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

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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.

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 engineerings, 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 WEC_S is depicted in Fig. 1(a), as follows.

The DFIG is a wound rotor induction machine can operate in super-synchronous and subsynchronous manner. The benefits of the DFIG as compared with fixed speed generators are to improve power quality, reduce mechanical stress and fluctuations also excellent power imprisons [3]. The function of the DFIG associated with the grid is facilitated through rotor as well as network side converter. However, inverter related to rotor side to give a fundamental frequency to sustain stator frequency at an invariable stage, even though variations in mechanical power. The control of

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; WEC, Wind Energy Conversion; VSC, Voltage Source Converter; WECS, Wind Energy Conversion Systems; PCC, Point of Common Coupling.

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Nomenclature:

ψ_{ds}, ψ_{qs}	Stator d-axis and q-axis winding flux linkage
ψ_{dr}, ψ_{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
$v'_{qr}\ v'_{dr}$	q-axis and d-axis rotor voltages referred to the stator windings
i'_{qr}, i'_{dr}	q-axis and d-axis rotor currents applied to the stator windings
X_{ss}	Stator and rotor self-inductive reactance
X_m	Mutual reactance
X_{ls}, X'_{rr}	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_r	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
ω	Synchronous of poles rotational speed (50 Hz)
ω_r	Rotor mechanical speed
ω_e, ω_b	Stator angular speed, Base speed
ω_s	Slip angular speed
A	Swept area of the blades (m^2)
ρ	Air density (kg/m^3)
θ	Pitch angle (degree)
λ, p	Ratio of the rotor blade tip speed and wind speed, number of poles

DFIG presents a dual dilemma to balance the velocity changes and reactive power. The stability, as well as performance of entire setup, are to preserve in features of model doubts, outer sound, a change of interior machine parameter plus velocity. In meaningful use, DFIGs should be cut off from the network while the voltage inequity is more than 6% [3]. It has described that the torque pulsation could concentrate using injected recompense current in the DFIG rotor, although using their method torque pulsation could not eliminate. The proposed control approach for the DFIG necessitates its altered models which be able to integrate using flexible AC transmission system (FACTs) based network models. On the other hand, Ekanayake et al. [4] present a relevant study of the simplified model; in which the authors compare the fifth plus third order model of DFIG followed using the investigation under faulted circumstances. However, Wang and Sun [5] offered magnitude along with frequency control of network associated DFIG based on a coordinated model for wind power production. The numerical differentiation based additive model approximately the nominal working position of DFIG has been used in this manuscript. The effectiveness of such type models can validate from the outcomes offered. The ranking of wind turbines from 800 kW to 3 MW but wind farm assortment is 2 MW–200 MW [6]. In this paper, we provide an alternate technique to design a controller for the system considered by KO et al. [7]. Using the particle swarm optimization method. The obtained results have compared with the existing solutions. Perdana, Carlson, and Persson [8] presented that dynamic response of a wind turbine with DFIG associated to the power system for the study of system response during grid disturbances.

The establishment of this paper is as follows. The basic theory related to non-conventional sources and wind energy conversion system is described in section-1. However, in section-2, the general idea of Wind Energy along with Wind Turbine have been described appropriately. The operating principle and technological modeling of DFIG are illustrated in section-3. In section-4, a voltage source converter controller, simplified system model, and PID supervisory controller design are described. The particle swarm optimization and its algorithm with fitness function for the design of a PID controller using PSO method are given in section-5. The simulation response to DFIG system is described in section-6. The experimental comparison between supervisory controls based PID controller and PSO based PID controller have been presented successfully in this section. Finally, the conclusion and brief discussions on research work are illustrated in the last section-7.

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;

$$P_m = \frac{1}{2}\rho A v_w^3 C_P(\lambda, \beta) \quad (1)$$

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