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Power Quality Improvement of Wecs Using Energy Storage System Under Fault Condition

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Abstract

Grid connected wind power generation faces power quality problems which include flickering, variation in voltage due to stochastic nature of wind and injected harmonics due to the use of power electronic converters. The aim of this paper is to present modeling and simulation of grid connected wind energy conversion system (WECS) comprising of a PMSG with consumer loads and batteries. In case of a fault the performance of grid connected WECS is evaluated with and without battery in terms of power quality so that the advantage of including the battery in the system is justified. Simulation results for voltage, active power generated/absorbed by different elements with battery voltage, current and state of charge are presented.

Keywords: Wind power, Energy storage systems, Electrical faults, Power Quality

INTRODUCTION

Wind energy is one of the most abundant sources of renewable energy. Different controllers are used so that generation at variable speed is possible and therefore power in bulk can be fed to the grid connected network thus increases the penetration of wind power in grid connected network leading to power quality issues. Therefore power quality improvement in the grid is a top priority for such systems.

Power quality detoriation due to irregularity in wind speed is controlled by controlling the reactive power in the grid connected network and lessens the impact of irregular wind speed on voltage either with the help of generator side converter or by using FACTS devices [1,9]. The limitations provided in grid codes for controlling strategies of reactive power on generator side [13] and is further repressed by the ratio subjected to network parameters that is reactance to resistance ratio [1,2]. Moreover, active power smoothening provides a solution to the intermittent nature of wind generation which is free from network parameters as well as reactive power. Active power fluctuation smoothening as a solution to intermittent nature of wind generation was particularly studied in [7-11].

The integration of energy storage systems in renewable energy source based generation can improve the power quality as it efficiently manages the active power. The major rechargeable battery technologies available are lead-acid, nickel-cadmium, lithium-ion, nickel metal hydride. Lead-Acid batteries have some advantages like high performance to cost ratio and lowest density in terms of energy. Ni-Cd has advantages like longer life cycle and can tolerate high temperature. However, one disadvantage with Ni-Cd is that its performance gets hampered due to the memory effect if not used at regularly. NiMH is an improved version of Ni-Cd and provides better energy density in comparison to Ni-Cd. Also using NiMH eliminates the environmental concern of cadmium and also has negligible memory effect. The latest development in this area is Li-ion technology that gives an option of high energy density which is approximately three times to that of Pb-acid. On the negative side, when the continuous charging and discharging process of the cell of the lithium is taken away the battery life would be shortened. At last the research shows that the lead-acid batteries based on advanced technology is highly efficient and it will play a significant role in energy storage system in coming time.

The PMSG based WECS produces power of variable voltage and variable frequency nature. Now, this power is rectified to DC with the help of generator side converters and then this DC power is used to charge the battery and feed the DC load or the inverter gets it converted to AC at a constant frequency and voltage. Here, the battery is connected to DC bus with a DC/DC converter which offers two advantages that is higher voltage requirement of battery is not needed and has sufficient controllable parameters in the coordinated control strategy. The very same approach with different methodology was mentioned in [5-6] where DC/DC converter is not used to connect the battery to the DC bus. Pitch angle control method is employed in PMSG which conventionally used PI controller and it makes the performance of the hybrid WECS-battery configuration better. The varying control systems applied on converters should adapt an efficient methodology with respect to the grid standards. This is necessary as grid codes in different countries have different requirements to meet [14-15].

Energy storage systems (ESS) play an important role in fulfilling the grid requirements as they have the ability to exchange active power and thus performs power management efficiently. ESSs also contribute in fault management. Till date a few studies have dealt with the ESSs under both situations [16]. A dummy load has been used to utilize extra energy which is left out after charging the battery to its maximum capacity [12]. In [7], under the voltage sag condition, extra power in the DC bus of a DFIG is utilized by the battery. This prevents the increase of DC voltage but at the same time is not feasible with the power system operation.

The main aim behind this paper is to give a detailed analysis of power quality with the help of voltage, current and power waveforms across different elements under fault condition for hybrid WECS-battery systems. The comparative analysis is done in two steps that is one without using battery and the other with the battery in the circuit. All the results as mentioned above are evaluated for both the cases and therefore analysis easily compares the performance of hybrid system to that system which does not include battery under fault condition.

