Control Strategy of Stand-Alone Wind Based Energy Systems or Small Scale Power Grid Applications

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***Abstract*:- The aim of this paper is analyzing the operation of stand-alone wind turbine system with variable speed permanent magnet synchronous generator (PMSG) and a system for storing energy during wind speed and load variations and supply the single phase energy for domestic appliances. The power absorbed by the connected loads can be effectively delivered and supplied by the proposed wind turbine and energy storage system. The stand-alone control featured is constant output voltage and frequency that is capable of delivering to variable load. The PI controller in switch mode rectifier can be replaced with fuzzy control technique to improve the output voltage level. Energy storage devices are required for power balance in the stand alone wind energy systems. Originally the holistic shape of the entire arrangement is achieved together with the PMSG, the AC-DC and DC-DC converter and storage system.**

Keywords-: stand-alone wind turbine, variable speed permanent-magnet generators, fuzzy control, energy storage system, small grid.

I. INTRODUCTION

This paper presents the control structure of stand-alone wind energy systems, for delivering the wind power to single phase domestic grids. From the past few years, research into the use of renewable energy sources (RESs), such as photovoltaic, wind and hydropower plants [1]-[3], for electricity generation has been more popular. In the case of wind energy conversion systems (WECSs), the interest is also focused on small units, for provide electricity supply to the remote areas where that are beyond the reach of an electric power grid or cannot be economically connected to the grid. Small scale WECS shave to be further optimized in order to achieve integration in flexible small grids and increased reliability [4]. The group of small grids is linked through power and data exchange highways, play a similar role in the small grids as the power generator do in classical power systems. The more flexibility of the small grids and easier integration of RES makes them more attractive[5],[6].WECSs are the most favored alternatives for supplying electricity in stand-alone cases at this moment due to the fact that wind energy is relatively easily harnessed, the maintenance required by the wind turbine generators is reasonable, and there is no fuel cost. Several electrical machines can be used to implement the electromechanical energy conversion and control, each of which presents different advantages and disadvantages [7]–[9].

For small-power wind systems operating in remote and isolated areas, the study of permanent-magnet synchronous generators (PMSGs) has been the subject of much research. PMSGs are particularly interesting in low-power wind energy applications, due to their small size and high power density. The primary advantage of PMSGs is that they do not require any external excitation current. A most important cost benefit in using the PMSG is the fact that a diode bridge rectifier may be used at the generator terminals since no external excitation current is needed. The system topology used in this paper is based on a PMSG connected through a diode bridge rectifier and a boost converter to the dc link for small- and medium-power ranges [9]–[11].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 [12]–[14]. 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 [2].The lead–acid batteries (LABs) are the dominant energy storage technology, with their advantages of low price, high unit voltage, stable performance, and a wide range of operating temperature [15], [16]. The LABs hence constitute an exciting challenge, as major components in the development of the stand-alone wind energy systems [17], [18].

II. STAND-ALONE WIND TURBINE SYSTEM CONFIGURATION

The proposed stand-alone wind power system supplies single-phase consumers at 230V/50 Hz. It is designed for a residential location, and it is based on a 2-kW wind turbine equipped with the following:1)a direct-driven

PMSG; 2) an ac/dc converter (diode rectifier bridge + boost converter) for the tracking of the maximum power from the available wind resource; 3) a LAB storage device; 4) an inverter;5) a transformer; and 6) resistive loads.

The wind turbine rotor 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 an ac/dc converter. 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 through an inverter further to the load. The voltage should stay constant for various wind speeds. When the wind speed is too high, the power excess supplied by the wind turbine is stored in the battery. When the wind speed is low, the generator, including the battery bank, can provide sufficient energy to the loads. The dc loads are supplied directly from the dc circuit. At high speeds, the turbine control system stops the energy production. The same protection is activated also in the case when the battery is fully charged and energy production exceeds consumption. At low wind speeds, load shedding is used to keep the frequency at the rated value. The storage system is collected of a LAB and a full-bridge single-phase inverter that converts the dc voltage of the battery to ac voltage. Furthermore, this voltage is applied to a single-phase transformer, which boosts up the voltage to 230 V. The inverter controls the power transfer.

