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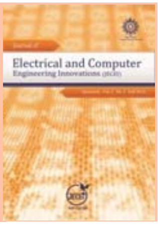

Control Strategies for Performance Assessment of an Autonomous Wind Energy Conversion System

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ABSTRACT

Renewable energy sources like wind, sun, and hydro are considered as a reliable alternative to the traditional energy sources such as oil, natural gas, or coal. This paper describes modeling and simulations to determine a method for the power performance evaluation of autonomous wind turbine system. A speed control regulator is utilized to control the DC bus voltage. The inverter gate's signals are generated by decoding the Hall effect signals of the motor. The three-phase output of the inverter is applied to the permanent magnet synchronous generator (PMSG) block's stator windings. This study shows that the use of resonant controllers ensures the stability of the three-phase source supplying the load which may be unbalanced and subjected to abrupt variations. It also shows that use of PI controller ensures the regulation of DC bus to a reference voltage.

1. INTRODUCTION

In recent years, the electrical power generation from renewable energy sources, such as wind, is increasingly attraction interest because of environmental problem and shortage of traditional energy source in the near future [1]. The wind power mainly depends on geographical and weather conditions and varies from time-to-time. Therefore, it is necessary to construct a system that can generate maximum power for all operating conditions.

Recently, permanent magnet synchronous generator (PMSG) is used for wind power generating system because of its advantages such as better reliability, lower maintenance, more efficient and so on [1], [2].Among these renewable energies, the most promising one is the wind energy with a high level of interest, because of its potential in electricity generation [2]. The technological progress in wind energy conversion system (WECS) equipment such as electrical machines, converters and power electronics allows the exploitation of the variable speed wind turbines (VSWTs) instead of those at fixed speed [3],[4].The use of power converters in a WECS gives the advantage of extracting the maximum power and controlling the energy transfer towards the network or an isolated site. This control offers the possibility to improve the generated power quality of a wind turbine [5]-[7].

Autonomous WECS with the capability of accommodating all the requirements of an isolated site should have a good performance and an acceptable level of [8]. These characteristics mainly depend on the control strategies designed for it. Many techniques were investigated in literature but most of them are intended to grid connected wind turbines [9]. References [10] and [11] have proposed a control strategy to extracting maximum power from a VSWT based on a permanent magnet synchronous generator (PMSG) with a diode bridge rectifier and a DC to DC boost converter. "Ghedamsi" et al. have illustrated the performance of the PMSG based wind turbine with back to back converter in the grid interconnection [5]. "Melício" has used a flywheel energy storage system to the WECS. This technique has improved the performance of grid integration [12].

Voltage control is very important in a distributed source, which ensures the system stability. Therefore, this paper, concentrates on designing a controller to achieve the voltage stability.

2. CONTROL SYSTEM SCHEME

In a variable speed wind energy conversion system, the generator rotor speed is adjustable to achieve maximum power output. According to wind turbine characteristics, the maximum power available at a certain wind speed can be acquired only at the corresponding turbine generator rotating speed. Maximum power point tracking (MPPT) is widely studied in the previous papers [13]-[15].

Fig. 1 shows the autonomous wind energy conversion system under study. The system consists of a PMSG that power requirements for operating it are provided by wind. The PMSG directly connected to a back to back converter. It consists of force commuted rectifiers which ensures the maximum power point tracking (MPPT), a common DC bus and a force commutated inverter. An LC filter is connected to the inverter which can attenuate switching harmonics and create the sinusoidal voltage source for supplying the three phase load [13].

