Maximum Power Point Tracking of Wind Energy Conversion System for Permanent Magnet Synchronous Generator

Amit R Baitha[1], A K Jhala[2], Manish Prajapati[3]
PG Scholar, RKDF College of Engineering, Bhopal, M.P., India[1]
Associate Professor, RKDF College of Engineering, Bhopal, M.P., India[2]
Assistant Professor, RKDF College of Engineering, Bhopal, M.P., India[3]
amit.advitya0@gmail.com[1],akjhala.35@gmail.com[2], manishprajapati475@gmail.com[3]

ABSTRACT
Wind power is the most reliable and developed renewable energy source over past decades. With the rapid growth of the wind generators in the power system grid, it is very essential to utilize the maximum available power from the wind for operate the wind turbine (WT) at its maximal energy conversion output. For this, the wind energy conversion system (WECS) has to track or operate at the maximum power point (MPP). However, making a choice on an exact MPPT algorithm for a particular case requires sufficient proficiency because each algorithm has its own merits and demerits. This paper develops the MPPT algorithm for tracking maximum power of the wind turbine. The simple and effective method is implemented in MATLAB for verification of result.

Keywords: WECS, MPPT, Power Converter etc

INTRODUCTION

With the increasing environmental concern the old method of power generation by burning fossil fuel has been substituted by suitable and environment friendly renewable sources. Among various types of renewable energy sources, wind energy is one of the fastest growing renewable energy sources. A renewable energy source has the advantages that it is abundant, clean, and becoming increasingly economical. In fact, renewableenergy sources help in reducing about 70 million metric tons of carbon emissions per year that would have been produced by fossil fuels. In wind energy conversion systems (WECSs), the key technologies include wind turbine technology, power electronics technology, and system control technology. For the wind turbines, based on the orientation of the rotation axis of the wind turbine, there are horizontal-axis wind turbines and vertical-axis wind turbines. In the horizontal-axis wind turbines, the rotation axis of the wind turbine is parallel to the ground, while in the vertical-axis wind turbines, the rotation axis is perpendicular to the ground. Compared to the vertical-axis wind turbines, horizontal-axis wind turbines have higher wind energy conversion efficiency, which are widely applied in the wind energy industry. The wind turbines can also be classified as fixed-speed wind turbines and variable-speed wind turbines based on whether the operation speed is controllable.

II BACKGROUND OF WECS

Environmental concerns in energy generation from the conventional sources make fast development of renewable energy sources (RES), like wind, solar, fuel cell, etc. Rapidly increasing demand for electrical energy and the issues associated with limited reserves and the rising cost of fossil fuels such as oil, coal, and natural gas are also responsible for the growth and rise of renewable energy application [1–5]. In this frame of reference, among the various RES, wind energy is the most adorable and quickly developing source of electricity nowadays [6–8]. According to the global wind market statistics released by the Global Wind Energy Council (GWEC), 51,473 MW of new wind generating capacity was added in 2014. This figure represents a 44% annual increase and the total cumulative installations stand at 369,597 MW at the end of 2014 [9]. Therefore, spreading of wind power in a power system is assumed to be highly developed. Here the crucial concern of the WECS is how to efficiently obtain the maximum output power from wind turbine at all instant in a wide range of wind speed [10]. To maximize the efficiency of the turbine, MPPT algorithm is used to bring the turbine to the MPP for all wind speed values.

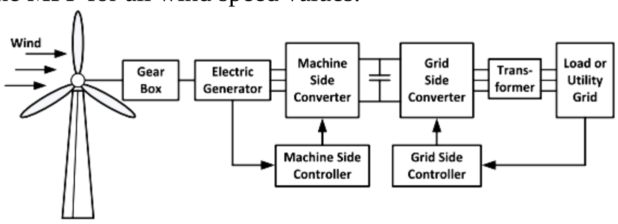

Fig 1: Block diagram of a typical grid-connected WECS.