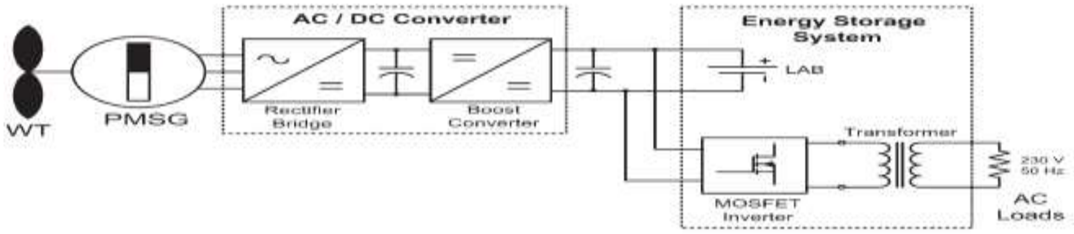

Figure1: stand-alone wind turbine generator with energy storage system.

A. WIND TURBINE MODEL:

Actually, the energy in the wind can be treated as the kinetic energy of a large amount of air particles with a total mass,m, moving at a wind velocity, V_W .Assuming that all the air particles are moving at the same speed and direction before impacting the rotor blades of the wind turbine, the potential available kinetic energy stored in the wind can be expressed according to the following expression:

$$\mathrm{E} = \frac{1}{2} m V_W{}^2 \tag{1}$$

$$m = \rho A V_W t = \rho \pi r^2 V_W t \tag{2}$$

$$E = \frac{1}{2} \rho \pi r^2 V_W{}^3 t \tag{3}$$

The power came from wind at any instant of time can be represented as follows:

$$P_{Wind} = \frac{E}{t} = \frac{1}{2} \rho \pi r^2 V_W{}^3 \tag{4}$$

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:

$$C_P = \frac{P_{Turbine}}{P_{Wind}} \tag{5}$$

$$C_P = C_1 (C_2 \frac{1}{\alpha} - C_3 \beta - C_4 \beta^x - C_5) e^{-C_6 \frac{1}{\alpha}} \tag{6}$$

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

$$\lambda = \frac{\omega_m r}{V_W} \qquad 8$$

Where,

$C_P = power coefficient$

$\beta = blade angle$

λ =is the tip speed ratio of the wind turbine,

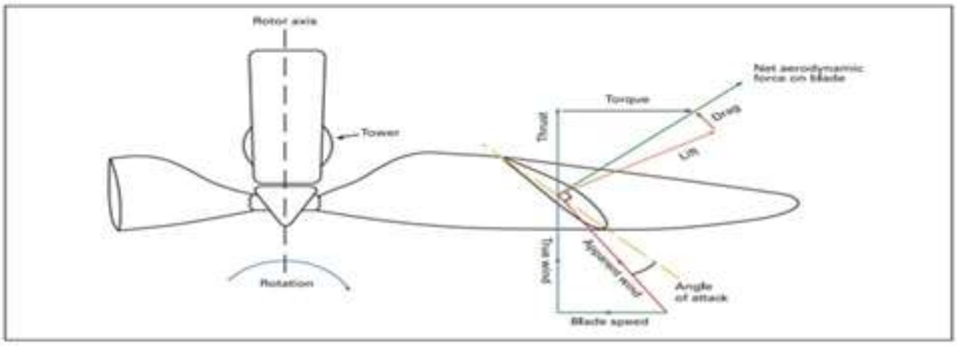

Figure2: Blade angle schematic diagram

B. PMSG Model

The dynamic model of PMSG is derived from the two-phase synchronous reference frame in which the *q*-axis is 90° ahead of the *d*-axis, with esteem to the direction of rotation. The electrical model of PMSG in the synchronous reference frame is given by

$$\frac{di_d}{dt} = -\frac{R_a}{L_d} I_d + \omega_e \frac{L_q}{L_d} i_q + \frac{1}{L_d} v_d \qquad \mathbf{9}$$

