

# The Design of Boost Circuit in Small Wind Generation System

Yaran Chen

The State Key Laboratory of  
Management and Control for Complex  
Systems

Institute of Automation, Chinese  
Academy of Sciences  
Beijing, China

Dongguan Research Institute of CASIA  
Cloud Computing Center, Chinese  
Academy of Sciences

Dongguan, China

Email: chenyan0313@163.com

Gang Xiong

Beijing Engineering Research Center of  
Intelligent Systems and Technology  
Institute of Automation, Chinese  
Academy of Sciences  
Beijing, China

Wenqiang Li, Jiani Qian, Bo Hu

Harbin Engineering University  
HEU  
Harbin, China

**Abstract**—This paper presents an effective solution to track the maximum power and improve the security of small scale wind power system, aiming to optimize the efficiency of wind energy conversion and connecting wind generators to the electrical grid. The controller of the generation system used Perturbation Method of duty cycle to facilitate the construction of control algorithm, and improved its robustness. Due to the complexity of the wind turbine operating environments. The effectiveness of the proposed control method is evaluated through simulation tests performed in MATLAB/SIMULINK. The article presents a controller which uses an ARM and also designed the boost circuit, measure circuit, processes circuit, as well as drive circuit. The results obtained demonstrate the effectiveness of the proposed control functionalities, which can be said that the design of boost circuit is reasonable.

**Keywords**—small scale wind power generation; MPPT; limiting voltage

## I. INTRODUCTION

With the growing exhaustion of the fossil fuels, many countries have paid more and more attention to the development and the application of the new types of the energy sources. At the mean time, renewable energy has been further developed over the past few decades.

Among all renewable resources, wind is one of the most accessible one. As the result, the wind power generation system is becoming maturer and its installed capacity is growing rapidly.

In all kinds of wind power generation systems, small scale wind power generation system with its flexibility and advantages in configuration becomes more and more widely used in micro-grid connection. This paper presents a Boost circuit(Fig.2) in small wind generation system. By adjusting the motor speed with variety of wind speed, we can get the optimal value of wind turbine tip speed ratio, and, the generation system will shutdown to protect itself when the power grid voltage is too high. This mechanism

was described in Fig.10.

The general scheme circuit was shown in Fig.3. During normal operations, the control strategy based on the DC-DC boost chopper was used to control the duty cycle. The concrete algorithm was described by flow chart in Fig.4. The simulation diagram was shown in Fig.7.

## II. ELEMENTARY THEORY

### A. Maximum power point tracking theory of Wind power generation system

Wind power system converts kinetic energy of wind into mechanical energy of wind turbine by blades, then converts into electrical energy by generator which directly connects the wind turbine. The relationship between mechanical power and incoming wind speed can be described by:

$$P_M = \frac{1}{2} \rho A v_w^3 C_p \quad (1)$$

Where  $P_M$  is the mechanical power (W);

$\rho$  is the air density ( $kg / m^3$ );

$A$  is the swept area( $m^2$ );

$v_w$  is the wind speed(m/s);

$C_p$  is the power coefficient of the wind turbine.

$C_p$  is a function of the tip speed ratio  $\lambda_T$  and the Blade pitch angle  $\beta$ , which can express as  $C_p(\lambda_T, \beta)$ .  $\lambda_T$  is calculated by

$$\lambda_T = \frac{\omega_m r_T}{v_w} \quad (2)$$

For a fixed pitch angle, the power coefficient  $C_p$  depends on the tip speed ratio  $\lambda_T$ . Namely in a certain wind speed,

wind turbine which is running in this state can capture wind power maximum. The Betz limit shows that the  $C_p$  theoretical maximum value of 0.59[1].

Due to the complexity of the Wind turbine operating environments, the wind turbine simulation in a laboratory may has high demand on the reality of wind power generation system behavior. This paper presents a dynamic model using the MATLAB/SIMULINK simulation software. There are many wind turbine tool boxes in the SIMULINK library. By this model, we obtain the maximum power output under different various wind speeds, property of maximum power output was shown in Fig.1.by researching the relationship between wind turbine output and its rotation

speed. Therefore, by controlling the motor speed, the wind power generation system can obtain the maximum output power.