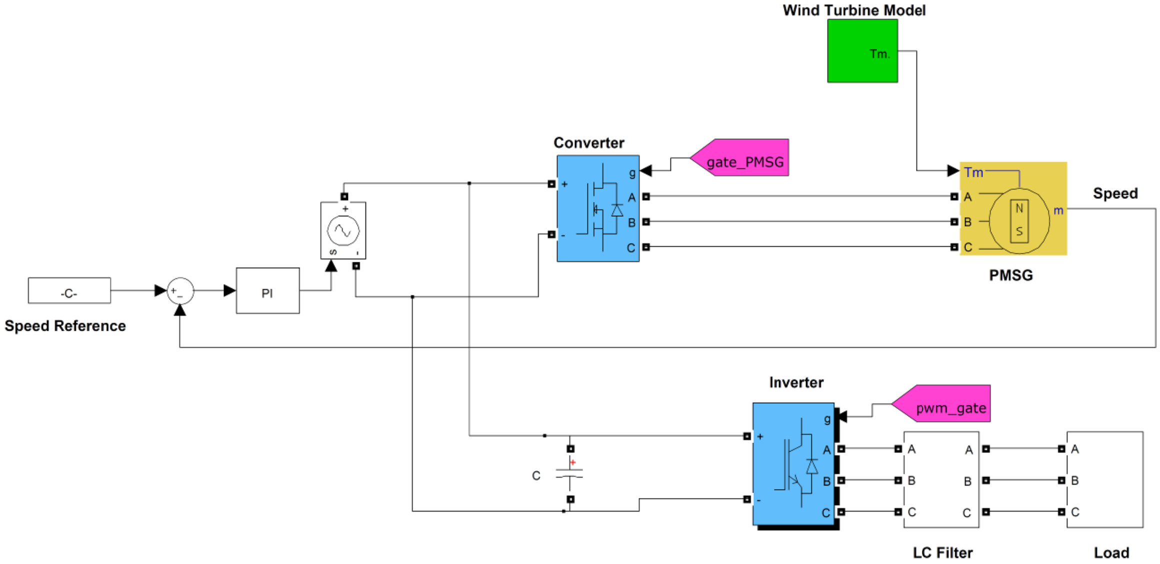


Figure 1: Configuration of PMSG wind energy conversion system.

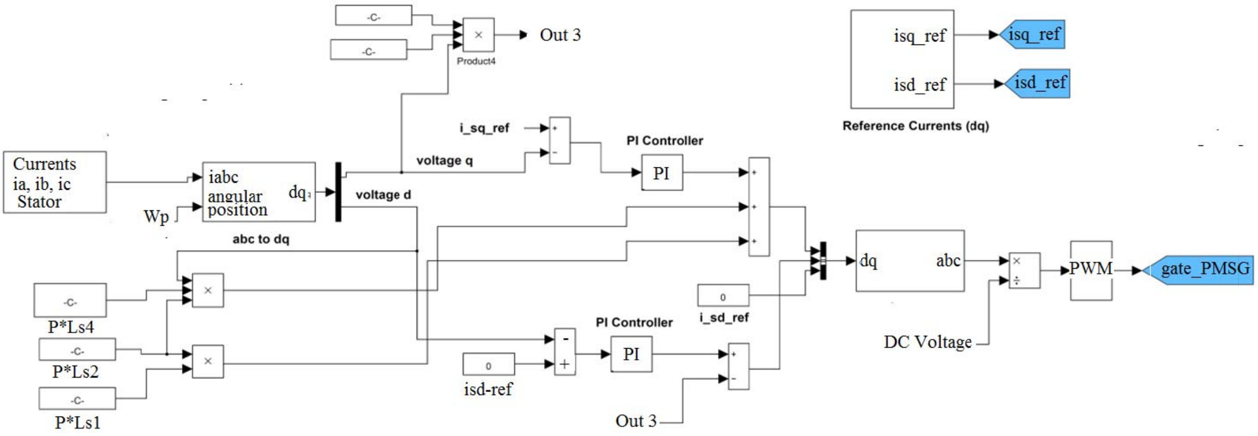


Figure 2: PMSG control strategy

A. *PMSG control strategy*

The PMSG control strategy is based on the measured currents from the stator “I_a”, “I_b” and “I_c”. d-q component stator currents “I_{sd}” and “I_{sq}” are obtained from the Park transformation. Two PI controller are designed to regulate the stator currents with respect to the reference currents “I_{sq_ref}” and “I_{sd_ref}” can be found as follows [4],[16],[17]:

$$\begin{cases} I_{sd\_ref} = 0 \\ I_{sq\_ref} = \dfrac{T_{em\_PMSG\_ref}}{p\phi_m} \end{cases} \tag{1}$$