MODELLING OF THE PMSG WT

The model of PMSG is described by d-q synchronous reference frame. The voltage equations of PMSG are given by:

$$\frac{d}{dt} i_d = \frac{v_d}{L_d} - \frac{R}{L_d} i_d + \frac{L_q}{L_d} p w_r i_q \qquad (1)$$

$$\frac{d}{dt} i_q = \frac{v_q}{L_q} - \frac{R}{L_q} i_q - \frac{L_d}{L_q} p w_r i_d - \frac{\lambda p w_r}{L_q} \qquad (2)$$

The electromagnetic torque in PMSG is given by:

$$T_e = 1.5\rho[\lambda i_q + (L_d - L_q) i_d i_q]$$

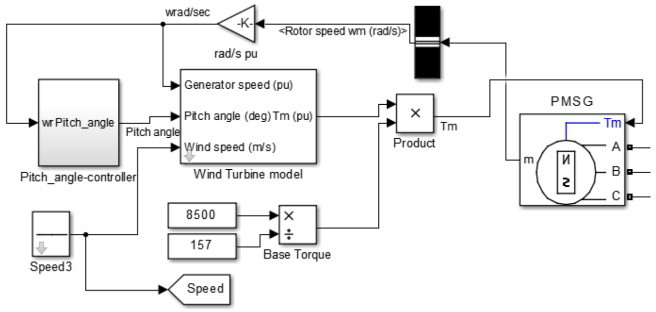

Figure 1. Matlab Simulink model of PMSG based wind power generation.

The Matlab Simulink model of PMSG based WT without gear box is used in this paper as shown in Fig.1. Here, Pitch Angle control is used for controlling the generator torque in accordance with the generator speed. With the help of generator speed the calculation of optimum torque of PMSG based WT is done so that the maximum input power for the generator system can be derived from the WT. Generally, WT which employs variable speed method includes two types of controllers. In the first case of low wind speed, the rotor speed is continuously adjusted by the speed controller so that it can maintain constant tip to speed ratio to that value which will provide the maximum power coefficient c_p, and therefore the noticeable increased in efficiency of WT. Now, in the second case when speed of the wind is beyond the rated value, the pitch angle regulation plays very crucial role in maintaining the rotational speed at constant value. In order to vary the pitch angle of the blade, a mechanical actuator is employed which in turn decrease the power coefficient c_p in such a way that it will maintain the rated power. The relation between the tip speed ratio λ and the blade pitch angle β (in degrees) is a non-linear function and this function is termed as power coefficient c_p . Now, maintaining the area swept by the blade and the density of the air as constant, the power coefficient c_p becomes the sole function of λ and it reaches to its maximum value at fixed λ_{opt}. Hence, in order to extract the total energy of wind, λ should approach to λ_{opt}, which is calculated with the help of blade design. Therefore

$$P_{turbine} = \frac{1}{2} \rho A c_{pmax} v^3$$

The non-linear function of $c_p(\lambda,\beta)$ vs λ, for different values of pitch angle β is described in fig. 2

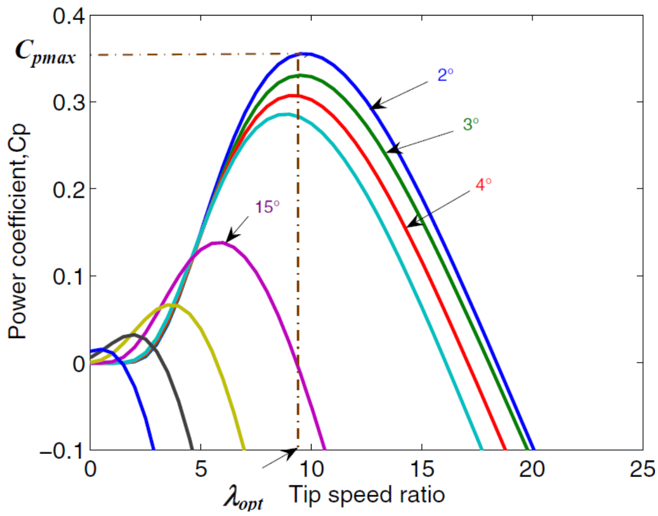

Figure 2. C_p vs λ curve

A. Converters

The power converter used in the PMSG based wind turbine is made up of two back-to-back IGBT bridges connected by a DC bus and a capacitor is used to stabilize the DC voltage.