#### B. Relationship between the Boost circuit duty cycle and the maximum output power

A control unit was added to the topology of DC-DC Boost circuit because of its simple structure and easy to control. The basic circuit element is rectifier diode, a power transistor with the anti-parallel diode, an inductor and a smoothing capacitor. It can be seen from Fig. 2

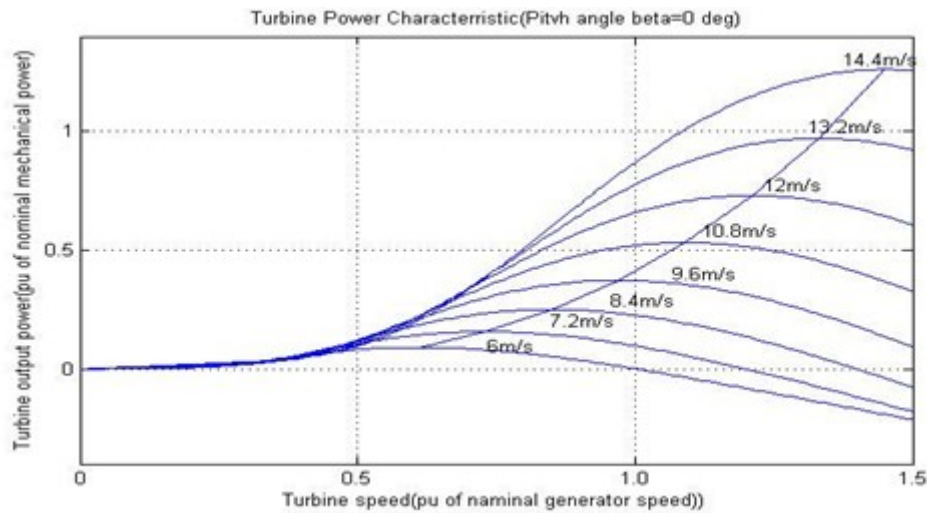


Fig.1 the wind turbine output power versus speed and maximum power point running

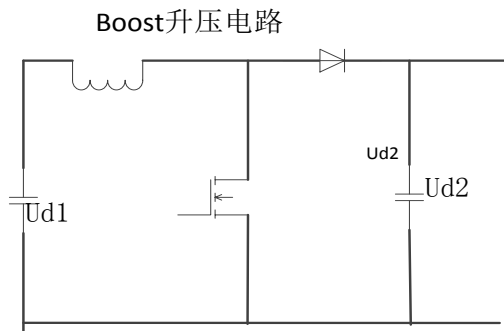


Fig.2 The topology of the DC-DC boost chopper

The chopper acts as a bridge between wind generation and the DC micro-grid. It limits the output voltage and achieves maximum power point tracked by employing PWM control techniques. The input terminal of the chopper connects to a diode rectifier which has a variable output DC voltage, and the output terminal of the chopper connects to a DC micro-grid which has a fixed DC voltage of 600V. The output power was controlled by controlling the output current  $I_{d2}$ .

The relationship between the input and output currents is described by the formula (3). So in order to control the output current, we just need to control the input current.

$$I_{d2} = \frac{1}{1-D} I_{d1} \quad (3)$$

By modulating the duty cycle of boost chopper, the system can set its output voltage to acceptable level and track the maximum power point.

At the same time, controlling the duty cycle can also control the output voltage. When the grid voltage becomes higher than 620V, controlling the duty cycle D is used to limit the output voltage under 620V, that is enabling the voltage of the DC micro-grid in the safe range.

As a matter of fact, controlling the boost chopper current is controlling the speed of the PMSG driven wind turbine in order to keep the tip speed ratio at the optimal operating point for all wind speeds.

