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Comparative Evaluation of PI and Fuzzy Logic Controller for Doubly Fed Induction Generator Based Wind Energy Conversion System

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Abstract:

This study aims to analyze the design of a wind turbine generator for a variable speed wind turbine generator based on a double Fed induction generator. Varieties of variations on generator types such as direct current (DC), synchronous (synchronous), and induction A system that converts wind energy into usable electricity uses generators. Weakly-Liquid-Cooled-Systems (WECS) typically use either a Permanent Magnet Synchronous Generator or a Doubly fed induction generator. However, DFIG became victorious over PMSG in terms of energy output at big wind farms, cost, Converter Size, etc. This article discusses the use of a PI controller and a Fuzzy Logic Controller to manage active and reactive power at the converters on both the rotor and stator sides of a power conversion system. MATLAB/SIMULINK is used for the full mathematical modeling of DFIG, and the results of the controllers' performances are compared in terms of output power, torque, rotor and stator currents, etc. Rotor side converter (RSC), Grid side converter (GSC), Power factor (PI) controllers, Voltage-oriented control (VOC), Pulse width modulation (PWM), and Doubly fed induction generator (DFIG) (PWM).

This study aims to analyze the design of a wind turbine generator for a variable speed wind turbine generator based on a double Fed induction generator.

Introduction

Non-conventional resources are being used to meet the world's energy needs as global warming and environmental pollution continue to rise. solar panels, windmills, hydropower, biomass, etc., to meet society's energy demands. Many researchers and organizations are attempting to find ways to make the most efficient use of alternative energy sources. Wind power is an alternative energy source that has been crucial throughout human development. Non-conventional energy sources were not employed commercially by previous generations owing to a lack of appropriate technologies. A breakthrough in wind turbine technology has led to a meteoric rise in the efficiency with which wind turbines produce electricity. Wind energy is significant in its own right thanks to the development and enhancement of a number of Wind Energy Conversion Systems (WECS).

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Nowadays, advanced wind power systems account for the majority of the world's energy production. One of the largest markets for wind energy is Germany. In addition to Germany, there are also

Wind energy is being taken seriously as an option for power production in several nations, including the United States, Spain, France, Denmark, China, and India. In 1980, the global total of newly installed

The total wind power capacity was close to 13 MW.

By the end of 2005, wind power had reached a total capacity of 59.024 GW. With an average yearly growth rate of around 23.8%, the total installed capacity of wind turbines reached 74.150 GW by the end of 2006. Ending 2007 with 93.926 GW and ending 2008 with 121.188 GW is an increase of nearly 26% per year in this installed capacity. The global installed capacity of wind power is projected to reach 597 GW by the end of 2012 and 2017 and as of 4th June 2019. Wind power producing capacity has also expanded in India during the last several years. Information gathered as of 31 March 2019 shows that the global installed capacity of wind power was 336.625 GW [1]. With this increase, India now has 443 operational wind farms. As a result, India's wind power capacity ranks fourth in the world. Wind power generation is mostly dispersed over the southern, western, northern, and eastern parts of the globe. Wind power installation may be chosen from a variety of possibilities. This study thus focuses extensively on methods for transforming wind energy into usable forms.

Mathematical modelling of DFIG

The blades of the rotor turbine first convert the kinetic energy of the wind into mechanical energy. The wind's kinetic energy may be calculated as:

$$K.E = \frac{1}{2} m v^2$$

Where m is the mass of the air current and v is its velocity. In order to calculate the volume of air, we need to know the density of air in kilograms per cubic meter (kg/m3) and the exposed area of the rotor blades that were swept by the wind.

access to the wind and rotor thickness equals wind speed. Alternatively, this K.E. may be represented in

$$K.E = \frac{1}{2} \rho A v^3.$$

The mechanical power generated by the turbine may be calculated as follows. The mechanical power generated by the turbine may be calculated as follows.