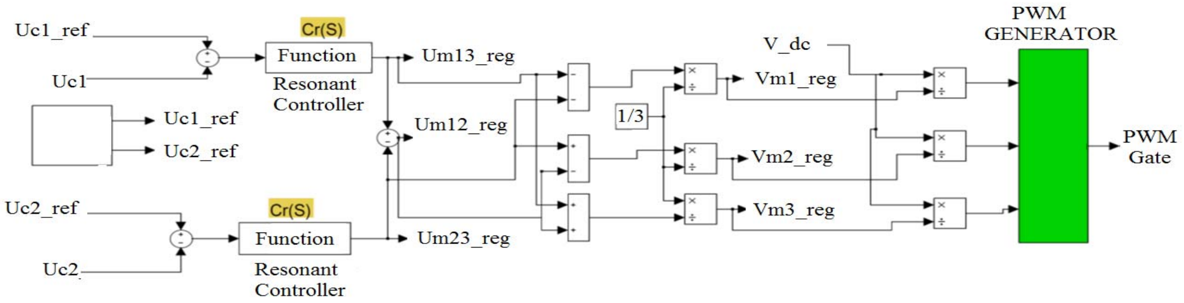


Figure 3: Load voltage control strategy.

Here, $T_{em\_PMSG\_ref}$ is the electromagnetic reference torque of the PMSG. According to reference [16], this torque should have the following expression which ensures the MPPT from the PMSG:

$$T_{em\_PMSG\_ref} = \frac{\rho\pi R^5 C_{p\max}}{2\lambda_{opt}^3}\Omega^2 \tag{2}$$

Then, the stator voltages "V_{sd}" and "V_{sq}", are calculated in the Park reference frame [10],[20]as

$$\begin{aligned} V_{sd} &= R_s I_{sd} + L_s\frac{dI_{sd}}{dt} - p\Omega L_s I_{sq} \\ V_{sq} &= R_s I_{sq} + L_s\frac{dI_{sq}}{dt} + p\Omega L_s I_{sd} + p\Omega\phi_m \end{aligned} \tag{3}$$

The inverse Park transmission of these voltages gives the three-phase voltages "V_a", "V_b" and "V_c". Three duty cycles are then determined to generate three PWM signals for the rectifier control. Fig. 2 shows PMSG control strategy.

B. DC bus control strategy

The DC bus control strategy mainly depends on the power flow management which if keeps a balance between generation and consumption. In order to maintain a DC voltage, a speed control regulator is designed to ensure the regulation of the DC bus to a reference voltage fixed at 400 V (Fig. 1)

C. Load voltage control strategy

According to references [4],[18]-[20], the load voltage consists in controlling the line-to-line voltages at the RLC filter output "U_{c1}" and "U_{c2}". Two resonant controllers "$C_r(s)$" are designed to regulate these sinusoidal quantities. This type of controller is well adapted for regulating alternating waveforms.

The reference voltage "$U_{c1\text{-}ref}$" and "$U_{c2\text{-}ref}$"which will be considered in regulating the line-to-line voltages can be expressed as follows [21]:

$$\begin{bmatrix} U_{c1\_ref} \\ U_{c2\_ref} \end{bmatrix} = U_{n\_ref}\sqrt{2}\begin{bmatrix} \sin(\omega t - \frac{\pi}{6}) \\ \sin(\omega t - \frac{\pi}{2}) \end{bmatrix} \tag{4}$$

"U_{n_ref}" is the RMS line to line voltage.

Since the transfer function of the RLC filter has a second order from as presented in Eq. (5), the resonant controller should be expressed as illustrated in Eq. (6):

$$\frac{U_{c1}}{U_{m1}} = \frac{U_{c2}}{U_{m2}} = \frac{1}{1+3R_tC_ts+3L_tC_ts^2} \tag{5}$$

$$C_r(s) = \frac{c_0 + c_1 s + c_2 s^2 + c_3 s^3}{(d_0 + d_1 s)(s^2 + \omega_p^2)} \tag{6}$$

where "c_0, c_1, c_2, c_3, d_0, d_1" are the resonant controller parameters and "ω_p" is the angular frequency of the regulated quantities. Determination of these parameters is given in detail in Ref. [4].

The resonant controller outputs "U_{m13_reg}" and "U_{m2_reg}" give the three-phase regulated voltages according to the following matrix form:

$$\begin{bmatrix} V_{m1\_reg} \\ V_{m2\_reg} \\ V_{m3\_reg} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 0 \\ -1 & 0 & 1 \\ 0 & -1 & -1 \end{bmatrix}\begin{bmatrix} U_{m12\_reg} \\ U_{m13\_reg} \\ U_{m23\_reg} \end{bmatrix} \tag{7}$$

From these voltages and the DC bus voltage, three duty cycles of the PWM signals driving the inverter are generated. Fig. 3 shows the load voltage control strategy.