### III. SYSTEM SCHEME

#### A. General scheme

Wind generators generate alternating current which can be

transformed into direct current by an uncontrolled rectifier. Then Boost circuit controls the current and limits the output voltage, which achieves MPPT and grid protection. General scheme includes an uncontrolled rectifier and a boost circuit, which expressed as Fig.3.

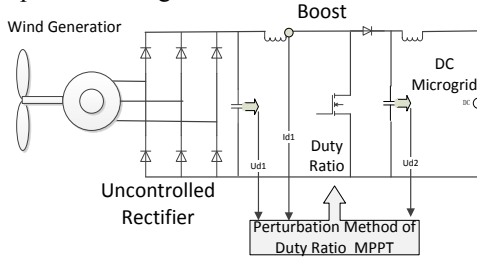


Fig. 3 Configurability of the small wind generation systems equipped with PMSG

#### B. Perturbation Method of the duty cycle method to decrease aerodynamic efficiency

During normal operating conditions, the control structure based on the DC-DC boost circuit was used to control the duty cycle. The paper controls the current to adjust the speed of the PMSG driven wind turbine by control the duty cycle in order to increase the tip speed ratio and aerodynamic efficiency. The system uses Perturbation Method of the duty cycle to search for the maximum power point. The advantage of Perturbation Method is that it needs less physical detection, simple structure and it's easy to implement, so that this method is more practical in all of the MPPT methods. The nature of Perturbation Method of the duty cycle is that the controller generates different current by comparing the current value output power and the previous value of output power, in order to calculate the duty cycle. The MPPT controller changes the output during each system cycle. The changes of the output was depended on the power generated by the system. The input voltage and current of the boost circuit were considered as research objects. Assign  $U_n$  is the voltage feedback from the uncontrolled rectifier, and  $I_n$  is its output current, so the output power of wind turbine is  $P_n = U_n * I_n$ . The output of the controller  $I_{ref}$  was changed by the fixed-step,  $I_{ref}$  was changed by comparing the output power at the instant and the output power in the previous cycle, when the power increased, a fixed value will be added into the output of the controller  $I_{ref}$ , when the power decreased, the output of controller  $I_{ref}$  also obeys the same rule. The concrete algorithm was described by flow chart in Fig.4. The difference between  $I_{ref}$  and  $I_{d1}$  which are feedback from the input termination of Boost circuit is the input of PI controller<sup>1</sup>. The output of the controller<sup>1</sup> is duty cycle  $D_1$ .

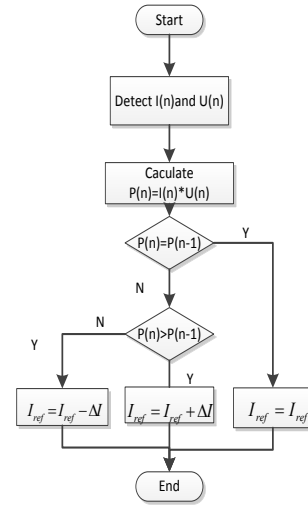


Fig. 4. Flow chart of Perturbation Method of the duty cycle method

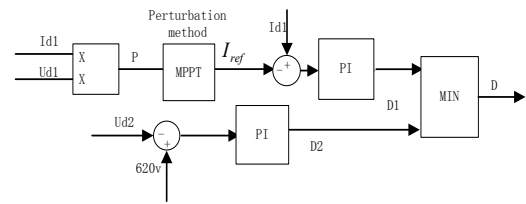


Fig. 5. The control scheme of maximum power tracking and voltage limiting

The rated voltage of the DC micro-grid is 600V. In normal circumstances voltage fluctuations cannot exceed 20V. The generation system has to work under the micro-grid voltage that's under 620V. The difference between given voltage of 620v and output voltage is the input of PI controller<sup>2</sup>. The output of the controller<sup>2</sup> is duty cycle  $D_2$ . Smaller values between  $D_1$  and  $D_2$  will be selected as the final value D of duty cycle, which controls power switching devices to turn down or turn off. When the voltage of micro-grid is more than 620V, PI controller will get a negative input, so  $D_2$  will less than  $D_1$ , the duty cycle of the power switching device will be  $D_2$ , so the increase of micro-grid voltage will be limited. Controlling strategy plot is presented in Fig.5. Thus, the proposed control strategies aim to provide additional control capabilities of PMSG driven wind systems, allowing them to limit the active power injective in micro grid when voltage rises above acceptable level.