$$P_m = \frac{1}{2} \rho A v^3$$

The actual power output of the rotor may be calculated using a power coefficient Cp, which is the ratio of the mechanical power of the rotor blades to the power of the wind. Consequently, the highest

potential energy extraction may be determined by the formula:

$$P_m = \frac{1}{2} \rho A C p v^3$$

From the equivalent circuit of DFIG, the voltage equations utilized in modeling are derived. Stator and rotor coil voltage differential equations are stated in vector form.

as:

$$\bar{V}_s = \bar{i}_s R_s + \frac{d\bar{\phi}_s}{dt}$$

$$\bar{V}_r = \bar{i}_r R_r + \frac{d\bar{\phi}_r}{dt}$$

By using the Clarke and park transformation, the values measured in a three-phase rotating reference frame may be expressed in terms of a two-phase stationary reference frame, which is employed in DFIG control.

frame by first transforming to a Clarke's frame, and then a Park frame, both of which are two-phase stationary reference frames.

In order to model DFIG, we must first convert the above equation from three to two phase components, and then rotate all the variables into a synchronous rotating reference frame (d-q) aligned with the stator flux. [6]

This idea of transformation is used to create a dynamic model of WRIM in both a rotating and a stationary reference frame. Here are the complete equations for the voltage and flux connection between the stator and rotor, which reflect the dynamic model of the induction machine in the stationary reference frame (-):

$$v_{\alpha s} = r_s i_{\alpha s} + \frac{d}{dt}(\varphi_{\alpha s})$$

$$v_{\beta s} = r_s i_{\beta s} + \frac{d}{dt}(\varphi_{\beta s})$$

$$\varphi_{\alpha s} = L_s i_{\alpha s} + L_m i_{\alpha r}$$

$$\varphi_{\beta s} = L_s i_{\beta s} + L_m i_{\beta r}$$

$$v_{\alpha r} = r_r i_{\alpha r} + \frac{d}{dt}\varphi_{\alpha r} + \omega_r \varphi_{\beta r}$$

$$v_{\beta r} = r_r i_{\beta r} + \frac{d}{dt}\varphi_{\beta r} - \omega_r \varphi_{\alpha r}$$

$$\varphi_{\alpha r} = L_r i_{\alpha s} + L_m i_{\alpha s} \quad \text{and} \quad \varphi_{\beta r} = L_r i_{\beta s} + L_m i_{\beta s}$$

By taking into account the axis position, we may construct the model of DFIG represented in a revolving d-q reference frame at synchronous speed.

as shown in Fig. 1.

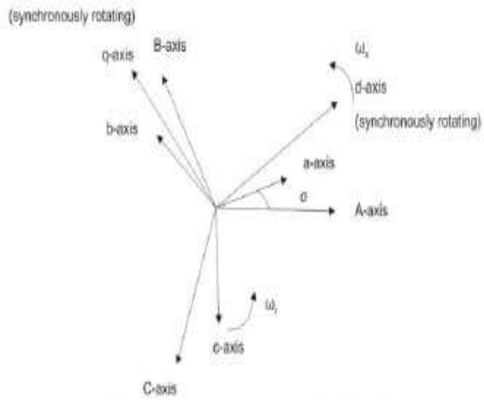

Fig. 1. Reference system used in DFIG

The equivalent circuit representation of dynamic model of induction machine in synchronous reference frame is shown in fig.,

