

An Optimal Method for Sensorless Control of DFIG based WECS using PSO

S. Surendar^{1*} and E. Priya²

¹Department of Electrical and Electronics, Valliammai Engineering College, Kattankulathur-603203, Tamil Nadu, India; iee.surain@gmail.com

²Department of Electrical and Electronics, Easwari Engineering College, Ramapuram, Chennai - 600089, Tamil Nadu, India; priyaedret@gmail.com

Abstract

Objectives: A sensorless method is employed to control real and reactive power for DFIG in an optimal way under various load conditions. The main objective of this paper is to maintain constant voltage and constant frequency. **Method/Analysis:** In this paper, a sensorless control technique with the optimal Proportional-Integral (PI) controller parameters of a test system using Particle Swarm Optimization (PSO) is explained. The techniques for the development of sensorless drives are: reduction of hardware complexity and cost, decreased maintenance requirements, elimination of sensor cables. Optimal tuning of PI controller parameters gives high quality solution. **Findings:** The system performance with PI controller parameters and PSO tuned PI controller parameters are compared. MATLAB software is used to develop the simulation and the results are presented. **Applications:** Low Voltage Ride Through, LVRT, OFFSHORE wind farms.

Keywords: Doubly Fed Induction Generator (DFIG), Fixed Speed Wind Turbines (FSWT), Particle Swarm Optimization (PSO), Variable Speed Wind Turbines (VSWT) and Wind Energy Conversion System (WECS)

1. Introduction

An amount of Fossil fuel and nuclear fuel resources are very limited in the world. So, it is important to find sources of renewable energy. Wind energy has become the most important renewable energy (Figure 1). With increased penetration of wind power in to electrical grids, DFIG wind turbines are largely developed due to their variable speed feature ^{1,2}. DFIG provides constant voltage and frequency even the rotor speed varies and control the overall system power factor. Also it reduces the mechanical stresses on the wind turbines, yielding maximum power output, high energy conversion, improved power quality, less requirements of the pitch angle controllers and low rating converters ^{3,4}.

The main advantages of the sensorless control technique are reduction of hardware Complexity and cost, increased mechanical robustness and noise immunity, elimination of sensor cables and improvement of the vibration behavior. In this method, the speed and position signal are obtained by using monitored voltages and currents by means of mathematical models or artificial intelligence based system ⁵. Sensor less drives operate in the speed range of 1% and 100% rated speed, and having speed control accuracy as high as $\pm 5\%$ of base speed. Its performance mainly depends on torque control capability ^{6,7}.

Particle Swarm Optimization is one of the modern searching algorithms, introduced by ^{8,9}. This technique is based on the social behavior of bird flocking and fish schooling. Its main advantage is to yield a high quality solution. The main steps in PSO are Initialization,

*Author for correspondence

Velocity updating, Position updating, Memory updating, and Termination checking^{8,9}.

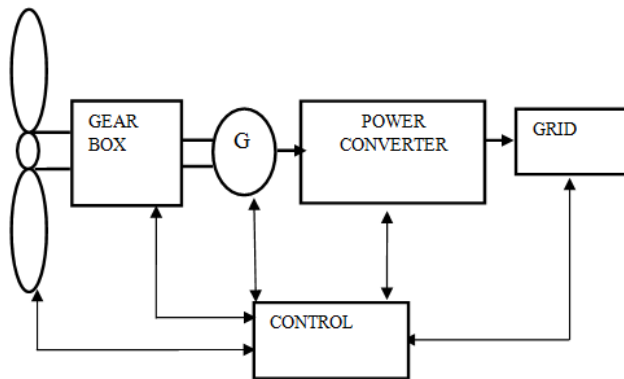


Figure 1. General block diagram of a WECS

2. Proposed work

A simple sensorless control algorithm does not require the rotor position information for reference frame conversions. Table 1 represents the induction generator data.

Table 1. PI controller parameters

Parameters	Without PSO	With PSO
kp(stator voltage controller)	0.1032	0.5157
ki(stator voltage controller)	0.1175	0.9598
kp(rotor current controller)	0.0598	0.0795
ki(rotor current controller)	0.0435	0.0867

2.1 Sensorless Control Technique

2.1.1 Three Phase to Two Phase Conversion

In order to make an easier calculation and to have an efficient speed control, this three phase to two conversions (i.e., abc to dq) is needed.