#### IV. SYSTEM SIMULATION AND ANALYSIS

##### A. Parameters calculation

The main circuit of the system is Boost circuit. The transfer function between duty cycle and output voltage is calculated by the follow equation (4)

$$\frac{U_{d2}(s)}{d(s)} \Big|_{U_{d1}(s)=0} = \frac{D'V(1 - \frac{sL}{D'^2R})}{LCs^2 + \frac{L}{R}s + D'^2} \quad (4)$$

A block diagram Fig.6. of the main circuit can be written by Boost circuit transfer function , and the parameters of PI controller can be calculated by the block diagram : Kp=0.19, Ki=0.0025;

#### B. A simulation in MATLAB/SIMULINK

The paper carries on a great deal of simulations in MATLAB in order to evaluate the performance of the Duty-cycle perturbation method, and the paper also selected S-Function as a controller to achieve maximum power point tracking and selects Matlab-Function block to achieve voltage limitation. The simulation parameters were designed based on the 5KW small wind turbine. Simulation system is presented in Fig.7.

The purpose of the simulation includes two aspects, the first aspect is to prove a control strategy to achieve the

maximum power point tracing, the second is to prove that the system can be turned off by their own overvoltage protection systems when the grid voltage is over the limited level. A given wind speed started 7m/s and later changed into 11m/s and finally became into 9m/s. Simulation waveforms of the output power was observed from Fig.8. Fig.9.shows the dynamic behavior of the boost circuit can be observed. And at 2 second, the voltage of the DC micro-grid changed into 650V.The change of the output power can be observed from Fig.10.