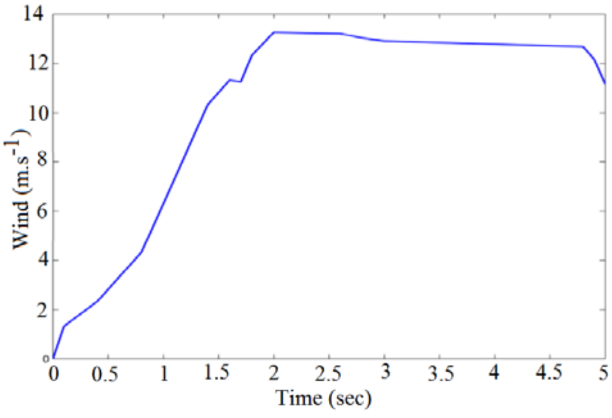


Figure 4: Wind profile.

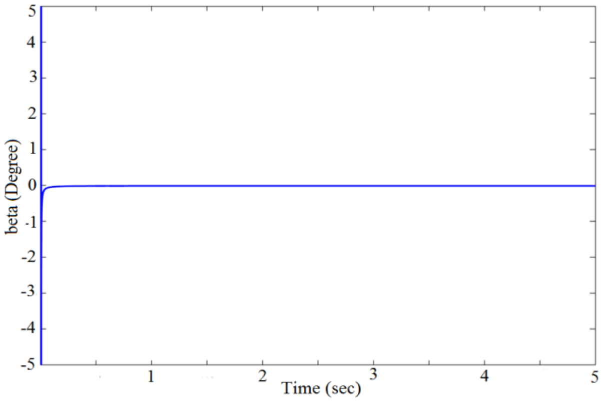


Figure 5: Pitch angle.

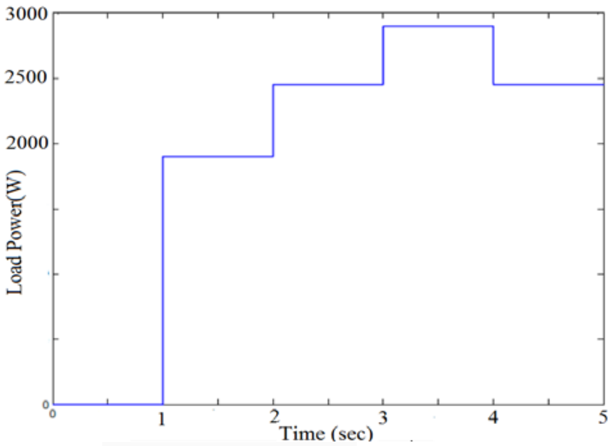


Figure 6: Consumer loads variation.

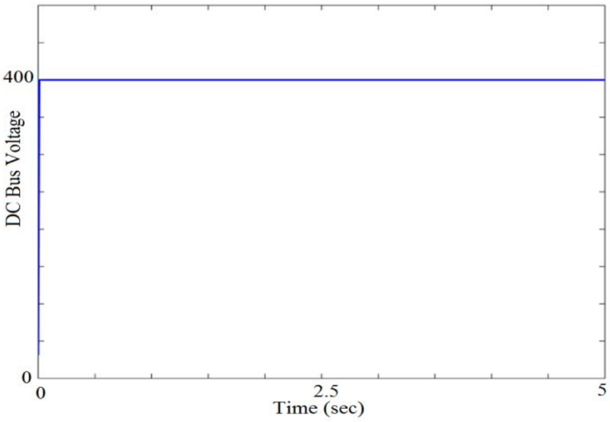


Figure 7: DC bus voltage.

3. SIMULATION RESULTS

This section shows the system performance by means of some simulation results. The proposed system is modeled and simulated in MATLAB, with Simulink and SimPowerSystems toolbox. The simulation is carried out with the ode23t (mod.stiff/Trapezoid) solver. The parameters are given in the Appendix.

Fig. 4 shows the rotational speed of the turbine. The rotational speed is limited to the nominal value with the pitch control system applied to wind turbine model which varies the pitch angle as depicted in Fig. 5.