For Stator

$$v_q^s = \frac{2}{3(V_d^s - 0.5V_b^s - 0.5V_c^s)} \quad (2.1.1)$$

$$v_d^s = \frac{2}{3(0.866V_b^s - 0.866V_c^s)} \quad (2.1.2)$$

For Rotor

$$\begin{bmatrix} i_{qr}^r \\ i_{dr}^r \\ i_{0r}^r \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos \theta & \cos \left(\theta - \frac{2\pi}{3} \right) & \cos \left(\theta + \frac{2\pi}{3} \right) \\ \sin \theta & \sin \left(\theta - \frac{2\pi}{3} \right) & \sin \left(\theta + \frac{2\pi}{3} \right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} I_{ar} \\ I_{br} \\ I_{cr} \end{bmatrix} \quad (2.1.3)$$

2.1.2 Flux Estimation

The stator field oriented reference frame is used for controller development. Stator flux linkage in d-axis and q-axis as follows

$$\lambda_d^s = \int [(V_d^s - r_s i_d^s)] dt \quad (2.1.4)$$

$$\lambda_q^s = \int [(V_q^s - r_s i_q^s)] dt \quad (2.1.5)$$

2.1.3 Stationary to Synchronous Reference Frame

This conversion corresponds to a rotating reference frame moving at synchronous speed ω_s .

$$\begin{bmatrix} v_q^s \\ v_d^s \end{bmatrix} = \begin{bmatrix} \cos \theta_s & -\sin \theta_s \\ \sin \theta_s & \cos \theta_s \end{bmatrix} \begin{bmatrix} v_q^s \\ v_d^s \end{bmatrix} \quad (2.1.6)$$

2.1.4 Rotor Current and Angle Estimator

The resultant current magnitude is given as,

$$I_r = \sqrt{(i_d^r)^2 + (i_q^r)^2} \quad (2.1.7)$$

$$\cos \theta_{rr} = \frac{i_d^r}{I_r}, \quad \sin \theta_{rr} = \frac{i_q^r}{I_r} \quad (2.1.8)$$

2.1.5 Stator Flux Oriented Reference Frame

d-axis and q-axis rotor current in the stator flux (Figure 2) oriented reference frame is,

$$i_q^{re} = -\frac{l_s i_q^{se}}{l_m} \quad (2.1.9)$$

$$i_d^{re} = \sqrt{(I_r)^2 - (i_q^{re})^2} \quad (2.1.10)$$

$$\cos \theta_{er} = \frac{i_d^{re}}{I_r}, \quad \sin \theta_{er} = \frac{i_q^{re}}{I_r} \quad (2.1.11)$$

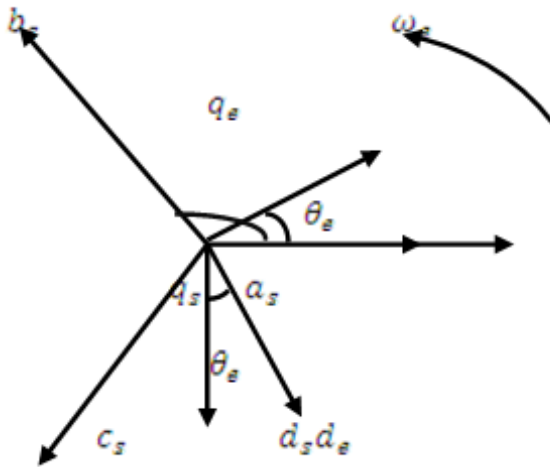


Figure 2. Phasor diagram for stationary to synchronous reference frame.

2.1.6 Synchronous to Rotor Current Oriented Reference Frame

Rotor voltage commands v_q^{rs*} and v_d^{rs*} from synchronously rotating reference to the rotor current oriented reference frame (Figure 3).

$$v_q^{rr*} = v_q^{rs*} \cos \theta_{er} - v_d^{rs*} \sin \theta_{er} \quad (2.1.12)$$

$$v_d^{rr*} = v_q^{rs*} \sin \theta_{er} + v_d^{rs*} \cos \theta_{er} \quad (2.1.13)$$

