Original Research Paper

Volume-9 | Issue-7 | July - 2019 | PRINT ISSN No. 2249 - 555X

Engineering

STANDALONE WIND ENERGY CONVERSION SYSTEM WITH BATTERY ENERGY STORAGE

Jisilamol S — P G Scholar, EE Department, RIT Kottayam.

Vijayakumari C K* — Professor, EE Department, RIT Kottayam *Corresponding Author

ABSTRACT The energy demand around the world increases; the need for a renewable energy source that will not harm the environment has been increased i.e., wind power is one of them. There are many loads (such as remote villages, islands, ships etc.) that are away from the main grid. They require stand-alone generator system (which can provide constant nominal voltage and frequency) to provide for their local electrification. Wind power can be used in off grid systems, also called stand-alone systems, not connected to an electric distribution system or grid. The power conversion unit includes a wind-turbine-driven PMSG, a diode rectifier, dc/dc converter, a battery bank, and an inverter. The operation of a stand-alone wind turbine system with variable-speed permanent-magnet synchronous generator (PMSG) and storing energy during wind speed and load variations are simulated. Energy storage devices are required for power balance and power quality in stand-alone wind energy systems. A bidirectional buck boost converter is introduced for the purpose of charging and discharging of the battery. Initially, the model of the entire system is developed which, includes PMSG, the boost converter, and the storage system. The power absorbed by the connected loads can be effectively delivered and supplied by the wind turbine and energy storage systems, subject to an appropriate control method. The topology is demonstrated using MATLAB Simulink.

KEYWORDS : wind turbine system, PMSG, Power conversion unit, Energy storage system

1.INTRODUCTION

The worldwide concern about the environment has led to increasing interest in technologies for generation of renewable electrical energy. The ever-increasing demand for conventional energy sources has driven society towards the need for research and development of alternative energy sources. Several new forms of renewable resources such as Wind Power Generation Systems (WPGS) and Photovoltaic Systems (PV) to supplement fossil fuels have been developed and integrated globally. However, the photovoltaic generation has low energy conversion efficiency and are very costly as compared to the wind power. In recent years, wind energy has been regarded as one of the significant renewable energy sources [3][6].

In the case of Wind Energy Conversion Systems (WECSs), the interest is also focused on small units, used to provide electricity supply in remote areas that are beyond the reach of an electric power grid or cannot be economically connected to a grid. While large wind turbines reached their technological maturity, small- scale WECSs have to be further optimized in order to achieve integration in flexible Micro Grids (MGs) and increased reliability. Due to the highly variable nature of the wind, the utilization of an energy storage device such as a battery can significantly enhance the reliability of a small stand-alone wind system. Integrating an appropriate energy storage system in conjunction with a wind generator removes the fluctuations and can maximize the reliability of the power supplied to the loads. In the autonomous system, the wind power converter may be operated to maximize the wind energy converted into electricity. The captured energy is supplied to the load directly, the difference between the wind power generation and user consumption being directed to or supplied by the battery energy storage device connected via the power electronic interface [3][4].

The paper is formulated as follows. Section 2 explains the block diagram and circuit diagram of the overall system. Section 3 deals with the system main parts, this includes the modelling of wind turbine and PMSG. Section 4 explains the MPPT used in the system. Section 5 deals the energy storage. Section 6 deals the result analysis and finally Section 7 draws conclusion.

2.STANDALONE WIND BASED ENERGY SYSTEM

Many countries have an abundant supply of renewable energy resources; however certain places are located in remote areas where connection with power grid is impractical or much expensive. Under such circumstances, a locally placed small scale stand-alone distributed generation system can utilize the renewable energy resources. A stand-alone power supply system based on wind energy is presented. A permanent magnet synchronous generator is connected to the load through a rectifier, DC-DC boost converter and an inverter. Battery is used as an energy storage device and interfaced to the wind energy system through bidirectional buck boost converter. The block diagram of stand-alone system using PMSG based wind turbine is shown in Figure 2.1