In WECS, electrical energy is generated from wind employing a wind turbine and an electric generator. The wind turbine is coupled to the prime mover either directly or by a gear box setup. The prime mover is coupled to the shaft of the generator's rotor, whereas the stator is linked either to standalone loads or the utility grid by an appropriate power electronic interface [11–18]. This setup converts mechanical energy to magnetic energy and later to electrical energy for the utility grid. The block diagram of a typical grid-connected WECS is shown in Fig. 1.

Although there are various types of wind turbines, relying upon fixed or variable wind speed, the maximum energy can be extracted only by variable speed wind turbines (VSWT). In contrast to fixed speed wind turbines (FSWT), VSWT needs a partial or full order power converter for power flow control, MPPT control and delivering a high quality of power [11–18]. Since these turbines can vary their rotational speed to follow the instantaneous variation in wind speed, they are able to preserve a constant rotational speed to wind speed ratio, called the optimum tip speed ratio (TSR) [22] for which the extracted power is maximized [23].

In addition to this, VSWT can be controlled to minimize the stress on the tower structure, gears and wind generator (WG) shaft, since the blades absorb peaks of WT torque during the variation of the WG speed of rotation, leading to a longer installation life of WECS [18]. In VSWT system, the electric generators mostly fall into either synchronous generator or asynchronous generator [18, 24, 25], in which the prime mover and subsequently the rotor rotate at synchronous and super-synchronous speed respectively for generating mode. The Wound Rotor and Permanent Magnet type of generators are considered under synchronous generator and under asynchronous generator, the Squirrel Cage, Wound Rotor and Doubly Fed type of generators are considered.

Under IPC three different types of MPPT algorithm have been considered. The first type of MPPT is the tip speed ratio (TSR) algorithm [27]. This requires an anemometer which, however, is inaccurate due to the turbulence of WT blades and the variation of the wind speed along the length of the blade [28]. The other two algorithms are power signal feedback (PSF) [27,29] and optimal torque (OT) MPPT algorithm [30–32] which do not need the anemometer, but still require the parameters of specific wind turbine.

III MODELING OF MPPT BASED WECS

A. System Modeling

The system block diagram of the gearless wind generation system is shown in fig 2. Wind energy obtained from the wind turbine is sent to the PMSG. To generate maximum power, rotational speed of the PMSG is controlled by a pulse width modulation (PWM) converter. The output power of the PMSG is supplied to the power system through a generator side converter and a grid side inverter.

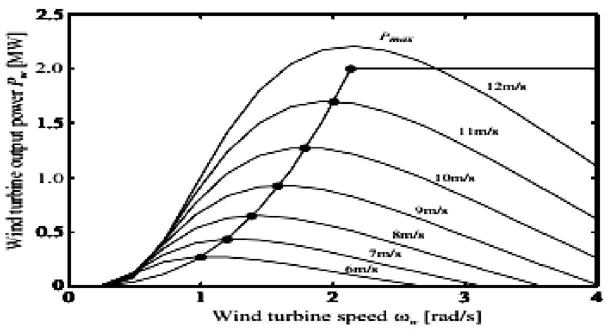

Fig 2: Gearless wind generation system using PMSG.

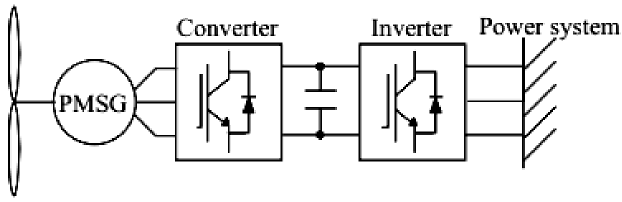

Fig 3: Wind turbine output power characteristics

B. Wind Turbine Model

For the effectiveness of the energy conversion in WECS, firstly available energy store in wind s needs to be determined. So the actual kinetic energy stored in the wind can me expresses as:

$$E = \frac{1}{2} mV^2 \qquad [1]$$

Where E, is the kinetic energy, m is the mass and V is the velocity of wind. Since the air particles are moving the total mass of the particles for a period of time, t, can be:

