Controller design for doubly fed induction generator using particle swarm optimization technique

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A R T I C L E   I N F O

Article history:
Received 1 March 2017
Received in revised form 11 June 2017
Accepted 18 June 2017
Available online 27 June 2017

Keywords:
Wind turbine
DFIG
PID controller
Matlab Simulink Models
PSO technique
Fitness function

A B S T R A C T

This manuscript describes the controller design for doubly fed induction generator (DFIG) driven by a variable speed wind turbine using particle swarm optimization technique. The mathematical model of the DFIG, its power converters, and their controllers have illustrated in this paper appropriately. The lower order simple illustration of DFIG have been used for PID controller design using numerical differentiation of Simulink model. The controller design for DFIG based WECS using PSO technique and its fitness functions are described in detail. The responses of the DFIG system regarding terminal voltage, current, active-reactive power and DC-Link voltage along with generator speed have slightly improved with PSO based controller. Finally, the obtained output is equated with a standard technique for performance improvement of the DFIG based wind energy conversion system.

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1. Introduction

The mainstream for electrical energy generation from conventional sources like gas, oil, and coal are predominantly non-renewable sources. This type of energy sources discharges an enormous quantity of carbon dioxide towards surroundings, that outcomes in global warming. Because of the fast growth of modern electrical power generation engineering, the older petroleum apparatus and electricity production component have been substituted by innovative technology. Amongst the advanced electrical power generation techniques, the renewable power converters are admirably glowing for optimum size and rate for each element also being extra environmentally affable. Wind energy is the best renewable energy sources which have extensively developed in recent years. Wind power has several advantages such as no pollution, the comparatively low capital cost involved and the short gestation period [1]. There were various kinds of generators for wind energy converters application.

A different type of generator during the earlier time was synchronous generator whereas this time through developed skill enhancement, induction generator of various kinds become additional accepted in wind power alteration field. Induction generator, mainly doubly fed is gorgeous and more fashionable in renewable source usage [2]. The simple induction generators have a few disadvantages such as reactive power utilization along with unfettered voltage profile throughout changeable rotor speed. These troubles can solve using the execution of DFIG along with power electronic converter.

However the Generator's configuration for WECs is depicted in Fig. 1(a), as follows.

Note: Abbreviations: DFIG, Doubly Fed Induction Generator; WRSG, Wound rotor synchronous generator; PMSG, Permanent magnet synchronous generator; SCIG, Singly excited induction generator; PID, Proportional Integral Derivative; PSO, Particle Swarm Optimization; FACTS, Flexible AC Transmission Systems; WECS, Wind Energy Conversion Systems; PCC, Point of Common Coupling.

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http://dx.doi.org/10.1016/j.renene.2017.06.061
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Nomenclature:

- \( \psi_{ds}, \psi_{qs} \): Stator d-axis and q-axis winding flux linkage
- \( \psi_{dr}, \psi_{qr} \): Rotor d-axis and q-axis winding flux linkage
- \( v_{ds}, v_{qs} \): Stator d-axis and q-axis winding voltage
- \( v_{dr}, v_{qr} \): Rotor d-axis and q-axis winding voltage
- \( i_{ds}, i_{qs} \): Stator d-axis and q-axis winding current
- \( i_{dr}, i_{qr} \): Rotor d-axis and q-axis winding current
- \( i_{ds}, i_{dr} \): q-axis and d-axis rotor voltages and currents applied to the stator windings
- \( X_{ss}, X_{mm} \): Stator and rotor self-inductive reactance
- \( X_{fs}, X_{fr} \): Stator and rotor leakage reactance
- \( r_s, r_r \): Stator and rotor leakage resistance
- \( P_s \): Stator active power
- \( Q_s \): Stator reactive power
- \( T_m \): Mechanical torque
- \( T_e \): Electromagnetic torque
- \( L_m \): Magnetizing inductance
- \( R_s, R_f \): Stator and rotor per phase winding resistance
- \( L_s, L_r \): Stator and rotor per phase winding inductance
- \( H, J \): System moment of inertia, inertia constant
- \( B \): System frictional constant
- \( \omega \): Synchronous of poles rotational speed (50 Hz)
- \( \omega_r \): Rotor mechanical speed
- \( \omega_{ke}, \omega_{kb} \): Stator angular speed, Base speed
- \( \omega_h \): Slip angular speed
- \( A \): Swept area of the blades (m²)
- \( \rho \): Air density (kg/m³)
- \( \theta \): Pitch angle (degree)
- \( \lambda, \beta \): Ratio of the rotor blade tip speed and wind speed, number of poles

2. An overview of wind energy conversion system

The renewable assets are valuable, and also obtainable throughout the earth. Shifting to renewable possessions in addition to financial benefits can obtain other benefits such as clean environment along with less weather change by means of declining greenhouse gas release [8]. However, the progressed wind turbines accessibility is too much 98% in a stormy area with capacity factors 35–40%. The electrical energy production by wind technology has tinted first time during the 1970s due to the oil crisis. The worldwide fashion toward clean energy is a motivation for supplementary integration of wind-based power in system [9]. However, the wind velocity changes radically depending on the environmental circumstances along with the time of operation. Therefore, it has a huge margin of the speed difference. Such margins of speed alteration compose wound rotor induction machines appropriate for power generation through wind energy [17]. The wind turbines can run either fixed speed (actually within a speed range about 1%) or varying speed [10], and wind turbine aerodynamic model has been characterized by the well-known \( C_{P}(\lambda, \beta) \) curves [11]. For the given power coefficient \( C_{P} \), the mechanical power that the wind turbine extracts from the wind is calculated as follows:

\[
P_m = \frac{1}{2} \rho A v^3 C_{P}(\lambda, \beta)
\]

whereas the fundamental description of DFIG based WTs are explained in Ref. [26]. Fig. 1(b) shows the typical DFIG along with its components.

- **Rotor**: it is composed of blades and a hub. Blades absorb the wind energy and transmit it to the hub. The receiving power of turbine is directly related to the squared length of blades as pointed in.

- **Pitch motor**: wind turbines equipped with pitch control, the blades turn to the wind direction according to Maximum Power Tracking (MPT).

- **Mechanical brakes**: The connection shaft between gearbox and generator is equipped with mechanical brake systems which are disc type brakes.

- **Gearbox**: Most DFIG units use a gearbox. The purpose of the gearbox is connected to the low-speed axis at one end and to electricity generator at the other end, to increase the low rate of rotor turn appropriately.

- **Generator**: Generators used in DFIG based wind turbines are of
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