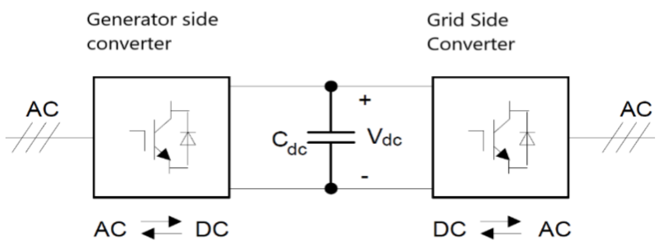

Figure 3. Block diagram of back-to-back converters

As clear from the above fig. 3, the power can flow in both the directions that it can either go to the generator side converter or to the grid side converter. Therefore, voltage source converter used here can perform two functions that is rectification and inversion. So, the converter at generator side converts AC to DC.

and the grid side converter, converts DC to AC. Therefore, in fig. 3 converter at generator side plays the role of rectifier and converter at grid side plays the role of inverter. By regulating the power flow to the AC grid, the DC link voltage can be maintained higher than the peak main voltage which is a must condition and by using generator side converter it is possible to control the speed and the torque of the generator by using MPPT methodology.

B. Battery Description

The model of lead-acid battery used in this paper was based on the model given in Sim Power Systems [8]. The critical parameters like the size of the battery, ampere hour capacity of the battery and the surrounding condition in which the battery is operating are the few design based parameters on which the magnitude of voltage source depends and this magnitude is calculated by the model used in this paper. It is important to maintain the SOC within defined limits of the battery so as to avoid the internal damage. The SOC of the battery at any time is defined as the following:

$$SOC = \frac{Ah\ capacity\ remaining\ in\ the\ battery}{Rated\ Ah\ capacity}$$

The battery was sized in terms of minimum capacity, so that its maximum instantaneous power is limited by the power of grid side converter. Considering a cell used here is of capacity 500Ah and 240V battery was accomplished. Fig. 4 shows the discharge curve of the battery which is obtained by the model implemented in this work.

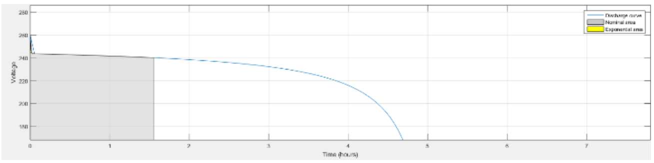

Figure 4. Discharge curve of battery

CONTROL STRATEGY

A. MPPT Controller

MPPT controller takes three input namely w_m, v_d, i_d and implements some normal equation to get maximum power output. Here w_m is the rotor speed of the generator, v_d and i_d are the respective voltage and current output of the generator side converter.

$$T_{ref} = {w_m}^2 \times (1.79 \times 10^{-3})$$

$$I_{d\_ref} = T_{ref} \times\ w_m/v_d$$

Now, the error between i_d and I_{d_ref} is used as a gate pulse to the generator side converter.

B. Battery Controller

With the help of battery controller, appropriate distribution of power between PMSG and battery can be efficiently done. The battery used is connected directly to the power converter and critical parameters are controlled by the control system strategy in such a way so that the PMSG DC voltage approaches to its rated value.

Here, controller uses three basic inputs to control IGBT switches of the battery power converter namely V_{dc} (output of booster converter), SOC, I_{bat}(current of battery). The battery controller configuration is shown in fig. 5.