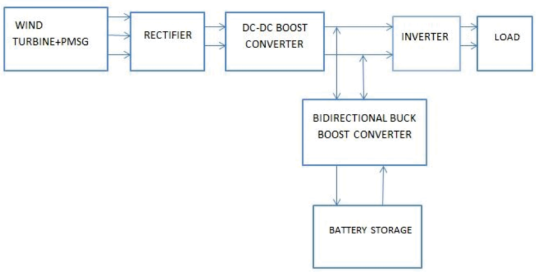


Figure 2.1 Block digram of standalone wind energy system

It consists of 1) a direct-driven PMSG; 2) diode rectifier bridge 3) boost converter 4) energy storage device with bidirectional converter 5) an inverter; and 6) resistive loads. The wind power is converted into the mechanical rotational energy of the wind turbine rotor. The circuit diagram of the standalone wind energy system is shown in Figure 2.2

The rotor of the wind turbine is connected to the wind generator, thus converting the mechanical energy into electrical energy. The generator's ac voltage is converted into dc voltage through an3 phase uncontrolled rectifier. The rectifier is matching the generator's ac voltage to the dc voltage, while the boost converter provides the required level of constant dc voltage. The dc output voltage is fed to the battery bank and an inverter further to the load. The voltage should stay constant for various wind speeds.

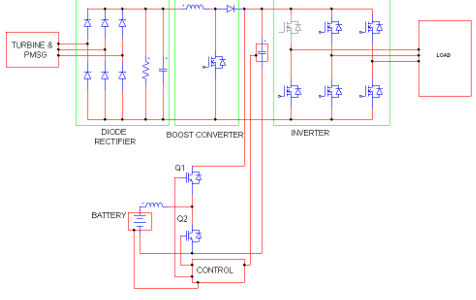


Figure 2.2 Circuit digram of standalone wind energy conversion system with battery

When the wind speed is too high, the excess power supplied by the wind turbine is stored in the battery. When the wind speed is low, the generator, together with the battery bank, can provide sufficient energy to the loads [1][2].

3. SYSTEM -MAIN PARTS

3.1 Wind turbine modelling

The wind turbine power at any wind speed is given by,

$$P_t = \tfrac{1}{2}\rho A(V_w)^3 C_P(\lambda, \beta) \quad (1)$$

where A is swept area covered by turbine blade (in m2), C_p is wind turbine power coefficient as a function of tip speed ratio λ and pitch angle β (in degrees), ρ is air density factor in (kg/m3), V_w is wind speed (in m/s). The turbine power mainly depends on various factors such as maximum power coefficient, air density factor, swept area of blades and wind speed [8].

The tip speed ratio of wind turbine is given by,

$$TSR = \lambda_{OPT} = \omega_m R / V_W \quad (2)$$

where ω_m is the machine angular speed (in rad/s), R is turbine blade radius (in m). Substituting v_w from (2) into (1) , the wind turbine output power can be written as

$$Pt = 0.5\rho AC_P(\omega_m R/\lambda)^3 \quad (3)$$

3.2 PMSG modelling

The PMSG model can be written, in the d-q synchronously rotating reference frame, by the following equation system

$$\frac{di_d}{dt} = \frac{-R_a}{L_d} i_d + \omega_e \frac{L_q}{L_d} i_q + \frac{1}{L_q} V_d$$

$$\frac{di_q}{dt} = \frac{-R_a}{L_q} i_q - \omega_e \frac{L_d}{L_q} i_d - \frac{1}{L_q} \omega_e \phi_m + \frac{1}{L_q} V_q$$

where d, q are the synchronous rotating reference frame; R_a is the armature resistance; L_d, Lq are the generator inductance on the d-q axis; i_d, i_q are, respectively, the d- and q-axis components of current; V_d, V_q are the d- and q-axis voltage components, respectively, p is the pole pairs number ϕ_m is the permanent magnet flux. In the d-q synchronously rotating reference frame, the electromagnetic torque is represented by,

$$T_e = (3/2)\, n\, ((L_d - L_q)\, I_d I_q + \phi_m I_q) \quad (4)$$

3.3 power conditioning system

The wind power varies with wind velocity. So the generator output voltage is varying. To avoid the changing output of PMSG a power conditioning circuit is needed. It consists of 3 phase uncontrolled rectifier, DC to DC boost converter.