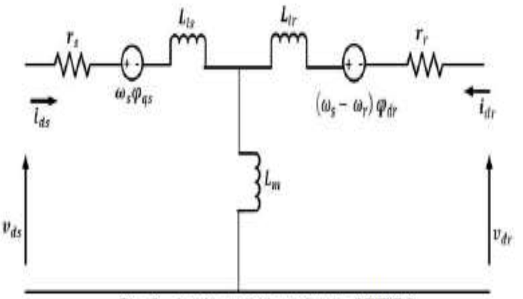

Fig. 2. d-axis equivalent circuit of WRIM

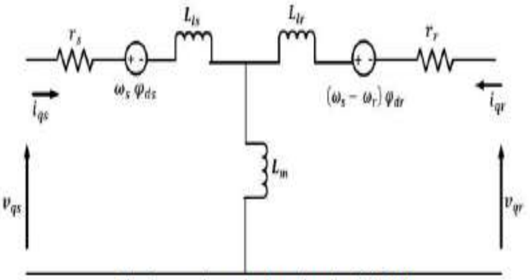

Fig. 3. q-axis equivalent circuit of WRIM

By combining the equations for the rotor and the stator, one may get the equivalent circuit. As a result, the equations defining the operation of the following DFIG equivalent circuit have been derived:

When the frame of reference is rotating, the DFIG is defined [7] as:

$$\bar{V}_{s,dq} = \bar{i}_s R_{s,dq} + \frac{d\bar{\phi}_{s,dq}}{dt} + j\omega_s \bar{\phi}_{s,dq}$$

$$\bar{V}_{r,dq} = \bar{i}_r R_{r,dq} + \frac{d\bar{\phi}_{r,dq}}{dt} + j(\omega_s - \omega_r)\bar{\phi}_{r,dq}$$

Where, $\bar{\phi}_{r,dq} = L_r i_{r,dq} + L_m i_{s,dq}$ an $\bar{\phi}_{r,dq} = L_r i_{r,dq} + L_m i_{s,dq}$.

The magnetizing inductance and leakage inductance of a stator or stator-referred rotor may be calculated using the formula:

]

$$L_s = L_m + L_{ls}$$
$$L_r = L_m + L_{lr}$$

Where the d-q are the axis of stator flux reference syste

$\bar{V}_{s,dq}, \bar{i}_{s,dq}, \bar{\phi}_{s,dq}$ are the stator voltage, current and flux vector.

$\bar{V}_{r,dq}, \bar{i}_{r,dq}, \bar{\phi}_{r,dq}$ are the rotor voltage, current and flux vector.

$\omega_s and \omega_r$ are the stator flux reference system and rotor electrical speed. The final equation representing the stator and rotor active and reactive powers for the DFIG are given by:

$$P_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs})$$
$$Q_s = \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs})$$
$$P_r = \frac{3}{2}(V_{dr} i_{dr} + V_{qr} i_{qr})$$
$$Q_r = \frac{3}{2}(V_{qr} i_{dr} - V_{dr} i_{qr})$$

The purpose of the suggested model is to regulate the aforementioned active and reactive power by means of Rotor side control and Grid side control, respectively. There is a rotor-side converter in the DFIG model, and

The next section discusses the control approach for a stator-side converter.

Control strategy

Rotor Side Control

The primary goal of RSC is to maximize energy extraction via separate regulation of active and reactive power. The reference voltage used to regulate RSC is voltage. Animated and

currents in the direct axis of the rotor (idr) and the quadrature axis of the rotor (iqr) regulate reactive power. When designing the rotor-side control, the pulse-width modulation approach was used in conjunction with the analogous steady-state circuit of a proportional-integral (PI) controller. In this regulatory framework, the d and q components of three-phase currents are isolated and controlled independently. Components like these are generated when an error signal is compared to a reference signal and then sent via a proportional integral (PI), which results in the d and q components.

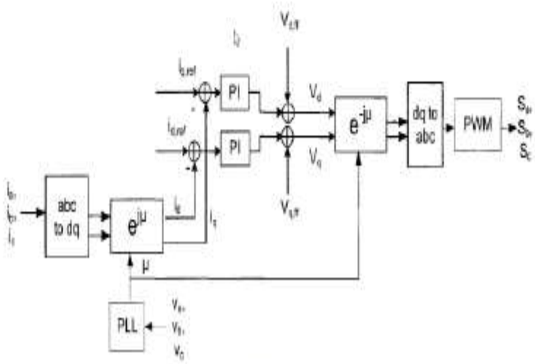

Fig. 4. PWM linear feedback current control scheme

Grid side converter control

The primary goal of the grid side controller is to maintain a constant DC-link voltage despite variations in the magnitude and direction of the rotor energy flow. The dq reference axis of rotation is perpendicular to the plane of the grid.

grid-side converter-operating voltage. Following a dc voltage error and reactive power reference-based q current reference production stage, a hysteresis current control block produces the gating signalaIs for the line-side converter. Yet again, a PLL is required for grid voltage synchronization and accurate conversion to dq components.

