRT for fault at the point of common coupling

The first test was made under symmetrical and unsymmetrical short circuit with a duration of 150 ms on the 110 kV bus near the wind farm, at the point of common coupling (PCC). It is assumed that the wind turbine generators remain connected to the network during the whole fault duration. The turbines works in two modes. The first mode is VAR Regulation while the other mode is the Voltage regulation. As first test the wind farm works in Voltage regulation mode. The three phase short circuit is applied at first second of simulation and lasts until 1.15 sec. Simulation with different voltage controller gain were made and the effect of the voltage support of the wind farm during the grid disturbances at the PCC is analyzed. The transient behavior of the voltage and reactive power are shown in figure 4 and 5.

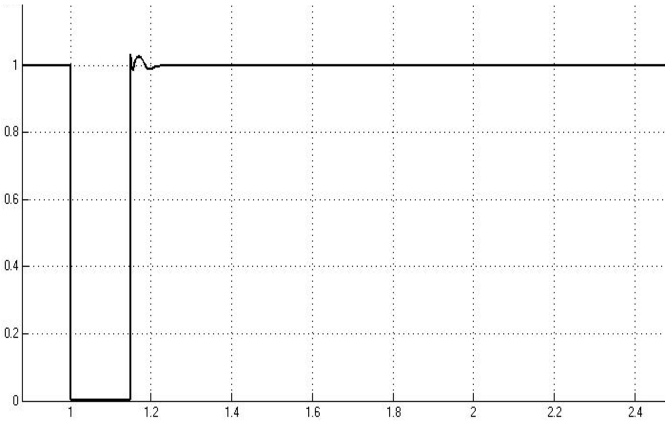

Fig. 4 Voltage at PCC during three-phase fault

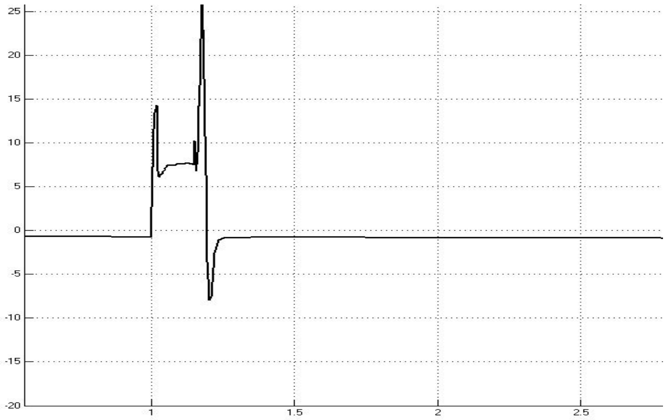

Fig. 5 Reactive power (MVAr) injected by wind farm

B. GFRT for remote fault

The remote fault below on transmission system is simulated by applied voltage dip of 70% at the busbar connecting wind farm to the grid for 300 ms. Results of simulations concern voltage at PCC and reactive power support are shown in figure 6 and 7.

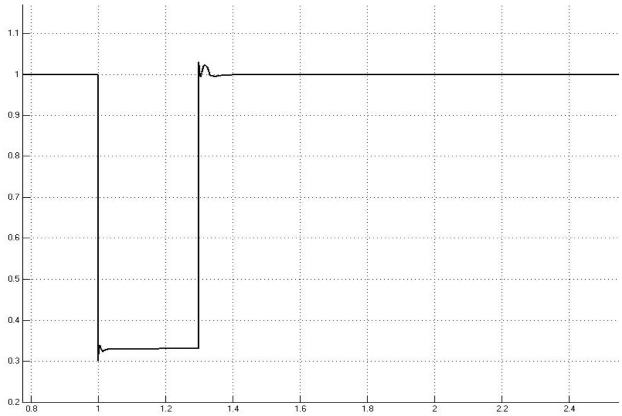

Fig. 6 Voltage at PCC during remote fault

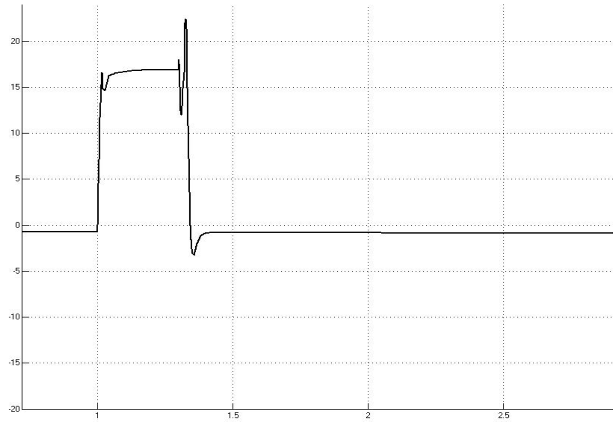

Fig. 7 Reactive power (MVAr) injected by wind farm during remote fault

V. CONCLUSION

High penetration of wind turbines imposes a big challenge to the safe operation of power system. This work has shown possibilities and limitations of DFIG concerning FRT capability during grid fault. Simulation have shown that the wind turbines are able to provide a considerable contribution to grid voltage support during short circuit periods by using their fast voltage control without additional compensation devices. The reactive power injected by the wind farm would be enough to accomplish grid code requirements and in accordance with technical requirements prescribe by the Macedonian transmission system operator (MEPSO). The Voltage regulation mode is more tolerant unlike the other mode, where the turbine trips and disconnects from the network.

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