$$m = \rho AVt = \rho \pi r^2 Vt \qquad [2]$$

Where ρ is the air density, and A is the swept area of the wind turbine rotor. Here r is the radius of the wind rotor. Hence the kinetic energy will be:

$$E = \frac{1}{2} \rho \pi r^2 V^3 t \qquad [3]$$

The actual wind at any instant of time can be:

$$P_{Wind} = \frac{E}{t} = \frac{1}{2} \rho \pi r^2 V^3 \qquad [4]$$

According to Betz's idea, after impacting the rotor blades of the wind turbine, the velocity of the wind decreases form V to V', this means that when the wind passes through the wind turbine blades, there is still some kinetic power left in the wind. The relationship between the power that is captured by the wind turbine and the potential maximum power in the wind can be expressed as follows:

$$C_p = \frac{P_{Turbine}}{P_{Wind}} \qquad [5]$$

Where $P_{Turbine}$, is the mechanical power captured by the wind turbine, and C_p is the power coefficient of the wind turbine which can be expressed as follows:

$$C_p = c_1 \left(c_2 \frac{1}{\alpha} - c_3 \beta - c_4 \beta^x - c_5 \right) e^{-c_6 \frac{1}{\alpha}} \qquad [6]$$

Where,

$$\frac{1}{\alpha} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta^3} \qquad [7]$$

And,

$$\lambda = \frac{\omega_m r}{V} \qquad [8]$$

Where β, is the blade angle which is indicated in Figure 1, and λ is the tip speed ratio of the wind turbine, while ω_m is the angular speed of the wind turbine generator. The values of the coefficients $(c_1 \sim c_6)$ depend on the type of the wind turbine. Now the power captured by the wind turbine can be written as:

$$P_{Turbine} = \frac{1}{2}\rho\pi r^2 C_p(\lambda,\beta)V^3 \qquad [9]$$

C. Maximum Power Point Tracking Control for PMSG based WECS

Wind energy, even though abundant, varies continually as wind speed changes throughout the day. Amount of power output from a WECS depends upon the accuracy with which the peak power points are tracked by the MPPT controller of the WECS control system irrespective of the type of generator used. The maximum power extraction algorithms researched so far can be classified into three main control methods, namely Tip Speed Ratio (TSR) control, Power Signal Feedback (PSF) control and Hill-Climb Search (HCS) control.

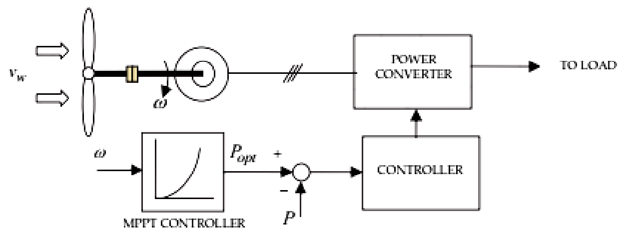

Figure 4: Power Signal Feedback (PSF) control of WECS

In PSF control, it is required to have the knowledge of the wind turbine's maximum power curve, and track this curve through its control mechanisms. The maximum power curves need to be obtained via simulations or off-line experiment on individual wind turbines. In this method, reference power is generated either using a recorded maximum power curve or using the mechanical power equation of the wind turbine where wind speed or the rotor speed is used as the input. Figure 4 shows the block diagram of a WECS with PSF controller for maximum power extraction.

The power from wind generator is fed to a diode rectifier, so

$$P_g = 3V_{ph}I_{ph} = V_{dc}I_{dc} \qquad [9]$$

Where, P_g = Generator output power

V_{ph} = Phase output voltage

I_{ph} = Phase output current

V_{dc} = DC output Voltage

I_{dc} = DC output current

The voltage V_{dc} can be calculated by:

$$V_{dc} = \frac{3}{\pi}\int_{-\frac{\pi}{6}}^{\frac{\pi}{6}} V_L \cos\theta d\theta = \frac{3}{\pi}V_L = \frac{3\sqrt{6}}{\pi}V_{ph} \qquad [10]$$