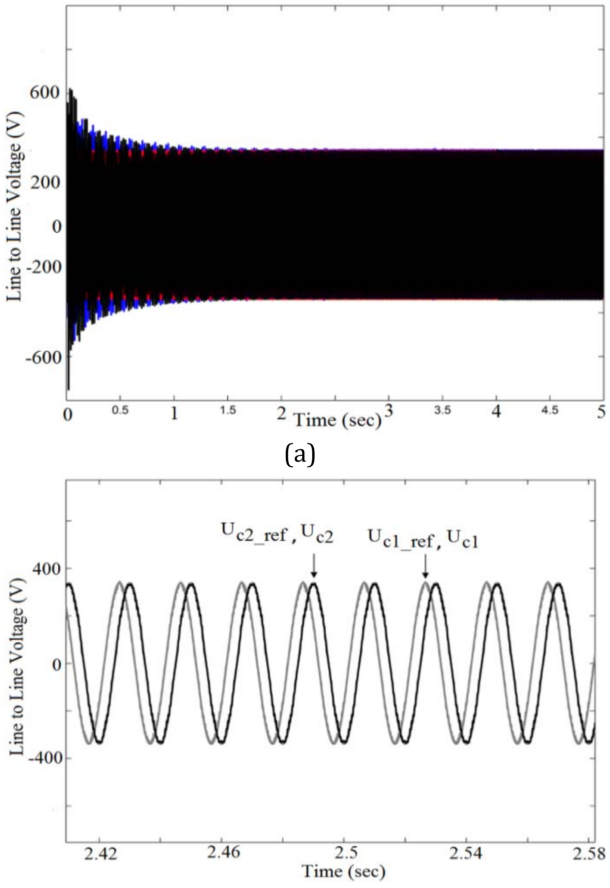
Fig. 6 draws the consumer load variation. As can be seen from Fig. 7, speed control regulator ensures the regulation of DC bus voltage according to a reference value fixed at 400 V.

Fig. 8 shows the line-to-line voltage at the filter outputs "U_{c1}" and "U_{c2}" which follow their reference voltages "U_{c1_ref}" and "U_{c2_ref}". The similarity between reference and measured the voltages proves the effectiveness of the resonant controller implementation in spite of the three-phase unbalance load.

Fig. 9 gives a description of the test sequences. Each time corresponds to the application of a resistive or an inductive load which may be balance or unbalance.

Fig. 10 (a-d), shows the stability of the three simple voltages "V_{c1}", "V_{c2}" and "V_{c3}" in spite of the variation of the three line currents "I_{L1}", "I_{L2}" and "I_{L3}".

Fig. 11 shows the harmonic voltage analysis. According to reference [22],it indicates that the system has an acceptable performance.



(a)

(b)

Figure 8: Line-to-line voltages.

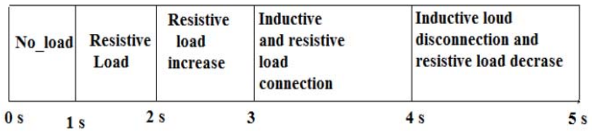
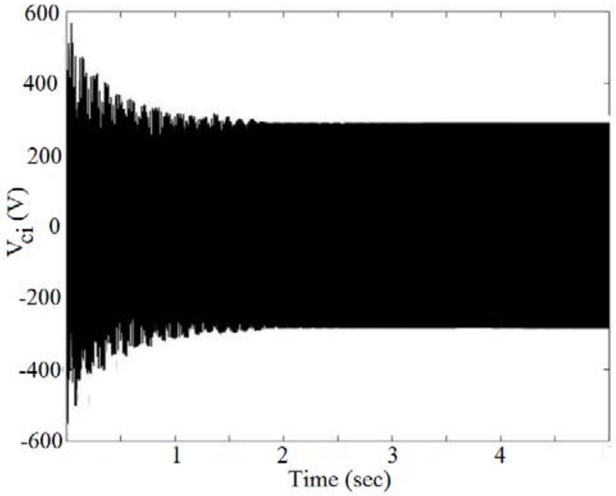
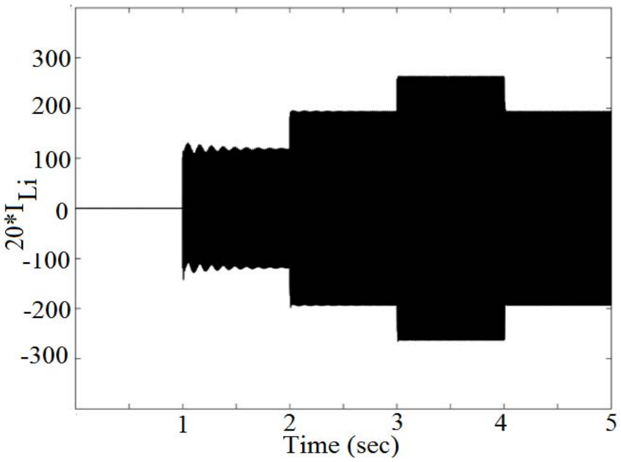