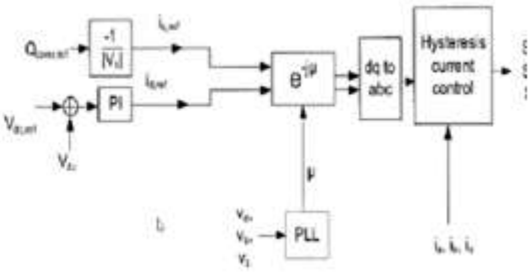

Fig. 4. PWM linear feedback current control scheme

PI Controller and Fuzzy Logic Controller are used to manage the rotor and stator, respectively.

4Simulation Outcomes

In order to test the suggested Fuzzy Logic control model, we used MATLAB/SIMULINK and the Fuzzy Logic Toolbox. The nominal bus voltage of the simulated DFIG model is 690V, and its power output is 2MW. Assuming a wind speed of 12 meters per second and setting the machine's characteristics as follows: Rs=Rr=0.0029ohm, Ls=Lr=0.0026H, Lm=0.0025H, J=135Kg, no.of pole pairs=2, and no.of blades=2. The transient performance of the model is examined at four different times: at t=0.25 s, t=2 s, t=4 s, and t=6 s, where the load transient and wind speed fluctuations are assessed.

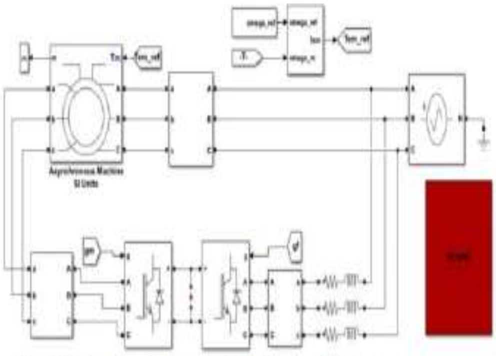

Fig. 6. Simulink diagram of doubly fed induction generator

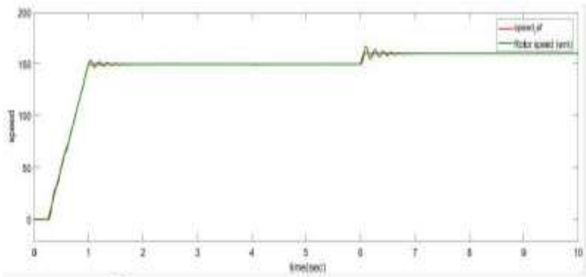

Fig. 7. Rotor speed tracking using PI controller

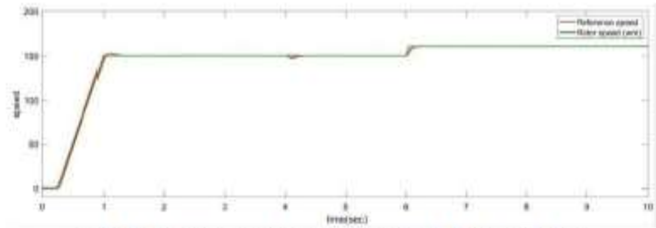

Fig. 8. Rotor speed tracking using fuzzy logic controller

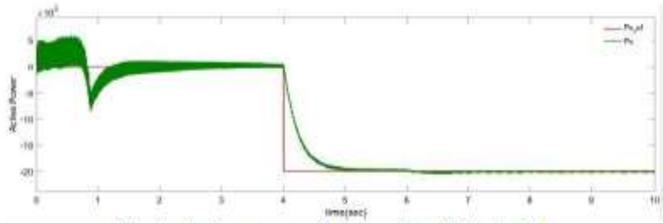

Fig. 9. Active power of stator using PI Controller

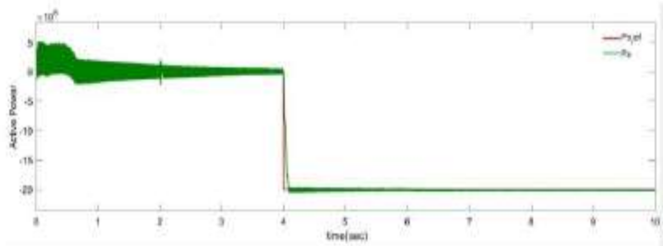

Fig. 10. Active power of stator using Fuzzy Logic Controller

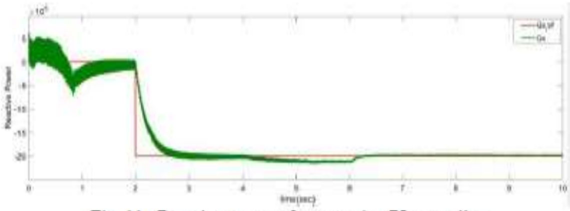

Fig. 11. Reactive power of stator using PI controller

