Dynamic Behavior of DFIG Wind Energy Conversion System under Various Faults with ANN

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Abstract: ***The dynamic behavior of a DFIG grid connected, wind energy conversion system (WECS) is simulated using MATLAB. in this paper ,Artificial neural network (ANN) with Multi Level Inverter(MLI) control technique has been developed for Doubly Fed Induction Generator(DFIG) based wind energy conversion system. With the increasing use of wind power generation, it is required to investigate the dynamic performance analysis of Doubly Fed Induction Generator under various operating conditions such as different fault conditions like line to ground faults, double line to ground faults, three phase faults and grid faults. The result of the proposed system is compared to that of the system with PI Controllers. The comparison shows that the integrated ANN controller results in an improvement in the dynamic behavior of the system under different operating conditions.***

Keywords: Doubly fed Induction Generator, Wind Energy Conversion System, Multi level inverter And ANN Controller

1. Introduction

Over the past few years, wind energy has shown the fastest rate of growth of any form of electricity generation with its developments stimulated by concerns of national policy makers over climate change, energy diversity and security of supply. The usage of conventional sources led to depletion of fossil fuel as well as carbon-di-oxide emissions ,great efforts have been done to produce electricity from renewable sources, especially wind power generation have found more attention .It is expected that wind energy will provide about 10% of the world's electrical energy in 2020.

Nowadays most of the wind forms are widely used doubly-fed induction generator (DFIG) technology. Compared to the fixed speed induction generators, the Doubly-Fed Induction generator have the following advantages:1) it allows extracting maximum power from the wind, 2) four-quadrant converter topology is possible which allows the fast active and reactive power control and it improves the stability and power quality of wind turbine,3) mechanical stresses are limited, 4) capacitor banks are not needed to compensate the reactive power consumed by the fixed speed induction generators, 5)low converter power ratings, and 6) ability to supply power at constant voltage and frequency while the rotor speed varies.

In this paper, a detailed model for representation of DFIG based wind farm in power system dynamics simulation is presented, ATLAB/SIMULINK software program is used for this study. This paper presents dynamic response analysis of DFIG based wind farm under various fault conditions using the ANN Controller. In this paper, two control techniques are investigated and they are Pi controller based technique and ANN with MLI based technique for better dynamic control of DFIG. To ensure better stability and power regulation generated by the wind turbine the ANN with MLI technique will allow the increase of robustness, performance, and flexibility.

2. DFIG Model

The DFIG consists of stator winding and the rotor winding equipped with slip rings. The stator is provided with three-phase insulated windings making up a desired pole design and is connected to the grid through a three-phase transformer. Similar to the stator, the rotor is also constructed of three-phase insulated windings. The rotor windings are connected to an external stationary circuit via a set of slip rings and brushes.

By means of these components, the controlled rotor current can be either injected to or absorbed from the rotor windings. The stator and rotor windings are usually coated with insulation and are mechanical assembled to form a closed structure to protect the machine from dust, damp, and other unwanted intrusions ensuring proper magnetic coupling between rotor and stator windings. In wind energy conversion system, this generator is mounted in the nacelle of the wind turbine system. The dynamics of the DFIG is represented by a fourth-order state space model using the synchronously rotating reference frame (qd-frame) as given in (1)-(4):

$$V_{qs} = r_s I_{qs} + \omega_e \lambda_{ds} + \frac{d}{dt}\lambda_{qs} \tag{1}$$

$$V_{ds} = r_s I_{ds} - \omega_e \lambda_{qs} + \frac{d}{dt}\lambda_{ds} \tag{2}$$

$$V_{qr} = r_r I_{qr} + (\omega_e - \omega_r)\lambda_{dr} + \frac{d}{dt}\lambda_{qr} \tag{3}$$

$$V_{dr} = r_r I_{dr} + (\omega_e - \omega_r)\lambda_{qr} + \frac{d}{dt}\lambda_{dr} \tag{4}$$