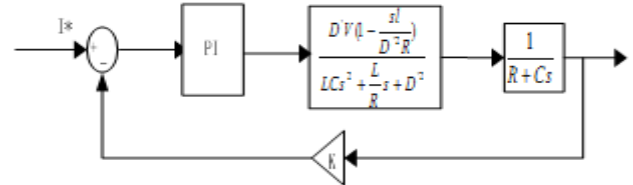


Fig.6. Block diagram of the dc-dc boost circuit

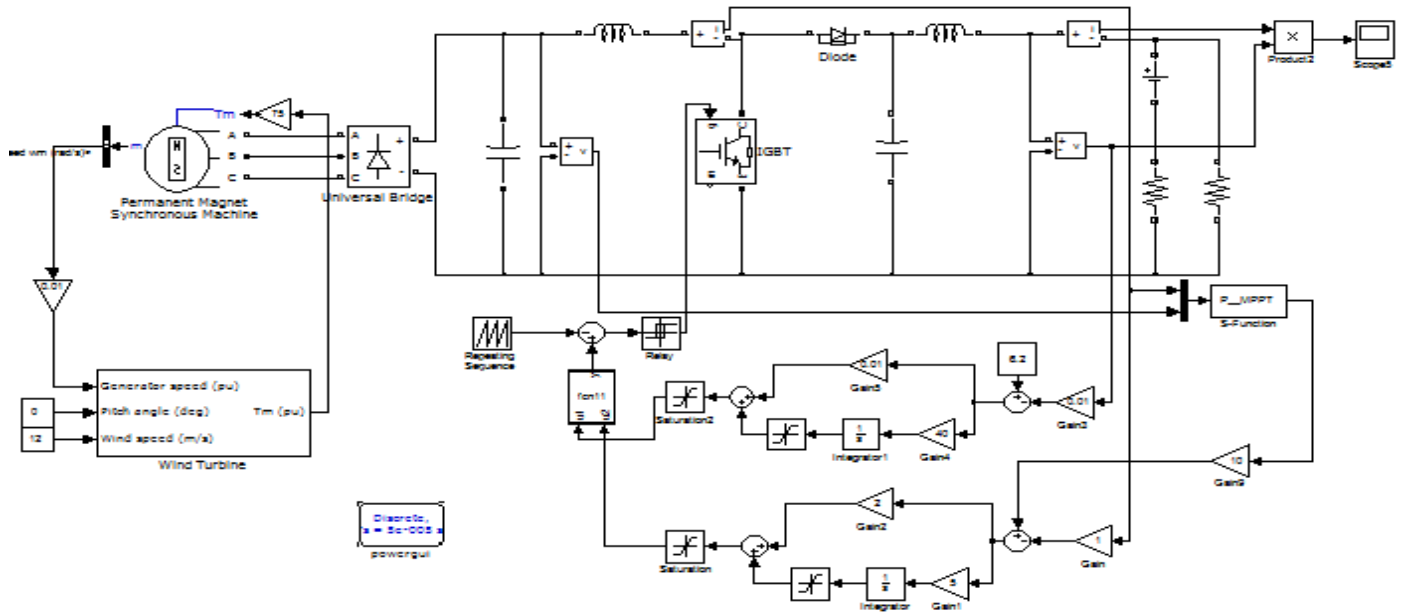


Fig.7.The simulation system with PMSG driven wind turbine

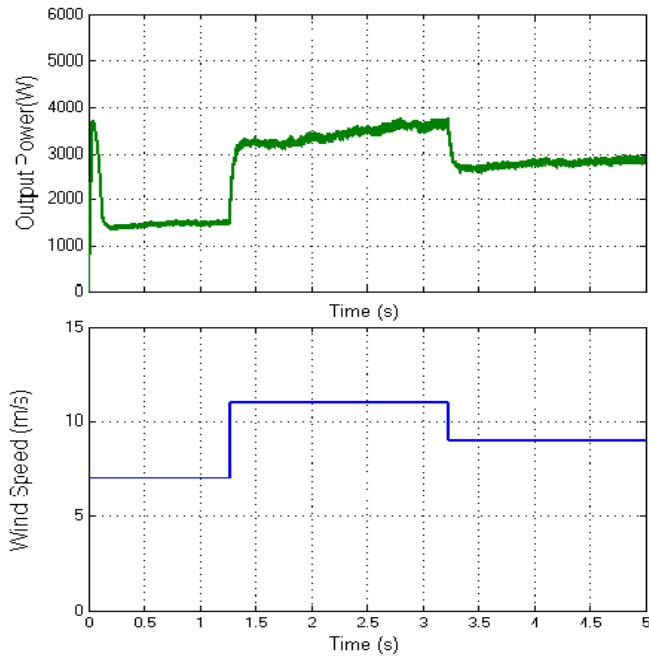


Fig. 8. Dynamic output power of the PMSG driven wind turbine with the wind speed changing