3.3.1 DC to DC Boost Converter

A DC-DC switching converter converts voltage directly from DC to DC and is simply known as a DC Converter. In a boost converter, the output voltage is greater than the input voltage hence the name "boost". A boost converter using a power MOSFET is shown in Figure 3.1

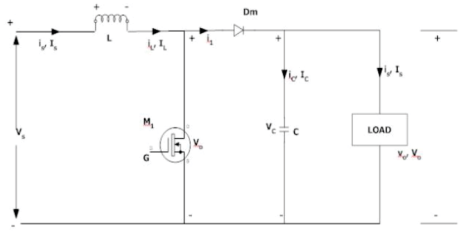


Figure 3.1: Circuit digram of boost converter

The function of boost converter can be divided into two modes, Mode 1 and Mode 2. Mode 1 begins when transistor M1 is switched on at time t=0. The input current rises and flows through inductor L and transistor M1. Mode 2 begins when transistor M1 is switched on at time t=t1. The input current now flows through L, C, load, and diode Dm. The inductor current falls until the next cycle. The energy stored in inductor L flows through the load. In boost converter the output voltage is given by,

$$V_{in} = V_{out}/1\text{-}D \quad (5)$$

From the above equation it is clear that the output voltage is related directly to the duty cycle.

3.3.2 Three phase inverter

Three phase inverters are used for variable-frequency drive and high power applications such as HVDC power transmission. A basic three phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60degree point of the fundamental output waveform. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square- wave such that the harmonics that are multiples of three are eliminated using filter.

Vector -PI Control of inverter

It is well known that the active power flows from the leading voltage to the lagging voltage and the reactive power flows from the higher voltage to the lower voltage. Therefore, both active and reactive power can be controlled by controlling the phase and magnitude of the converter voltage fundamental component with respect to load voltage. Here, the three-phase grid voltages and line currents are converted into an equivalent two-phase system, called stationary reference frame. These quantities are further transformed into a reference frame called synchronous reference frame, which revolves at the grid frequency. Load voltage components in synchronous d q reference frame given by,

$$V_{ld} = Ri_{cd} + L\frac{di_{cd}}{dt} + \omega L i_{cd} + V_{cd}$$

$$V_{lq} = Ri_{cq} + L\frac{di_{cq}}{dt} + \omega L i_{cq} + V_{cq}$$

where R and L are filter Resistance and Inductance respectively; ω is the angular speed of the rotating reference frame; V_{cd}, V_{cq}, V_{ld} and V_{lq} are output voltage of the converter and load on d and q axis respectively. The dq load voltage components are not absolutely dependent owing to the involvement of cross coupled terms ωLi_{cd} and ωLi_{cq}. The effect of q-axis on d-axis and vice versa degrades the performance of the controller. For improving the dynamic performance of the controller, the cross coupling terms are nullified by decoupled network with feed forward signals Vd and Vq as shown in Figure 3.2

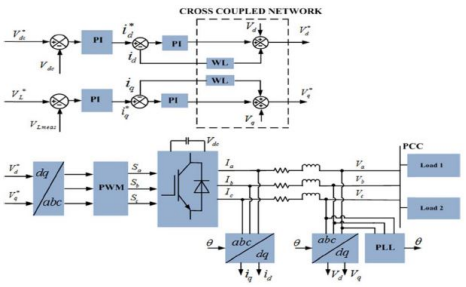


Figure 3.2: Vector -PI control of 3 phase inverter

Control system of output current consist of several blocks. As the inverter is connected to the grid the PLL block applies to synchronise the current and grid voltage. The d and q component of current obtained from the output current that was already measured and converted by Parks transformation. These components compare with reference values compose errors to be cancelled by PI controllers. The d component is summed with measured value of grid voltage, while q component of grid current that multiplied to ωL is subtracted. The same procedure is performed by q component. Obviously d and q current components are mutually affect each other. These output signals go to the reverse Parks transformation in order to obtain 3 phase sinusoidal output signals.