The most common way of representing DFIG for the purpose of simulation and control is in terms of direct and quadrature axes (dq axes) quantities, which form a reference frame that rotate synchronously with the stator flux vector

$$\frac{dE_q'}{dx} = -s\omega_s E_d' + \omega_s \frac{L_m}{L_{rr}} v_{dr} - \frac{1}{T_o'}\left[E_q' - (X_s - X_s')i_{qs}\right] \tag{5}$$

$$\frac{dE_d'}{dx} = s\omega_s E_q' - \omega_s \frac{L_m}{L_{rr}} v_{qr} - \frac{1}{T_0}[E_d' + (X_s - X_s')i_{qs}] \quad (6)$$

Whereas, the parameters are defined as: $X_s = \omega_s L_{ss} = x_s + X_m$,

$$X_s' = \omega_s\left(L_{ss} - \frac{L_m^2}{L_{rr}}\right) \text{ and } T_0' = \frac{L_{rr}}{R_r} \quad (7)$$

The equations can be expressed as

$$P_s = -E_d' i_{ds} - E_q' i_{qs} \quad (8)$$

$$Q_s = E_d' i_{qs} - E_q' i_{ds} \quad (9)$$

$$E_d' = -r_s i_{ds} + X_s i_{qs} + v_{ds} \quad (10)$$

$$E_q' = -r_{qs} - X_s i_{ds} + v_{qs} \quad (11)$$

Where s is the rotor slip; P_s is the output active power of the stator of the DFIG; L_{ss} is the stator self-inductance; L_{rr} is the rotor self- inductance; L_m is the mutual inductance; ω_s is the synchronous angle speed; X_s is the stator reactance; x_s is the stator leakage reactance; x_r is the rotor leakage reactance; X_s' is the stator transient reactance; E_d' and E_q' are the d and q axis voltage behind the transient reactance, respectively; T_0' is the rotor circuit time constant; i_{ds} and i_{qs} are the d and q axis stator currents, respectively; v_{ds} and v_{qs} are the d and q axis stator terminal voltages, respectively; v_{dr} and v_{qr} are the d and q axis rotor voltages, respectively; Q_s is the reactive power of the stator of the DFIG. The voltage equations and the flux linkage equations of the DFIG are based on the motor convention.

3. Controllers for DFIG

3.1. PI Controller

Fig.1. shows a wind turbine connected to a DFIG. The AC-DC-AC converter is divided into two components: the rotor-side converter (Crotor) and the grid-side converter (Cgrid). Crotor and Cgrid are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected to the DC side can act as the DC voltage source. A coupling inductor (L) is accustomed to connect Grid side converter to the grid. Here the three phase rotor winding is connected to Rotor side converter (Crotor) by slip rings, brushes and the three phase stator winding is directly connected with the grid. The power capture by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates pitch angle command and the voltage command signals Vgc for Crotor and Cgrid respectively so as to control the power of the wind turbine, the DC bus voltage , reactive power otherwise voltage on grid terminal.