From the Figure 3 of wind generator power versus speed characteristics, it is evident that it has a single maximum power point and at maximum power production

$$\frac{dP}{d\omega} = 0 \qquad [11]$$

Where ω represents the wind generator speed. Now applying differentiation chain rule to the above equation we get

$$\frac{dP}{d\omega} = \frac{dP}{dD} * \frac{dD}{dV_{dc}} * \frac{dV_{dc}}{d\omega_e} * \frac{d\omega_e}{d\omega} = 0 \qquad [12]$$

For DC-DC boost converter:

$$V_{dc} = (1-D) * V_0 \qquad [13]$$

$$\frac{dD}{dV_{dc}} = -\frac{1}{V_0} \neq 0 \qquad [14]$$

For wind generator

$$\frac{d\omega_e}{d\omega} = p \neq 0 \qquad [15]$$

$$V_{dc} \propto V_{ph} \qquad [16]$$

Combining all the above results it is clear that

$$\frac{dP}{d\omega} \propto -\frac{dP}{dD} \qquad [17]$$

This shows that the steepest-ascent algorithm is ensures convergence. The negative sign indicates that the rate of change of power with respect to generator speed is opposite to that of the duty cycle. Similarly from the plot of P_{dc} versus V_{dc} in Figure 4.2, it is also evident that at MPP

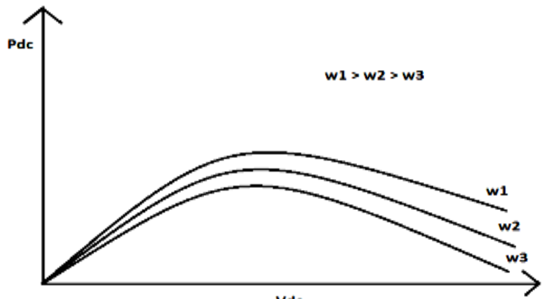

Figure 5: Rectifier output versus voltage graph for changing wind

IV SIMULATION & RESULT

The complete MPPT based WECS with PMSG was simulate by MATLAB/Simulink using the parameter given in Table 1. The simulation is based on generator side control strategy. The PSF methodology is implemented for MPPT for boost converter. The wind speed is kept contat at 12 m/S. pitch angle is selected zero.

Table 1: Parameter and operating condition of Generator side control system

Wind Turbine Data	
Nominal Mechanical Output Power	8.5 kW
Power Factor	0.9
Base wind speed (m/s)	12
Maximum Power at base wind speed	1
Pitch angle	0
Generator Data	
Generator type	PMSG
Generator Power	10kW
Back EMF waveform	sinusoidal
Flux linkage	0.433

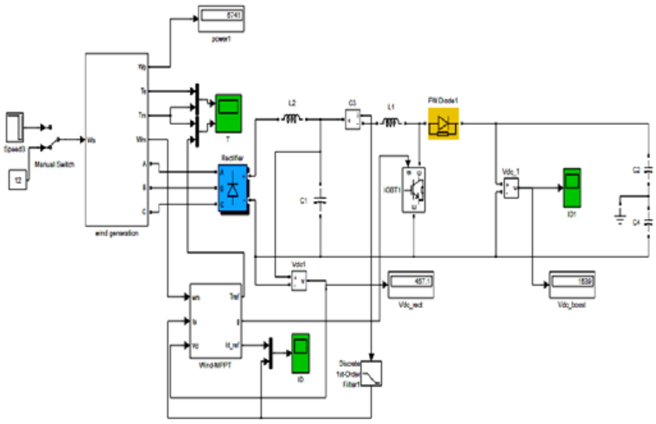

Figure 6: SIMULINK Model of MPPT based WECS with PMSG.

Figure 6 shows the Simulink model of the work. Here PMSG is used of generation of the voltage. The MPPT algorithm is used for generating pulse for boost converter to give the voltage.