4. IMPLEMENTATION OF THE TSR MPPT

Tip-speed ratio (TSR) control is a well-known technique in which the turbine and wind speeds are continually measured by sensors or are estimated using different physical parameters. Moreover, the optimum TSR is also needed to regulate the TSR of the turbine to the optimum TSR. In this project the Tip Speed Ratio control algorithm is used to

tracking the maximum power as well as to control the switch of boost converter [7].

For the wind turbine used in the WECS, the TSR is defined as in equation (1). From the circuit of the boost converter, Duty ratio DS1 is defined as

$$D_{s1} = T_{ON}/T_S \quad (6)$$

where T_{ON} is the switch ON time. The input resistance of the converter (Rin) is obtained as

$$Rin = (1 - D_{S1})^2 R_L \quad (7)$$

where RL is the load resistance of the converter. The flowchart of the proposed MPPT is shown in Figure.4.1

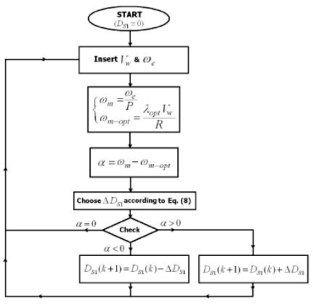


Figure 4.1: Flow chart of TSR method of MPPT

In this paper, to minimize the tracking convergence time and maximize the MPPT efficiency, the amount of the increase/decrease in D_{S1} is selected based on the absolute value of the difference between the turbine angular speed and the optimum angular speed [7].

5. BATTERY MANAGEMENT SYSTEM

Energy storage devices are required for power balance and power quality in stand-alone wind energy systems. Due to the highly variable nature of the wind, the utilization of an energy storage device such as a battery can significantly enhance the reliability of a small stand-alone wind system. Integrating an appropriate energy storage system in conjunction with a wind generator removes the variations and can maximize the reliability of the power supplied to the loads. In the autonomous system, the wind power converter may be operated to maximize the wind energy converted into electricity. The captured energy is supplied to the load directly, the difference between the wind power generation and user consumption being directed to or supplied by the battery energy storage device connected via the power electronic interface [4][5]. This paper discusses a bidirectional buck-boost converter to manage the storage and sup- ply of power between wind power generation systems and batteries. Due to the circuit structure of a bidirectional converter allows bidirectional power flows, two operation modes can be set for this converter depending on the direction of the power flow: boost and buck modes [1]. The battery control scheme for bi-directional converter is discussed in Figure 5.2. In this control scheme, the outer loop regulates the DC-link voltage by comparing the reference DC link voltage with the actual DC link voltage.

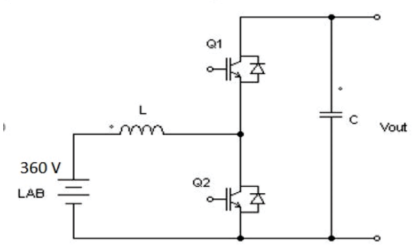


Figure 5.1: Circuit diagram of bidirectional buck boost converter

The mismatch is processed by PI regulator to set the reference battery current for the inner loop. The battery reference current is compared with original battery current and the mismatch is processed by PI regulator. The PI controller output is passed through PWM (Pulse Width Modulated) generator which generates the gate signals to trigger the upper and lower switches of DC-DC converter to control Power in and out of battery [1].