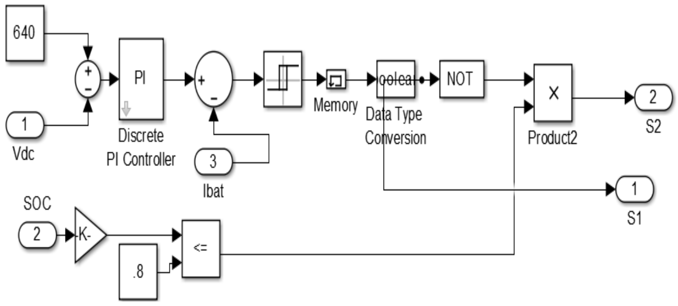

Figure 5. Matlab Simulink model of battery controller

The logic shown in fig. 5 implements PI controller , relay and a relational operator which together creates a simple logic in the form of S1 and S2 which is used to control the gate pulse of IGBT switches. Further, these switches allow operating the breaker so that it connects to the battery converter circuit by operating the relay during fault duration interval. Therefore, the DC voltage is stabilized by the controller when power flow varies under fault condition between rotor side and grid side converter. Accordingly battery will charge and discharge depending upon the fault duration.

SIMULATION RESULTS

The power quality performance analysis of WT configuration with and without battery under fault condition are been compared. Simulations were carried out in which main parameter like voltage, current and power was evaluated in order to compare the power quality performance under two conditions i.e. with and without the battery configuration. So, the purpose is to point out the main improvement that the hybrid WT presents under fault condition. Here, analysis is done for three phase fault and at constant speed of 12m/s to avoid power fluctuation due to variable wind speed and therefore focus is solely on battery that how we can improve the performance under fault condition.

In the following results, wind battery hybrid system is connected to a 5000 watt consumer load considering purely resistive and at 12m/s wind speed is presented. Fault is assumed to be occurred between 2 to 3 seconds. Now, response is shown by graphs of the following variables: Load voltage /current, load power, grid voltage current, grid power and battery power. These graphs are shown in two cases i.e. with battery and without battery.

A. Simulation results without battery

Firstly, the graph of voltage, power and current is shown in fig. 6,7 and 8 across a load of 5000 watt which is considered purely resistive. The three phase fault occurs between 2 to 3 sec and the circuit breaker used in simulation will operate in that time period.

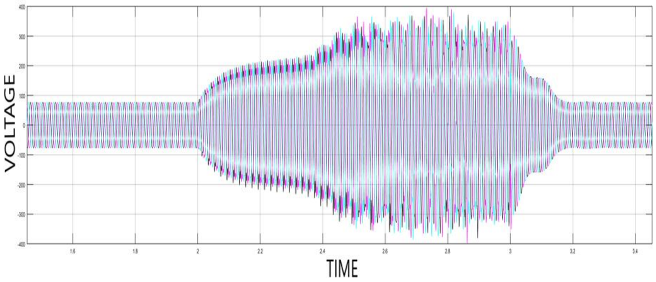

Figure 6. Load voltage curve without battery

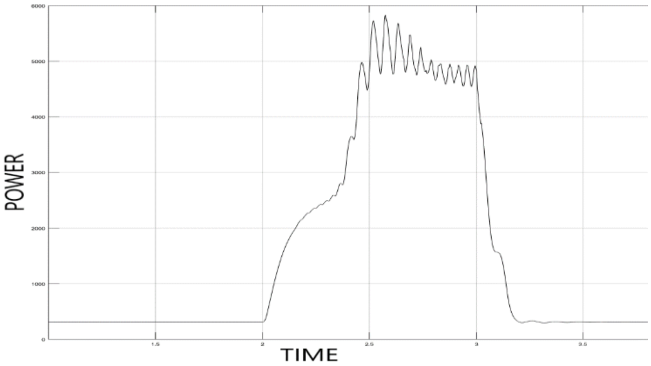

Figure 7. Load power curve without battery

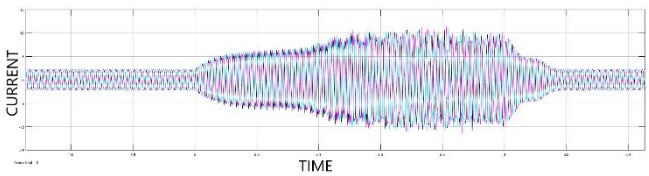

Figure 8. Load current curve without battery

Now, the graph of voltage, current and power across grid is shown in fig. 9,10 and 11.