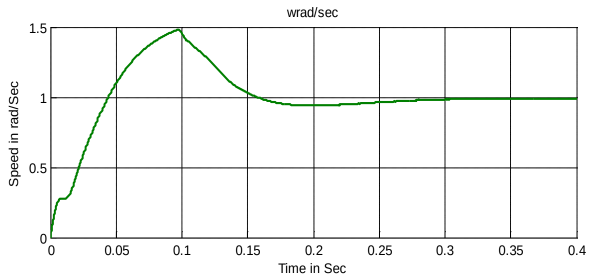

Figure 7: Generator speed in PU system with MPPT

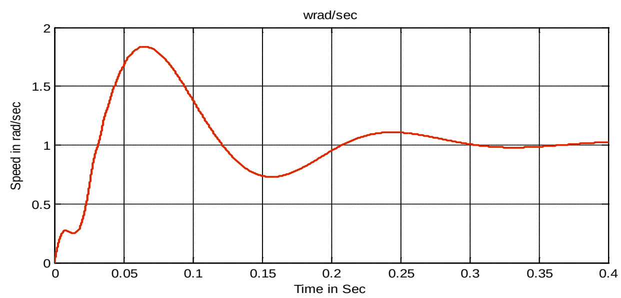

Figure 8: Generator speed in pu system without MPPT

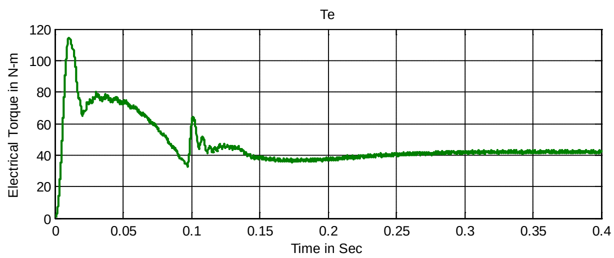

Figure 9: Electric Torque developed by Wind Generator with MPPT

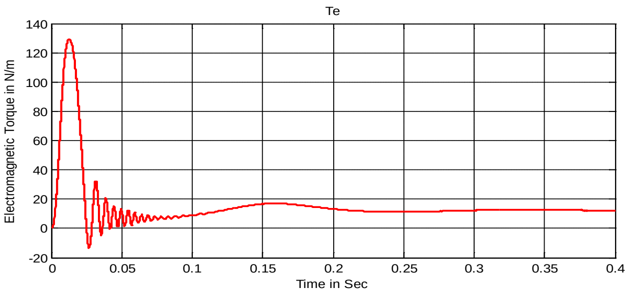

Figure 10: Electric Torque developed by Wind Generator without MPPT

Figure 7-14 shows the outputs generated with and without MPPT based WECS with PMSG. Here it is clear the MPPT is very useful for generation for optimal application of WECS.