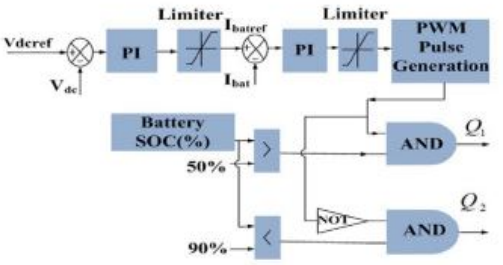


Figure 5.2: Control of bidirectional converter

6. SIMULATION MODELS AND RESULTS

The wind energy system can be modelled using the following parameter

Parameter	Rating
PMSG Rated Power	20kW
PMSG Rated Voltage	295V
PMSG Stator Resistance, Rs	1.8750 pu
Direct Inductance	0.085 (mh)
Number of pole pairs	4
Rotor speed	200 rpm
DC link Voltage	600
DC link capacitance	10 mF
Operating Wind speed	12 m/s
Battery Rated Capacity(amp-h)	160
Rated voltage of battery	360(V)
PI controller parameters	K_P=12, K_I=0.1

Figure 6.1 shows the simulation model of entire system. The WECS connected to a 9000KW resistive load. The system model consists of four subsystem and model of PMSG. It consists of wind turbine model, rectifier model, boost converter and MPPT, inverter model and bidirectional converter model.

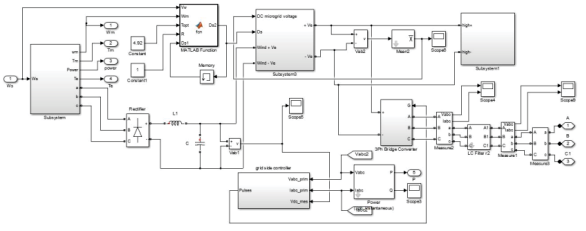


Figure 6.1: simulation model of the WECS

Wind Turbine can be modelled according to the equations explained in section 3.1. Model of boost converter and control consists of general boost converter and MPPT. The TSR control algorithm is used as MPPT method explained in section 4. Here the output voltage of converter is controlled by MPPT method. The controlling signal is connected to gate terminal of the converter. The model of three phase inverter consist of 6 switches. The six switching signals are generated by vector PI control and are given to the gate terminals of the switches.

6.1 SIMULATION RESULTS

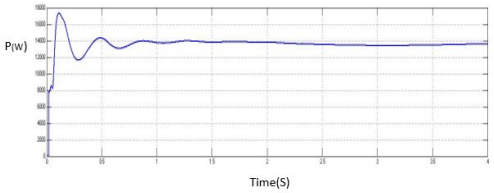


Figure 6.3: Output power of Wind Turbine

The graph 6.3 shows that the output power of PMSG at wind speed 12m/s is maintained constant at 14kW. The rated power of PMSG is about 20kW. Here the power obtained as 14kW.

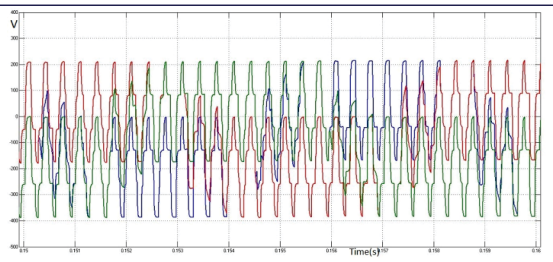


Figure 6.4: Output voltage Va, Vb, Vc of PMSG

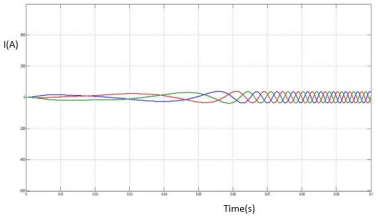


Figure 6.5: Output current Ia,Ib,Ic of PMSG

The graph 6.4 and 6.5 shows the three phase output voltage Va, Vb, Vc and three phase output current Ia, Ib, Ic of PMSG. The rated voltage of PMSG is about 295V. Here the voltage obtained as 195V. The wind speed is varying so the output voltage is varying, Here the current is obtained as 10A.