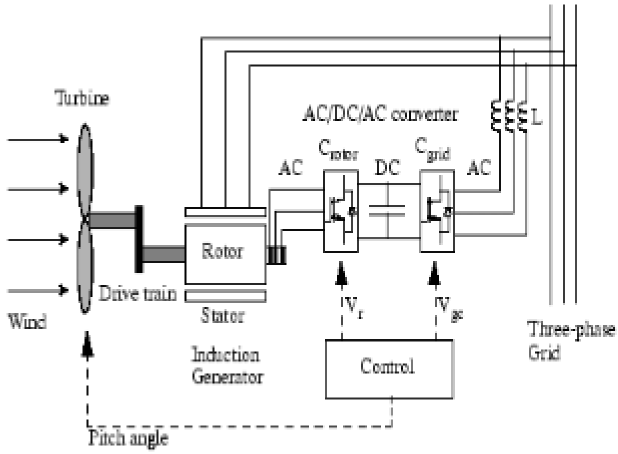

Figure 1: DFIG system

The generic power control loop is illustrated in the fig.2. Called Rotor-Side Converter Control System. The actual electrical output power, precise at the grid terminals of the wind turbine, is added to the total power losses (mechanical and electrical) and is compared with the reference power obtained from the tracking characteristic. A Proportional Integral (PI) regulator is used to decrease the power error to zero. The output of the regulator is the reference rotor current (Iqr_ref) that must be injected in the rotor by rotor side converter (Crotor). This reference rotor current (Iqr_ref) that produces the electromagnetic torque (Tem). The actual Iqr component of positive-sequence current is compared to Iqr_ref and the error is reduced to zero by a current regulator (PI). The output of this current controller is the voltage Vqr generated by Crotor. The current regulator is assisted by providing the forward terms which forecast Vqr.

Measurement systems measuring the d and q components of AC positive-sequence currents to be controlled as well as the DC voltage Vdc. An outer regulation loop consists of a DC voltage regulator. The DC voltage regulator output is the reference current Idgc_ref for the current regulator. An inner current parameter loop consists of a current regulator. The current regulator used to controls the magnitude and phase angle of the voltage generated by converter C grid (Vgc) from the Idgc_ref produced by the DC voltage regulator and specified Iq_ref reference. The current regulator is assisted by providing the forward terms which predict the grid side converter output voltage. The magnitude of the reference grid side converter current Igc_ref is equal to

$$\sqrt{I^2_{dg\_ref} + I^2_{qr\_ref}}$$

The maximum value of this current is limited to a value defined by the converter maximum power at nominal voltage. When Idgc_ref and Iq_ref are such that the magnitude is higher than this maximum value the Iq_ref component is reduced in order to bring back the magnitude to its maximum value.

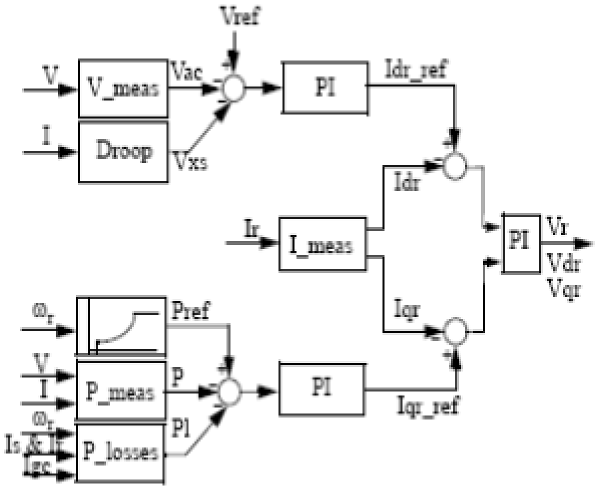

Figure 2: Rotor side converter

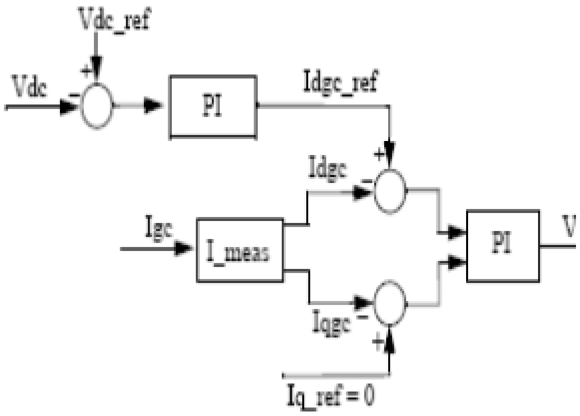

Figure 3: Grid side converter

3.2. Artificial Neural Network Controller

We can train a neural network to perform a particular function by adjusting the values of the hidden layer in the network.The artificial neural network controller provides better efficiency and quicker response during the faulty conditions. The system is first run under the PI controller with almost better efficiency. The data's before and after the PI controller are computed and saved to the workspace. The data's are represented in the array format and they shows the input and output variations.