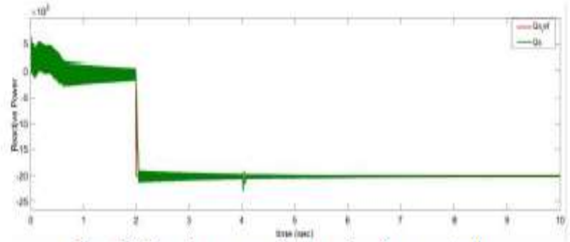

Fig. 12. Reactive power of stator using fuzzy controller

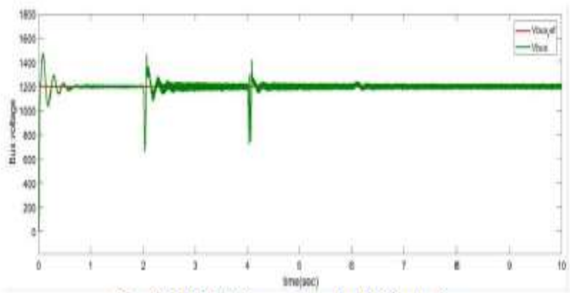

Fig. 13. DC link bus voltage for PI Controller

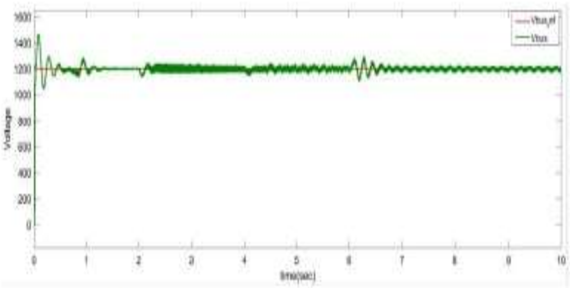

Fig. 14. DC link bus voltage for fuzzy logic Controller

Conclusion

Understanding the dynamic models of the Doubly Fed Induction Generator in different reference frames is essential for creating control algorithms for DFIG-based standalone WECS. In order to do this, two control algorithms—the proportional-integral (PI) controller and the fuzzy logic controller—are used, and their transient output performance is evaluated in the face of abrupt changes in both the load and the wind speed. Both the rotor side converter and the stator side converter are controlled using a vector control approach. The rotor side and stator side converter are both controlled by a vector control approach. Both controllers were utilized to get results, which highlight the significance of the control technique. The suggested model's efficiency is measured and compared in terms of current, voltage, power quality, torque, active power, and reactive power. Thus, it is clear that the performance of the fuzzy logic controller exceeds that of the traditional PI controller, particularly at low wind speeds

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