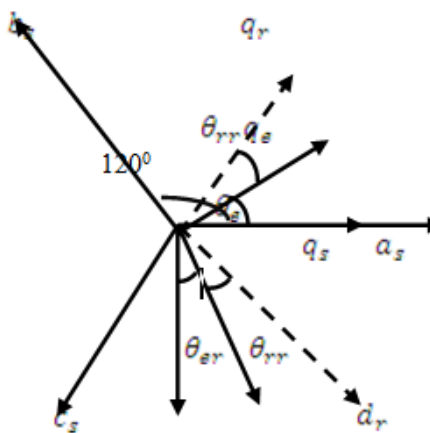


Figure 3. Phasor diagram for synchronous to rotor current oriented reference frame

2.1.7 Rotor Current to Rotor Reference Frame

$$v_q^{rr*} = v_q^{rr*} \cos \theta_{rr} + v_d^{rr*} \sin \theta_{rr} \quad (2.1.14)$$

$$v_d^{rr*} = -v_q^{rr*} \sin \theta_{rr} + v_d^{rr*} \cos \theta_{rr} \quad (2.1.15)$$

2.1.8 Block Diagram

The stator and rotor parameters are converted abc to d-q coordinates for easy calculation because inductance varies with respect to time (Figure 4). If it is converted to d-q coordinates it is assumed to be as constant. Since, the Sensorless control technique is employed current; flux can be determined by using estimators. The DFIG reference conversion was employed to control the parameters effectively. Particle swarm optimization technique was employed to control the real and reactive power¹². Finally, the inverse conversion can be done to have the control parameters in the phase quantities. By using these firing pulse can be generated by using PWM technique as a gate pulse for rotor side converter and grid side converter.

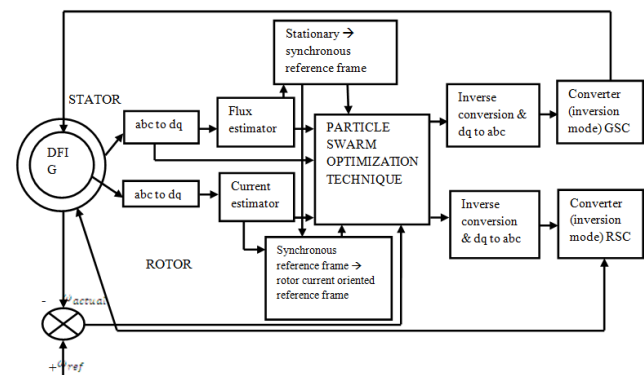


Figure 4. Control block diagram for sensorless flux oriented control.

2.2 Particle Swarm Optimization

PSO is a heuristic method that yields an optimal solution for a problem. Table 2 represents PI controller parameters^{10,11}.

Table 2. Induction generator data

Stator (6 pole, delta connected)	415 V, 50 Hz
Rotor (6 pole, delta connected)	690 V, 50 Hz
Rated power	400 KW
Stator resistance/phase	0.023 pu
Rotor resistance/phase	0.016 pu
Stator reactance/phase	0.18 pu
Rotor reactance/phase	0.16 pu
Magnetizing inductance	2.9 pu

The fitness function 1, 2 and 3 for improving real power and reducing reactive power and optimal tuning of pi controller can be expressed as,

$$f_1(t) = (\alpha_1 T_1 + \alpha_2 T_2 + \alpha_3) * \frac{\alpha_4 T_1 + \alpha_5 T_2 + \alpha_6}{\alpha_4 T_1 + \alpha_5 T_2 + \alpha_7} \quad (2.2.1)$$

Min,

$$f_1(t) = \frac{\alpha_8 T_1 + \alpha_9 T_2 + \alpha_{10}}{\alpha_4 T_1 + \alpha_5 T_2 + \alpha_7} \quad (2.2.2)$$

$$f_2(t) = err^2 * \beta + overshoot * \alpha \quad (2.2.3)$$

Several modifications have been done to improve the performance of the system.

3. Test System

To evaluate the performance of the sensorless control technique, simulations are done with variable speedwind turbine. The single line diagram of a test system 2MW variable speed WECS equipped with DFIG. Adaptive parameter control strategies can be described by PSO. There are 40 wind turbines each rated at 2 MW.

Simulation results under various conditions are presented (Figure 5).