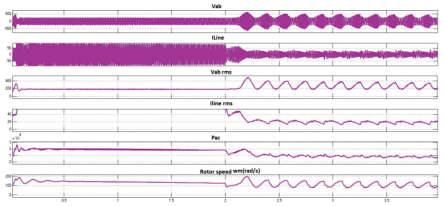


Figure 6.6: Electrical parameters of the PMSG

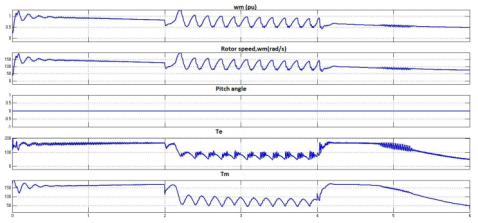


Figure 6.7: Mechanical parameters of the PMSG

Figure 6.6 and 6.7 shows the electrical and mechanical parameters of the PMSG. From the graph 6.6 the line voltage, line current, output power and rotor speed of PMSG are plotted in different wind speeds. The 12m/s wind speed given to wind turbine in first two seconds. Another two seconds the wind speed given to wind turbine is 8m/s. The variation in the parameters can be clearly shown in graph. Similarly, mechanical parameters such as rotor speed, mechanical torque, electrical torque, and pitch angle is plotted in 12m/s in first two seconds and 8m/s in another two seconds again 12m/s remaining two seconds.

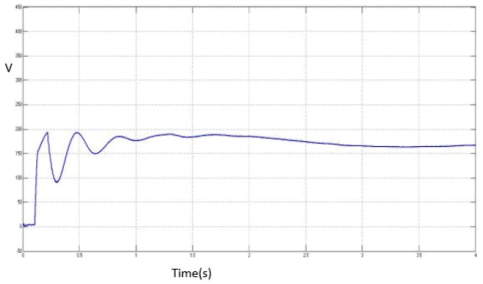


Figure 6.8: Rectifier Output voltage

The graph 6.8 shows the output voltage of three phase uncontrolled rectifier. The output voltage of rectifier is given by Vout = 1.654Vm From the graph the output voltage is 190V at wind speed is 12 m/s and rotor speed is 200rps.

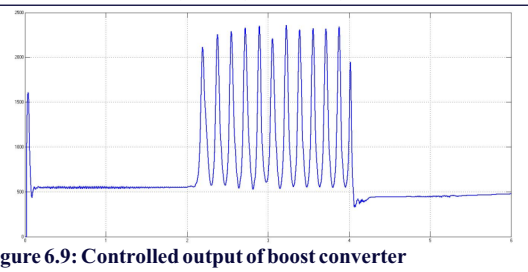


Figure 6.9: Controlled output of boost converter

The graph 6.9 shows the output voltage of boost converter. The converter boosts the voltages from 190V to 595V at wind velocity 12m/s. The MPPT method is used to controls the voltage about 595V approximately. The gain of boost converter is 3.

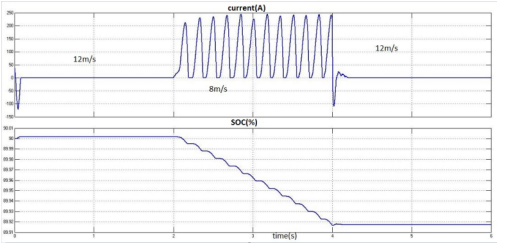


Figure 6.10: Battery charging current and SOC

Figure 6.10 shows that the battery charging current and SOC for 12m/s and 8m/s. During the time 0 to 2 seconds wind speed is 12m/s. The wind power obtained is 20Kw ie., the wind power is greater than load power. So the battery is charging with negative current. During the time 2 to 4 seconds the wind power is low as 8m/s. Battery is discharging with positive current. Also State Of Charge(SOC) of battery is decreasing.

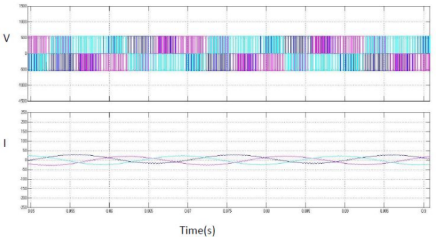


Figure 6.11: Inverter output voltage and current

Figure 6.11 shows that the 3 phase inverter output voltage and current. The input of 3 phase full bridge inverter is equal to the output of boost converter. so the inverter converts the constant 595V DC voltage to +595V to -595V AC voltage. This is shown in above graph.