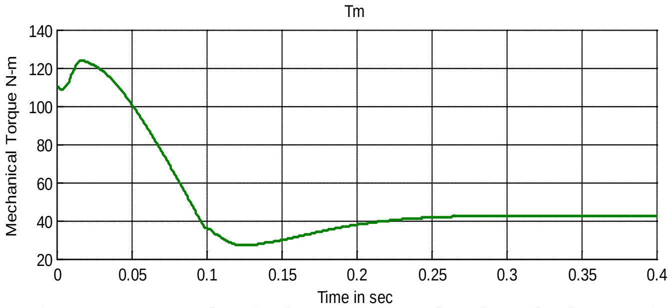

Figure11: Mechanical Torque developed by Wind Generator with MPPT

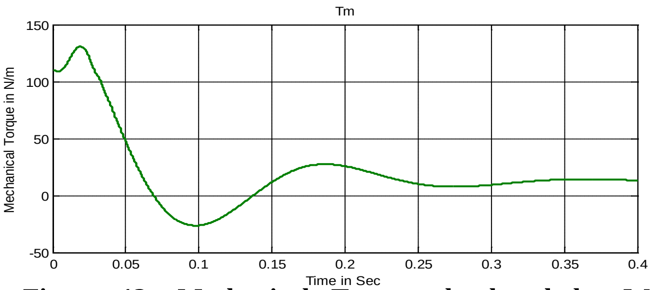

Figure 12: Mechanical Torque developed by Wind Generator without MPPT

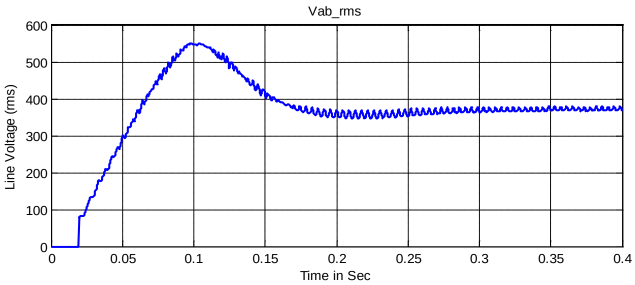

Figure 13: R.M.S value of Generated Line Voltage with MPPT

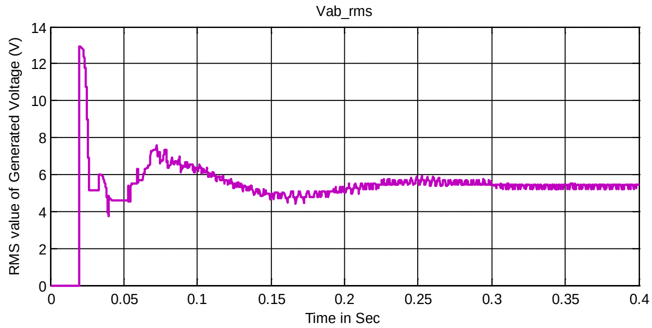

Figure 14: R.M.S value of Generated Line Voltage without MPPT

V CONCLUSION

Wind energy conversion system is now a very useful system in that area where power grid is not available for supply the power. Here is this paper the a wind energy conversion system is developed with permanent magnet synchronous generator. The power signal feedback MPPT algorithm is applied on it for giving maximum power conversion. The whole work is simulated in MATLAB for finding the results. The simulations highlight that the designed controllers shows very good response and work very well for PSF based WECS with PMSG.

REFERENCES:-

[1]. Liang R-H, Liao J-H. A fuzzy-optimization approach for generation scheduling with wind and solar energy systems. IEEE Trans Power Syst 2007;22:1665–74.

[2]. Saber AY, Venayagamoorthy GK. Efficient utilization of renewable energy sources by gridable vehicles in cyber-physical energy systems. IEEE Syst J 2010;4:285–94.

[3]. Nikolova S, Causevski A, Al-Salaymeh A. Optimal operation of conventional power plants in power system with integrated renewable energy sources. Energy Convers Manag 2013;65:697–703.

[4]. Bansal M, Khatod DK, Saini RP. Modeling and optimization of integrated renewable energy system for a rural site. IntConfReliabOptimInfTechnol 2014:25–8.

[5]. Böttger D, Götz M, Theofilidi M, Bruckner T. Control power provision with power-to-heat plants in systems with high shares of renewable energy sources – an illustrative analysis for Germany based on the use of electric boilers in district heating grids. Energy 2015;82:157–67.

[6]. Michalak P, Zimny J. Wind energy development in the world, Europe and Poland from 1995 to 2009; Current status and future perspectives. Renew Sustain Energy Rev 2011;15:2330–41.

[7]. Bataineh KM, Dalalah D. Assessment of wind energy potential for selected areas in Jordan. Renew Energy 2013;59:75–81.

[8]. Ghosh SK, Shawon MH, Rahman A, Nath SK. Wind energy assessment using weibull distribution in coastal areas of Bangladesh. In: Proceedings of the 3rd