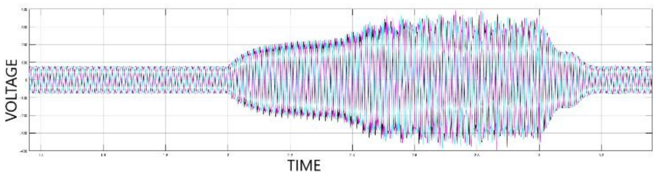

Figure 9. Grid voltage curve without battery

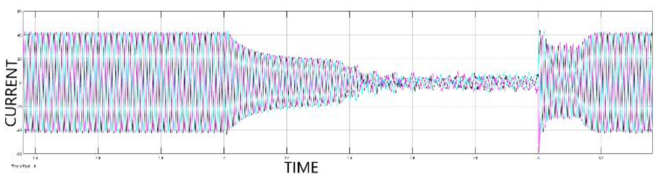

Figure 10. Grid current curve without battery

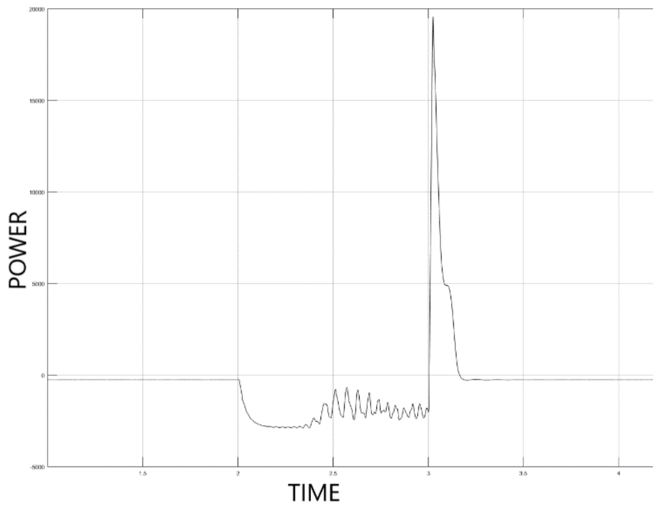

Figure 11. Grid power curve without battery

The graph shown above clearly shows the fluctuation of voltage, current and power across load and grid during fault duration that is between 2 to 3 seconds. Now, the comparison is to be done when battery is connected as shown in above graph.

B. Simulation results with battery

Here, the graph of voltage, current and power is shown in fig. 12,13 and 14 respectively across a load of 5000 watt which is considered purely resistive when the battery is connected. Now, during the fault duration circuit breaker will operate and therefore battery will be connected in that duration so that we can verify that how far the fluctuations is controlled by the battery as during fault duration better will try to supply the equivalent power to load and grid so as to reduce the fluctuations and therefore, maintain the constant voltage, current and can supply the required power to the load and grid.