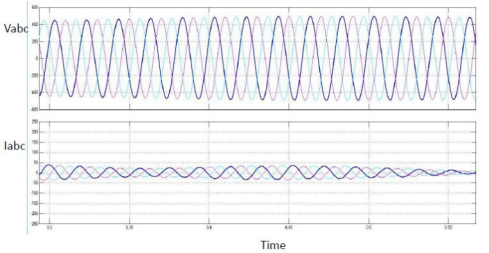


Figure 6.12: Filter output voltage and current

The graph 7.22 represents the filter output voltage and current. This is the voltage given to the load. Here the output voltage is about 595V.

7. CONCLUSIONS

Modelling and simulation of Standalone wind energy conversion system with battery storage is analysed and presented using MATLAB/SIMULINK tool. The wind energy has been considered as one of the significant renewable energy sources. wind turbine,3 phase rectifier, boost converter+MPPT, and a bidirectional buck boost converter is successfully modelled. Here the control of boost converter is achieved by MPPT method. Here various methods of MPPT is discussed. In this project the TSR control method is used for MPPT. By

using power conditioning scheme, the output voltage as well as output power of PMSG can be maintained constant. So further scope of error will be minimized. So the stability of the system can be achieved. This includes an associated energy storage system, with the role to stabilize the output voltage in autonomous applications. Simulation and experimental test results show that the active power balance of the system proves to be satisfied during transient loads and variable wind speed conditions.

REFERENCES:

[1] Dynamic performance improvement of standalone battery integrated PMSG wind energy system using proportional resonant controller Dileep Kumar Varma Sagiraju a, Obulesu Y.P. b, Sai Babu Choppavarapu c, Engineering Science and Technology, an International Journal 20 (2017) 1353{1365. L. Barote, C. Marinescu, M.N. Cirstea, Control structure for single-phase standalone wind-based energy sources, IEEE Trans. Ind. Electron. 60 (2013) 764{ 772.

[2] L. Barote, C. Marinescu, M.N. Cirstea, Control structure for single-phase standalone wind-based energy sources, IEEE Trans. Ind. Electron. 60 (2013) 764 { 772}.

[3] Stand-Alone Wind Energy Supply System" by C. N. Bhende Department of Electronics and Communication Engineering, Indian Institute of Technology Guwahati, Guwahati, India, 2009 Third International Conference on Power Systems, Kharagpur, INDIA December 27-29

[4] Battery Energy Storage System for Variable Speed Driven PMSG for Wind Energy Conversion System"by Rajveer Mittal, K.S. Sandu and D.K. Jain , International Journal of Innovation, Management and Technology, Vol. 1, No. 3, August 2010

[5] Design and Implementation of a Bidirectional DC-DC Converter for Stand-Alone Photovoltaic Systems 1*Kuei-Hsiang Chao, 1 Ming-Chang Tseng, 1 Chun-Hao Huang, 2 Yang-Guang Liu and 2 Liang Chiao Huang, International Journal of Computer, Consumer and Control (IJ3C), Vol. 2, No.3 (2013)

[6] Gour, R., Jain, P., Mittal, R., & Deswal, S. S. (2012, December). PMSG based isolated wind energy conversion system (WECS) for variable load. In 2012 IEEE 5th India International Conference on Power Electronics (IICPE) (pp. 1-6). IEEE.

[7] Fathabadi, H. (2017). Novel maximum electrical and mechanical power tracking controllers for wind energy conversion systems. IEEE Journal of Emerging and Selected Topics in Power Electronics, 5(4), 1739-1745.

[8] Elbeji, O., Hamed, M. B., & Sbita, L. (2014). Pmsg wind energy conversion system: Modeling and control. International Journal of Modern Nonlinear Theory and Application, 3(03), 88.

[9] Mcmurray, W. (1972). A study of asymmetrical gating for phase-controlled converters. IEEE Transactions on Industry Applications, (3), 289-295.