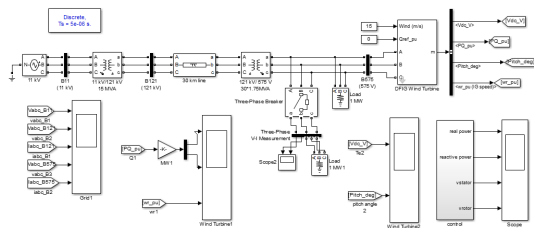


Figure 5. Simulated test system.

The control block includes sensorless control technique for stator and rotor to get firing pulses for rotor side converter and grid side converter. The Figures 6-18 represent the graphical analysis of simulation and results.

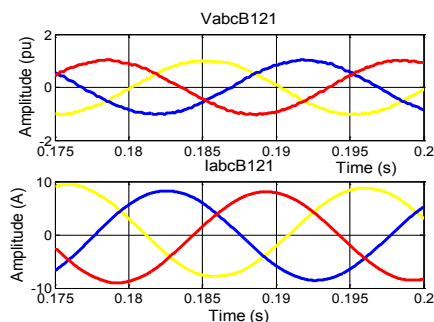


Figure 6. Input voltage waveform.

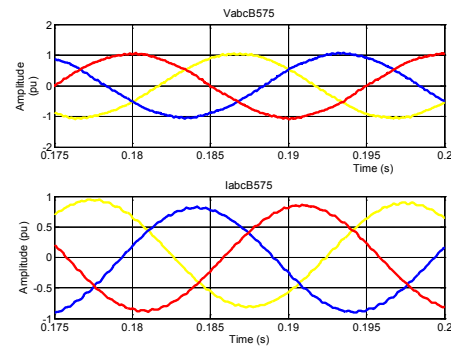


Figure 7. Voltage and current at B575.

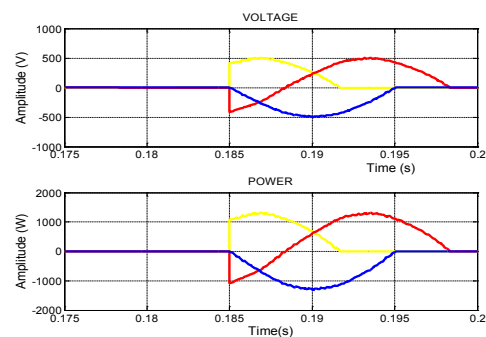


Figure 8. Voltage and current at B575.

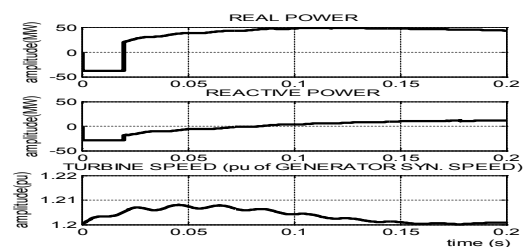


Figure 9. Voltage and power across load2.

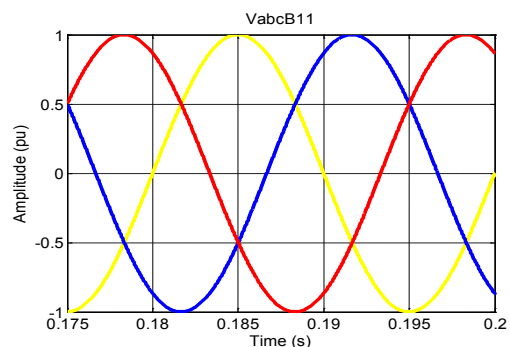


Figure 10. Real and reactive power

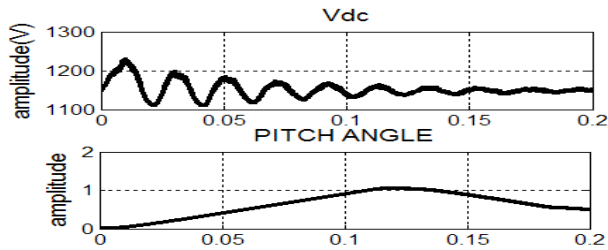


Figure 11. DC Voltage and pitch angle waveform.