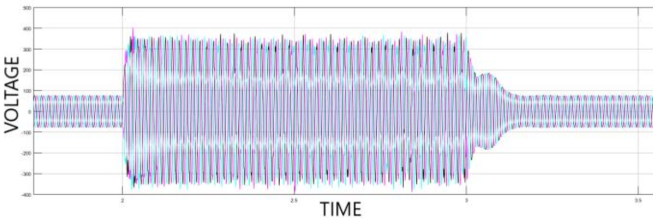

Figure 12. Load voltage curve with battery

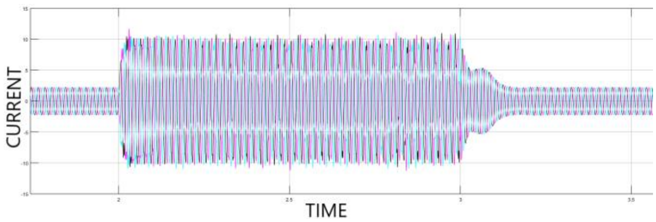

Figure 13. Load current curve with battery

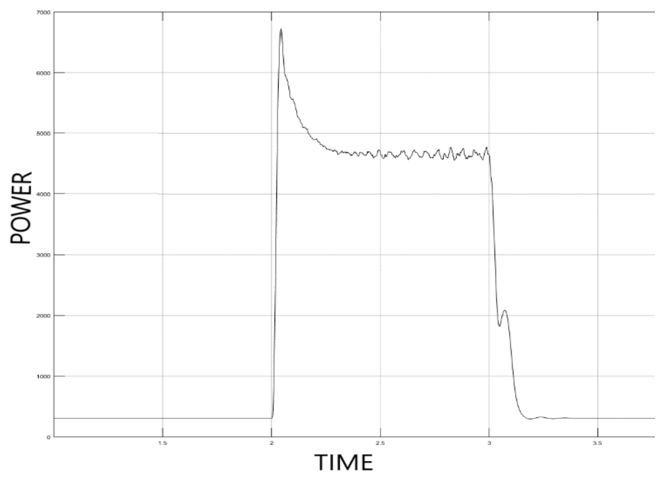

Figure 14. Load power curve with battery

Now, the graph of voltage, current and power across grid is shown in fig. 15,16 and 17 respectively when battery is connected.

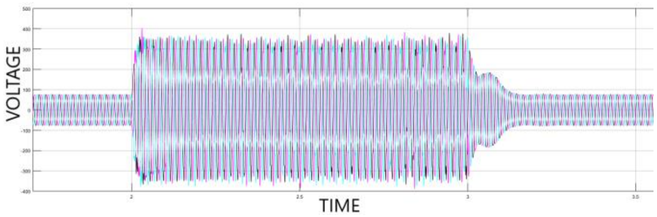

Figure 15. Grid voltage curve with battery

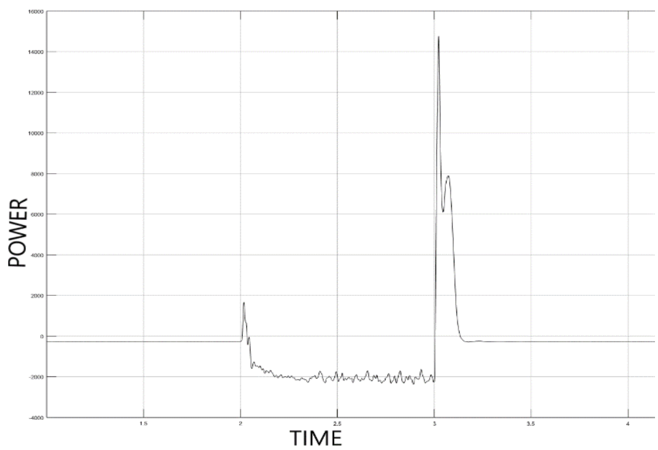

Figure 16. Grid power curve with battery

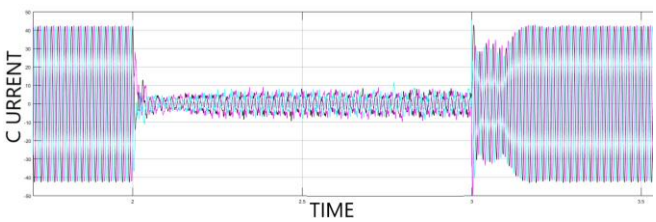

Figure 17. Grid current curve with battery

At last the graph shown in fig. is of power across battery which explains the power delivered during fault duration.

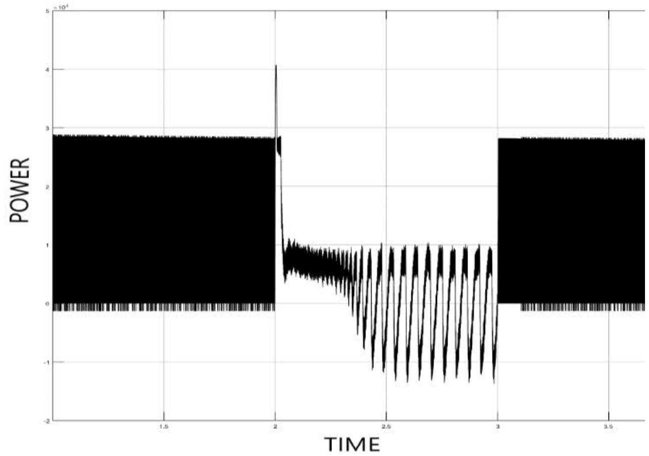

Figure 18. Battery power curve

CONCLUSION

This paper presented a in-depth comparative study of two different configurations for PMSG based WECS with and without battery as ESS. Pitch angle, battery and MPPT controller are employed to control the flickering of voltage and maintain the continuity of supply. The MPPT controller tracks the maximum power output and the battery controller helps it in proper power management. With the battery in circuit the flickers are controlled and thus constant voltage is maintained as compared to the case without battery where significant fluctuations were seen. Moreover, the current and the power graphs with battery connected in circuit indicate better performance. So, with the battery connected the overall performance is enhanced thus improving the power quality under fault condition.