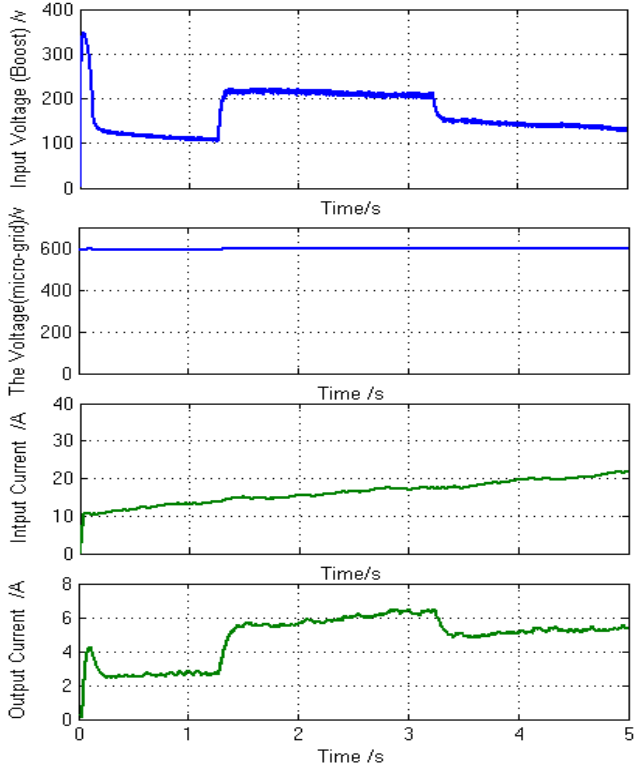


Fig. 9. Dynamic behavior of the boost circuit, including its input voltage, output voltage, input current and output current with the wind speed changing

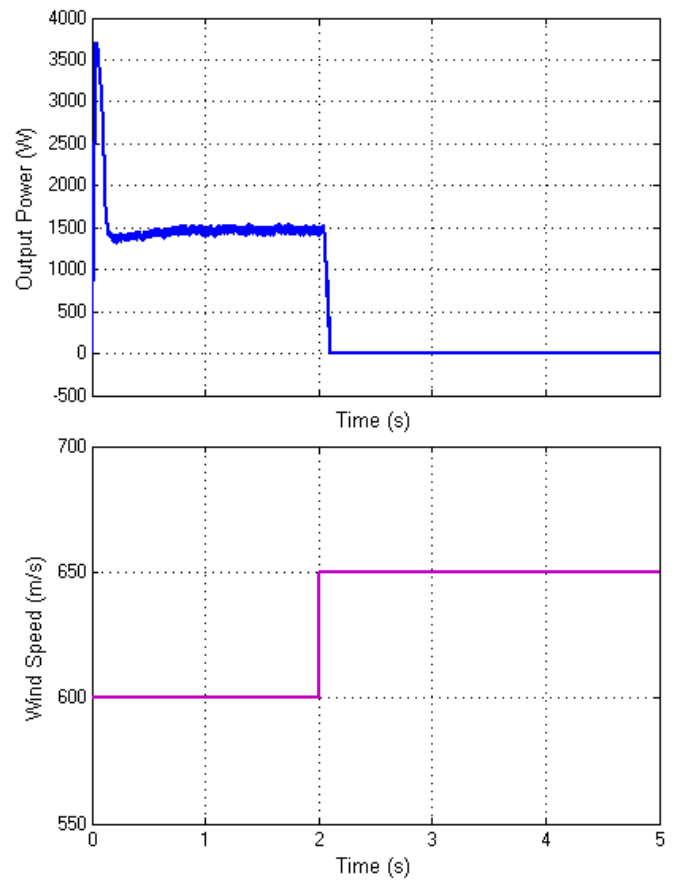


Fig. 10. Dynamic output power of the PMSG driven wind turbine with the voltage of the DC micro-grid changing

It illustrates that the wind turbine has a different average output power with different wind speed, and the output power is always around the maximum output power. The output power increases when the wind speed increases. When the voltage of the grid is too high, the output power of the generation system goes to zeros.

## V. CONCLUSIONS

A generation model of a small scale wind power generation system was developed in this paper. The optimum curve power was obtained by this model. This study made it possible to use a chopper to control the generation system. The result showed that the Perturbation Method of the duty cycle method which was used to tracking the maximum power point of the generation system works efficiently, and the feedback control strategy adopted generation system is successful in monitor the voltage of DC micro-grid. By analyzing the experimental data of SIMULINK model, the wind turbine can get an optimum output power whatever the wind speed is. At the same time, the result showed when the grid voltage is higher than 20% of the rated voltage, the system can efficiently limit the vise of the output voltage in order to protect generation system. The robustness of this generation system is highly

improved by using the boost chopper.

#### ACKNOWLEDGEMENT

Thanks for the support from NSFC (Natural Science Foundation of China) projects 61233001 and 71232006.