3.3. ANN Training for DFIG

Using the neural network fitting tool in MATLAB, the input and output data's are fed in the neural network tool for training. Hidden layers are kept at 20 and the network was trained. The network training was done until the system undergoes 1000 iterations. As a result of the training a neural network, a control function block was created. The PI controller was replaced by the created neural network function block. The same procedure is done for all the controllers in the system separately.

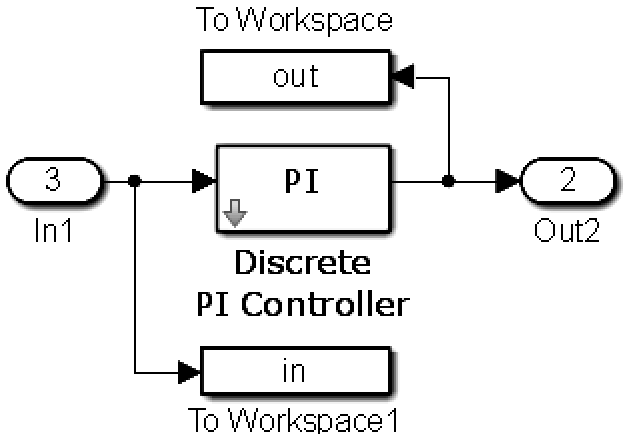

Figure 5: ANN training

4. Simulation diagram

A 6*1.5 MW wind farm is connected to a 25 kV distribution system, which exports power to a 120 kV grid via a 30 km, 25 kV feeder. Wind farm uses a doubly-fed induction generator (DFIG) and an AC-DC-AC IGBT-based PWM converter. The stator winding of DFIG is directly connected to the 60 Hz grid while the rotor is fed at variable frequency through the AC-DC-AC converter. The doubly fed induction generator technology allows extracting maximum power from the wind for low wind speeds by optimizing the turbine speed. In this project the wind speed is maintain stable at 15 meter per second. The torque controller in control system is used to maintain the speed at 1.2 per unit.

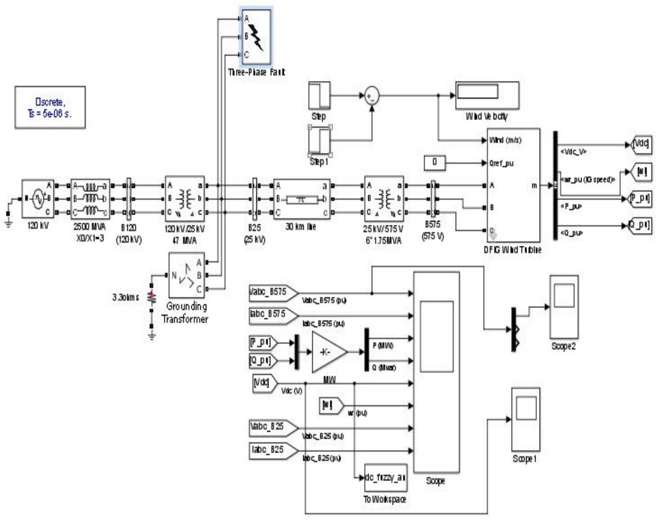
Figure 4: Simulation setup

Wind turbines using a doubly-fed induction generator consist of a wound rotor induction generator and an AC-DC-AC IGBT- based PWM converter. The switching frequency is chosen to be 1620 Hz. The stator winding is connected directly to the 60 Hz grid while the rotor is fed at variable frequency through the AC-DC-AC converter. The DFIG technology allows extracting more energy from the wind for low wind speeds by optimizing the turbine speed, while reducing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing more mechanical energy for a given wind speed is proportional to the wind speed.