International Conference on Devlopmental Renewable Energy Technology; 2014. p. 1–6.
[9]. Global Wind Energy Council (GWEC); 2014. ⟨http://www.gwec.net/globalfigures/graphs/⟩ [accessed 14.02.15].
[10]. Jena D, Rajendran S. A review of estimation of effective wind speed based control of wind turbines. Renew Sustain Energy Rev 2015;43:1046–62.
[11]. Baroudi JA, Dinavahi V, Knight AM. A review of power converter topologies for wind generators. Renew Energy 2007;32:2369–85.
[12]. Chakraborty S, Kramer B, Kroposki B. A review of power electronics interfaces for distributed energy systems towards achieving low-cost modular design. Renew Sustain Energy Rev 2009;13:2323–35.
[13]. Chen Z, Guerrero JM, Blaabjerg F. A review of the state of the art of power electronics for wind turbines. IEEE Trans Power Electron 2009;24:1859–75.
[14]. Iglesias RL, Arantegui RL, Alonso MA. Power electronics evolution in wind turbines - A market-based analysis. Renew Sustain Energy Rev 2011;15:4982–93.
[15]. Chakraborty A. Advancements in power electronics and drives in interface with growing renewable energy resources. Renew Sustain Energy Rev 2011;15:1816–27.
[16]. Wang H, Nayar C, Su J, Ding M. Control and interfacing of a grid-connected small scale wind turbine generator. IEEE Trans Energy Convers 2011;26:428–34.
[17]. Muyeen SM. Wind energy conversion systems: technology and trends. 1st ed. New Delhi, India: Springer; 2012.
[18]. Duran MJ, Barrero F, Pozo-Ruz A, Guzman F, Fernandez J, Guzman H. Understanding power electronics and electrical machines in multidisciplinary wind energy conversion system courses. IEEE Trans Educ 2013;56:174–82.
[19]. Bianchi FD, Battista HD, Mantz RJ. Wind turbine control systems: principles, modelling and gain scheduling design. 1st ed. London: Springer-Verlag; 2007.
[20]. Xu F, Zhang J, Cheng M. Analysis of double objectives control for wind power generation system with frequency separation. 4th IntConfElectrUtilDeregulRestruct Power Technol 2011:1366–71.
[21]. Abad G, López J, Rodríguez MA, Marroyo L, Iwanski G. Doubly fed induction machine: modeling and control for wind energy generation. Wiley-IEEE Press; 2011.
[22]. Hui J, Bakhshai A, Jain PK. An adaptive approximation method for maximum power point tracking (MPPT) in wind energy systems. IEEE Energy Convers Congr Expo 2011:2664–9.
[23]. Freris LL. Wind energy conversion systems. London, UK: Prentice Hall; 1990.
[24]. Li H, Chen Z. Overview of different wind generator systems and their comparisons. IET Renew Power Gener 2008;2:123.
[25]. Alnasir Z, Kazerani M. An analytical literature review of stand-alone wind energy conversion systems from generator viewpoint. Renew Sustain Energy Rev 2013;28:597–615.
[26]. Kazmi SMR, Goto H, Guo H-J, Ichinokura O. A novel algorithm for fast and efficient speed-sensorless maximum power point tracking in wind energy conversion systems. IEEE Trans Ind Electron 2011;58:29–36.
[27]. Buehring IK, Freris LL. Control policies for wind-energy conversion systems. IEE Proc C GenerTransmDistrib 1981;128:253.
[28]. Pao LY, Johnson KE. A tutorial on the dynamics and control of wind turbines and wind farms. Am Control Conf 2009:2076–89.
[29]. Hua G, Geng Y. A novel control strategy of MPPT taking dynamics of wind turbine into account. 37th IEEE Power Electron Spec Conf 2006:1–6. [30] Morimoto S, Nakayama H, Sanada M, Takeda Y. Sensorless output maximization control for variable-speed wind generation system using IPMSG. IEEE Trans IndAppl 2005;41:60–7.
[30]. Morimoto S, Nakayama H, Sanada M, Takeda Y. Sensorless output maximization control for variable-speed wind generation system using IPMSG.IEEE Trans IndAppl 2005;41:60–7.
[31]. Abdullah MA, Yatim AHM, Tan CW, Saidur R. A review of maximum power point tracking algorithms for wind energy systems. Renew Sustain Energy Rev 2012;16:3220–7.
[32]. Zhao Y, Wei C, Zhang Z, Qiao W. A review on position/speed sensorless control for permanent-magnet synchronous machine-based wind energy conversion systems. IEEE J EmergSel Top Power Electron 2013;1:203–16.