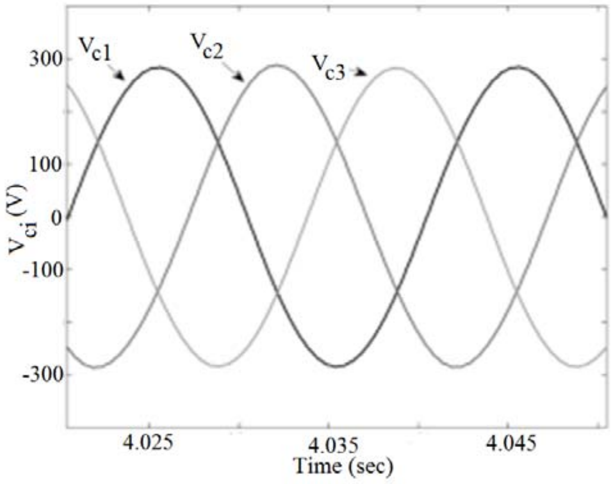
Figure 9: Test sequences.



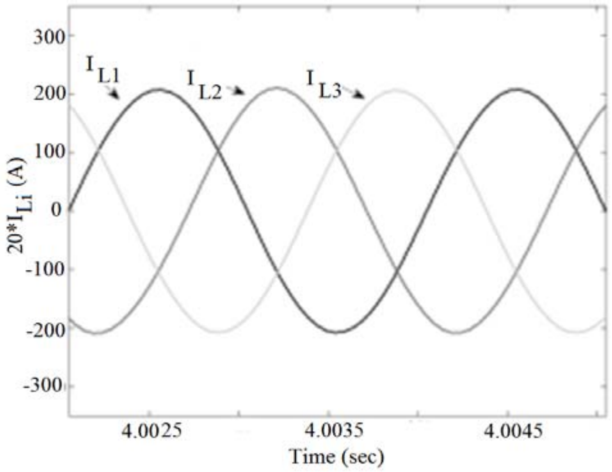
(a)



(b)



(c)



(d)

Figure 10: Load voltages and currents.

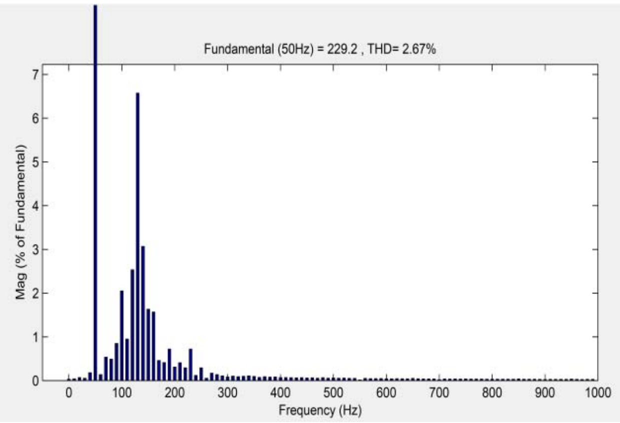


Figure 11: Harmonic voltage analysis.

4. CONCLUSIONS

In this paper, a simple system and control method for small scaled wind power generating system using permanent magnet synchronous generator has been proposed. The above analysis and simulation have shown that the step and search algorithm developed is suitable for wind turbine generation systems. In addition, an autonomous WECS supplying a three-phase load was proposed. In order to avoid any disturbance on the generation system, the line-to-line voltages was directly regulated through two resonant controllers. A speed control regulator was also designed to control the DC bus voltage. In conclusion, this control strategy and system design can be easily implemented and will be able to improve the efficiency of wind turbine systems.

APPENDIX

The corresponding system parameters used to obtain the simulation results are:

- PMSG: nominal power: 3 kW, number of pole pairs: 4, stator resistance: 0.82 Ω, stator inductance: 15.1 mH, inertia: 99×10^{-4} kgm^2, friction coefficient: 10^{-3} N m s rad^{-1}, permanent magnetic lux: 0.5 Wb.
- DC bus: Capacitance 2200μF, Maximum voltage: 800 V.
- Three-phase load: maximum active power: 3 kW, Maximum reactive power 1.5 k VAR.

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BIOGRAPHIES

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