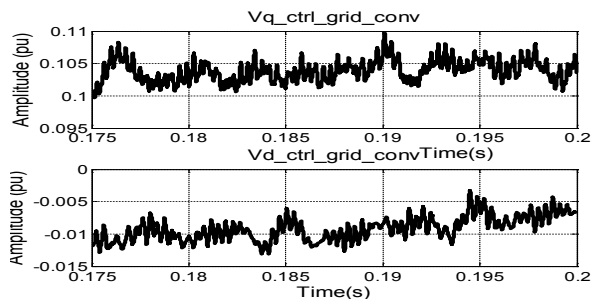


Figure 12. Stator controlled d-axis and q-axis voltage.

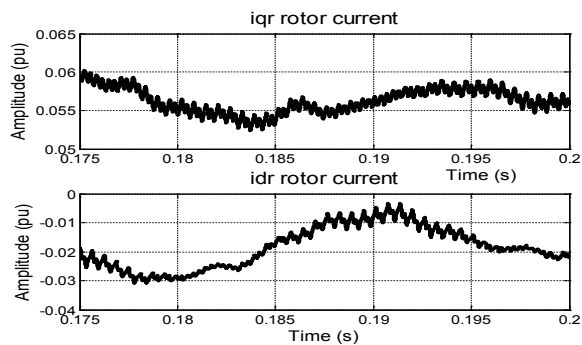


Figure 13. Rotor controlled d-axis and q-axis current.

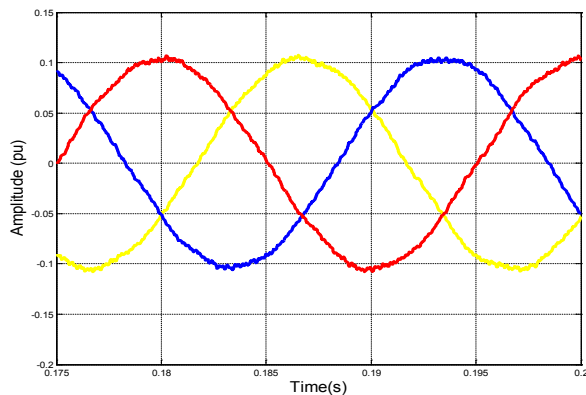


Figure 14. Stator controlled three phase voltage.

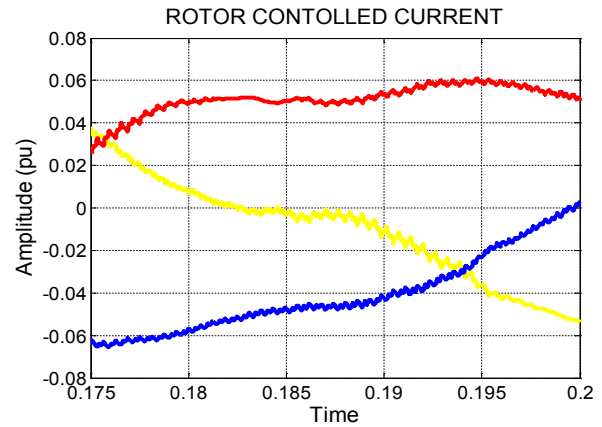


Figure 15. Rotor controlled three phase current.

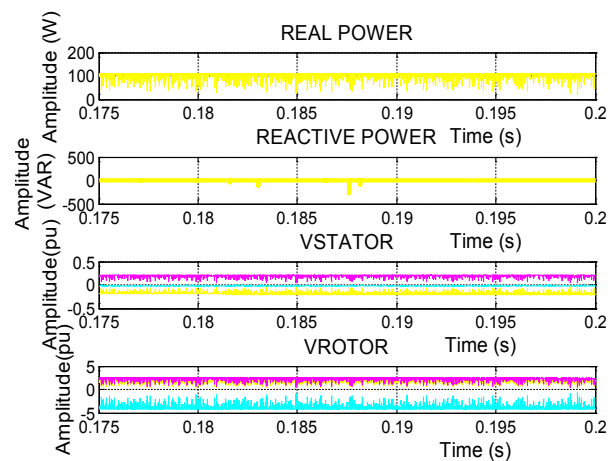


Figure 16. PSO output waveform.