REFERENCES

[1] M. Ammar and G. Joos, "The impact of distributed wind generators reactive power behavior on flicker severity," *IEEE Trans. Energy Convers.*, vol.28, no. 2, pp. 425-433, Jun. 2013.

[2] W. Hu, Z. Chen, Y. Wang, and Z. Wang, "Flicker mitigation by active power control of variable-speed wind turbines with full-scale back-to-back power converters," *IEEE Trans. Energy Convers.*, vol. 24, no.3, pp. 640-649, Sep.2009.

[3] A. Keane, L.F. Ochoa, E. Vittal, C.J. Dent, and G.P. Harrison, "Enhanced utilization of voltage control resources with distributed generation," *IEEE Trans. Power Syst.*, vol. 26, no. 1, pp. 252-260, Feb. 2011.

[4] M.Z. Sujod, I. Erlich, and S. Engelhardt, "Improving the reactive power capability of the DFIG-based wind turbine during operationaround the synchronous speed," *IEEE Trans. Energy Convers.*, vol. 28, no. 3, pp. 736-745, Sep. 2013.

[5] V.C. Ganti, B. Singh, S.K. Aggarwal, T.C. Kandpal, "DFIG based wind power conversion with grid power leveling for reduced gusts," *IEEE Trans. Sustain Energy*, 2007, pp. 12-20.

[6] A. Yazdani, "Islanded operation of a DFIG wind-power system with integrated energy storage," *IEEE Canada Electrical Power Conference*, 2007, pp. 1-7.

[7] C. Jin, P. Wang, "Enhancement of low voltage ride-through capability for wind turbine driven DFIG with active crowbar and battery energy storage system," *IEEE Power and Energy Society General Meeting*, 2010, pp. 1-8.

[8] SimPowerSystems™, Reference. Natick, Hydro-Quebec/MathWorks, Inc,:2010.

[9] S. Tao, C. Zhe, and F. Blaabjerg, "Flicker study on variable speed wind turbines with DFIG," *IEEE Trans. Energy Convers.*, vol. 20, no. 4, pp. 896-905, Dec. 2005.

[10] H. Chong, A.Q. Huang, M.E. Baran, S. Bhattacharya, W. Litzenberger, L. Anderson, A.L. Johnson, and A.A. edris, "STATCOM impact study on the integration of a large wind farm into a weak loop power system," *IEEE Trans. Energy Convers.*, vol. 23, no. 1, pp. 226-233, Mar. 2008.

[11] Y. Zhang, Z. Chen, W. Hu, and M. Cheng, "Flicker mitigation by individual pitch control of variable speed wind turbines with DFIG," *IEEE Trans. Energy Convers.*, vol. 29, no. 1, pp. 20-28, Mar. 2014.

[12] N. Mendis, K.M. Muttaqi, S. Sayeef, S. Perera, "Control coordination of wind turbinegenerator and a battery storage unit in a remote area power supply system," *IEEE Power and Energy Society General Meeting*, 2010, pp. 1-7.

[13] *Requirements for the Interconnection of Distributed generation to the Hydro-Quebec Medium-Voltage Distribution System, 2009.*

[14] M. Tsili, S. Papathanassiou, "A review of grid code technical requirements for wind farms," *IET Renew Power Genr.*, 2009, pp. 308-332.

[15] M. Mohseni, S.M. Islam, "Review of international grid codes for wind power integration: diversity, technology and a case for a global standard,"*Renew Sustain Energy Rev., 2012, pp. 3876-90.*

[16] Z. Jiang, X. Yu, "Modelling and control of an integrated wind power generation and energy storage system," *IEEE Power and Energy Society General Meeting*, 2009, pp. 1-8.