#### REFERENCES

- [1] Munteanu, Iulian, "Optimal control of wind energy system: towards a global approach", 2011
- [2] M. E. Haque, M. Negnevitsky, K. M. Muttaqi, "A novel control strategy for a variable speed wind turbine with a permanent magnet synchronous generator," *IEEE Transactions on Industry Applications*, vol. 46, no. 1, pp. 331-339, 2020
- [3] K. Tan and S. Islam, "Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors," *IEEE Trans. Energy Convers.*, vol. 19, no. 2, pp. 392 – 399, Jun. 2000
- [4] S. Morimoto, H. Nakayama, M. Sanada, and Y. Takeda, "Sensor less output maximization control for variable-speed wind generation system using IPMSG," in *Conf. Rec. IEEE IAS Annu. Meeting*, 2003, vol. 3, pp. 1464 – 1471.
- [5] S. Vlachopoulos, C. Demoulias, "Voltage regulation in low-voltage rural feeders with distributed PV systems," in *Proc. 2011 IEEE EUROCON – International Conference on Computer as a Tool*, pp. 1-4, April 2011.
- [6] B. Gwisdorf, T. Borchard, T. Hammerschmidt, C. Rehtanz, "Technical and economic evaluation of voltage regulation strategies for distribution grids with a high amount of fluctuating dispersed generation units," *Proc. of 2010 IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES)*, pp. 8-14, Sept. 2010.
- [7] Muljadi E, Pierce K, Migliore P. Soft-control control for variable-speed stallregulated wind turbines. *Wind Engineering* 2000;85:277e91.
- [8] Riahy GH, Abedi M. Short term wind speed forecasting for wind turbine applications using linear predictionmethod. *Renewable Energy* 2008;33:35e41.
- [9] Wang Q, Chang L. An intelligent maximum power extraction algorithm for Inverter-based variable speed wind turbine systems. *IEEE Transaction on Power Electronics* September 2004;19:1242e9.
- [10] Koutroulis E, Kalaitzakis K. Design of a maximum power tracking system for wind-energy-conversion application. *IEEE Transaction on Industrial Electronics* April 2006;53:486e94.
- [11] Jabr, H.M.; Dongyun, L.; Kar, N.C. Design and implementation of neuro-fuzzy vector control for wind-driven doubly-fed induction generator. *IEEE Trans. Sustain. Energy* 2011, 2, 404–414.
- [12] Kazmi, S.M.R.; 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.
- [13] Park, K.W.; Lee, K.B. Hardware simulator development for a 3-parallel grid-connected PMSG wind power system. *J. Power Electron.* 2010, 10, 555–562.
- [14] Grenier D, Dessaint LA, Akhrif O, Bonnassieux Y, Le Pioufle B. Experimental nonlinear torque control of a permanent-magnet synchronous motor using saliency. *Industrial Electronics, IEEE Transactions* 1997;44:680e7.
- [15] Muljadi E, Butterfield CP, Wan YH. Axial flux, modular, permanent-magnet generator with a toroidal winding for wind turbine applications. *IEEE industry applications conference* St. Louis, Mo; 1998.
- [16] Jabr, H.M.; Dongyun, L.; Kar, N.C. Design and implementation of neuro-fuzzy vector control for wind-driven doubly-fed induction generator. *IEEE Trans. Sustain. Energy* 2011, 2, 404–414.
- [17] Kazmi, S.M.R.; 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.
- [18] Park, K.W.; Lee, K.B. Hardware simulator development for a 3-parallel grid-connected PMSG wind power system. *J. Power Electron.* 2010, 10, 555–562.
- [19] Lee, J.S.; Jeong, H.G.; Lee, K.B. Active damping for wind power systems with an LCL filter using a DFT. *J. Power Electron.* 2012, 12, 326–332.
- [20] Chwa, D.K.; Lee, K.B. Variable structure control of the active and reactive powers for a DFIG in wind turbines. *IEEE Trans. Ind. Appl.* 2010, 46, 2545–2555.