5. Result and discussion

The Dynamic behavior of above system for different faults such as single line to ground fault, lint to line fault and symmetrical fault are studied and the graphs for generated real power and reactive power are presented in the following figures

Simulation Result: Single line to ground fault

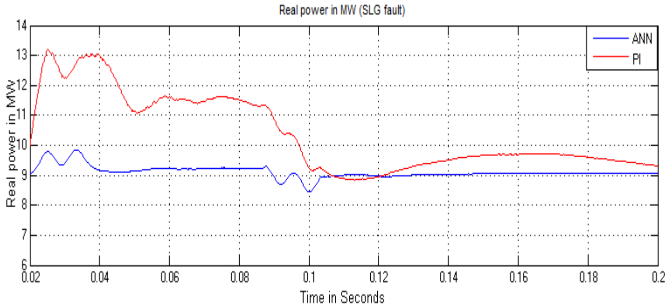

Figure 6: Real power for PI and ANN controller

From the above figure the real powers for single line to ground fault as shown (Fault period: 0.02 seconds to 0.1 seconds). It shows that during the single line to ground fault period the dynamic behavior of doubly fed induction generator with ANN controller is improved as compared with PI controller

Double line to ground fault

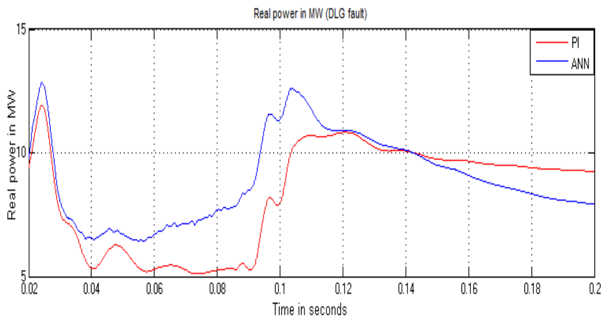

Figure 7: Real power for PI and ANN controller

From the above figure the real powers for double line to ground fault as shown (Fault period: 0.02 seconds to 0.1 seconds). It shows that during the double line to ground fault period the dynamic behavior of doubly fed induction generator with ANN controller is improved as compared with PI controller

Three phase fault

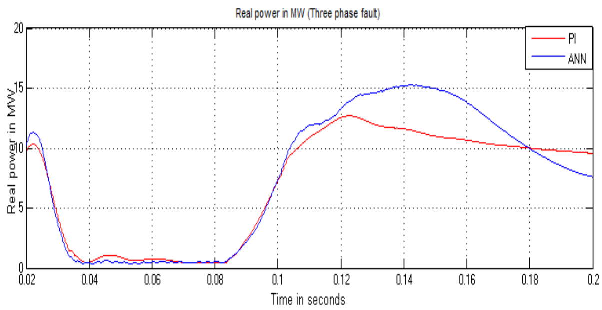

Figure 8: Real power for PI and ANN controller

From the above figure the real power for three phase fault as shown (Fault period: 0.02 seconds to 0.1 seconds). It shows that during the three phase fault period the dynamic behavior of doubly fed induction generator with ANN controller is same as with PI controller

Grid fault

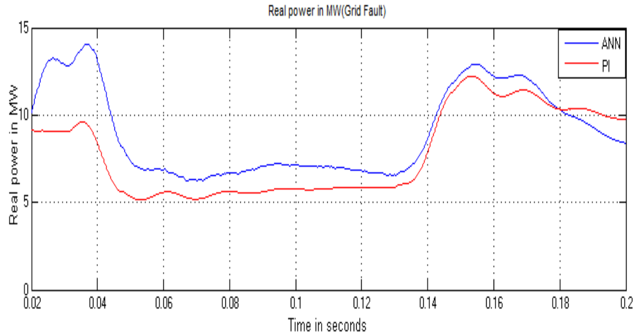

Figure 9: Real power for PI and ANN controller

From the above figure the real power for grid fault as shown (Fault period: 0.02 seconds to 0.1 seconds). It shows that during the grid fault period the dynamic behavior of doubly fed induction generator with ANN controller is improved as compared with PI controller.

6. Conclusion

The dynamic behavior of a Doubly Fed Induction Generator grid connected Wind Energy Conversion system is simulated using MATLAB. The response of the system under fault condition has been compared graphically with PI controller and ANN controller. A comparison of the simulation results reveals that there is in improvement in the dynamic behavior of the system with ANN controller. From the graphs it can be seen that fluctuations in the real and reactive power during the fault recovery are considerably reduced for the system with ANN controller.

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