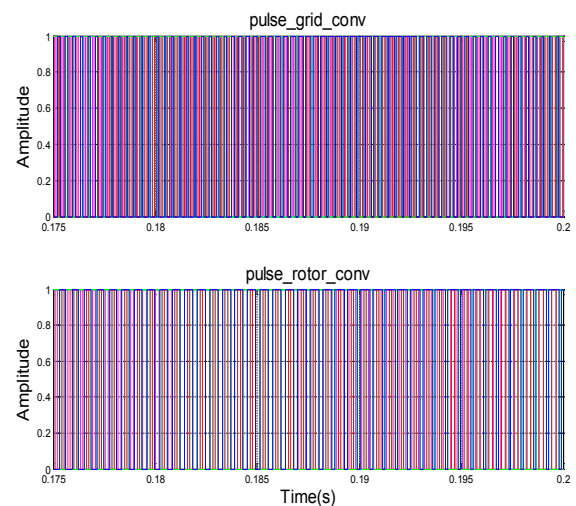


Figure 17. Pulses for RSC and GSC.

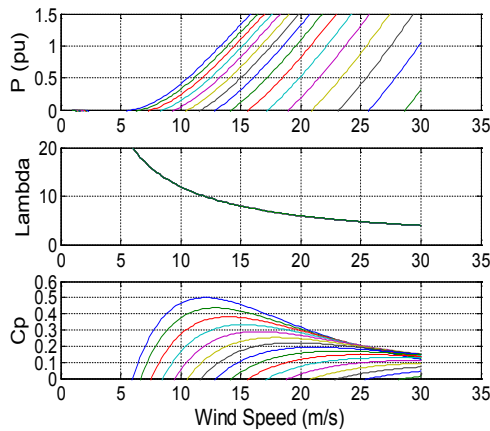


Figure 18. Turbine characteristics.

4. Conclusion

This paper has presented a Sensorless flux oriented control technique with PSO for a DFIG based VSCF generator. The proposed algorithm yields an optimized solution to control real and reactive power. It also maintains the reactive power drawn from the grid as low as possible. The flux and torque are controlled directly and indirectly by the selection of optimal inverter switching modes. Therefore, the optimal switching voltages are determined by using PSO technique. Hence, the proposed algorithm meets the objective of maintaining the voltage and frequency as constant.

5. Reference

1. Pattnaik M, Kastha D. Adaptive speed observer for a stand-alone doubly fed induction generator feeding non-linear and unbalanced loads. *IEEE Transaction on Energy Conversion*. 2012 Dec; 27(4):1018–26.
2. Marques GD, Pires VF, Sousa S, Sousa DM. A DFIG Sensorless rotor-position detector based on a hysteresis controller. *IEEE Transaction on Energy Conversion*. 2011 Mar; 26(9):9–17.
3. Phan VT, Lee HH. Stationary frame control scheme for a standalone doubly fed induction generator system with effective harmonic voltages rejection. *IET Electric Power Application*. 2011 Nov; 5(9):697–707.
4. Ali AJS, Ramesh GP. Comparison of PI and PID Controlled Wind Generator Fed Γ -Z Source based PMSM Drives. *Indian Journal of Science and Technology*. 2016 Jan; 9(1):1–6.
5. Sedaghati R. A novel control strategy study for DFIG-based Wind Turbine. *Indian Journal of Science and Technology*. 2012 Dec; 5(12):3741–5.
6. Sivakumar P, Arutchelvi M, Soundarapandian R. Improved control strategy for grid connected scheme based on PV array and wind-driven induction generators. *Indian Journal of Science and Technology*. 2014 Nov; 7(S7):165–73.
7. Maaref M, Monsef H, Karimi M. A reliability model for a doubly fed induction generator based wind turbine unit considering auxiliary components. *Indian Journal of Science and Technology*. 2013 Sep; 6(9):5282–88.
8. Rajaji L, Kumar C. Neural network controller based induction generator for wind turbine applications. *Indian Journal of Science and Technology*. 2009 Feb; 2(2):70–4.
9. Kennedy J. The particle swarm: The social adaptation of knowledge. *IEEE Conference Evolutionary Computation*, Indianapolis, IN; 1997. p. 303–08.
10. Teodorescu R, Liserre M, Iruetz PR. Grid converters for photovoltaic and wind power systems. John Wiley & Sons Inc: UK; 2011.
11. Rashid M. *Power Electronics Handbook*, 3rd (ed.), Elsevier Inc: Netherlands; 2010.
12. Singh LP. *Advanced power system analysis and dynamics*, 4th (edn), New Age International (P) Ltd.: New Delhi; 2006. p. 528.