$$\frac{di_q}{dt} = -\frac{R_a}{L_q} i_q - \omega_e \left(\frac{L_d}{L_q} i_d + \frac{1}{L_d} \varphi_{PM}\right) + \frac{1}{L_q} v_q \qquad 10$$

where subscripts *d* and *q* refer to the physical quantities that have been transformed into the *d*–*q* synchronous rotating reference frame; R_a is the armature resistance; ω_e is the electrical rotating speed which is related to the mechanical rotating speed of the generator as $\omega_e = n_p \cdot \omega_g$, where n_p is the number of pole pairs; and ψ_{PM} is the magnetic flux of the permanent magnets. The electromagnetic torque can be derived, as shown in

$$T_e = \frac{3}{2} n_p [(L_d - L_q) i_d i_q + \varphi_{PM} i_q \quad (11)$$

If the PMSG is taken without rotor saliency (where $L_d = L_q = L$), can be rewritten as

$$\frac{di_d}{dt} = -\frac{R_a}{L} I_d + \omega_e \frac{L_q}{L} i_q + \frac{1}{L} v_d \quad (12)$$

$$\frac{di_q}{dt} = -\frac{R_a}{L} i_q - \omega_e (\frac{L_d}{L} i_d + \frac{1}{L} \varphi_{PM}) + \frac{1}{L} v_q \quad (13)$$

$$T_e = \frac{3}{2} n_p \varphi_{PM} i_q \quad (14)$$

C. FUZZY CONTROLLER:

To obtain maximum power from a controlled WECS, this has to operate in the variable-speed mode. Thus, Fuzzy logic controlling method, based on MPPT, must be used, in order to maximize the electric output power and to adjust the generator speed.

Depending on the wind speed, the MPPT control adjusts the power transferred, bringing the turbine operating points onto the "maximum power curve," In the case of the system studied, in the simulations the converter control system did not allow obtaining maximum power over the entire range of wind speeds, but only from 3 to 6 m/s, due to current limitations introduced by the motor inverter which emulated the wind turbine. A PI regulator is used to apply the MPPT function, which provides the location of the power for the boost converter, based on the wind speed dimentions ($v_{p.u.}$) and the turbine generator speed ($n_{p.u.}$).

A control strategy for a rectifier with variable speed direct driven permanent magnet synchronous generator. The fuzzy logic controller is used to track generator speed with varying wind speed to optimize turbine aerodynamic efficiency in the external speed loop. The voltage space vector PWM in FOC is adopted in the control of the generator side converter. By means of the field-oriented control, the highest effectiveness of wind turbine can be reached. The Fuzzy controller of inner current loop is used instead of the traditional PI controller to improve the performances of current loop. Simulation have been conducted to validate the performance

TABLE- FUZZY-RULE-BASED MATRIX

DOT ERROR / ERROR	LN	MN	SN	VS	SP	MP	LP
LN	LN	LN	LN	LN	LN	LN	LN
MN	LN	LN	LN	LN	LN	LN	LN
SN	LN	LN	LN	LN	LN	LN	LN
VS	LN	LN	LN	LN	LN	LN	LN
SP	LN	LN	LN	LN	LN	LN	LN

MP	LN	LN	LN	LN	LN	LN	LN
LP	LN	LN	LN	LN	LN	LN	LN

FUZZY RULE RIEWER:

Figure 3: Fuzzy rule reviewer

D. BOOST CONVERTER MODEL:

The unidirectional boost converter achieves an interface between the battery and the rectifier capacitor and ensures the rapid transfer of power. The block diagram is shown in Fig. and a simplified model of the boost converter is shown in Figure.4

The voltage and current relationship between the primary and secondary sides is given by (14) and (15)

$$V_b = \frac{V_{dc}}{1-D} \qquad 15$$

$$I_b = I_{LCONV}(1-D) \qquad 16$$

Where *D* is the pulse-width modulation (PWM) modulation factor. When $Vdc \geq Vb$, the boost converter is not working, and the current provided by the generator is channeled through the bypass Scotty diode *Ds*. In (14) and (15), it is assumed that there is no power loss in the converter. The input and outputsignals of the boost converter are modeled by two controlled current sources.

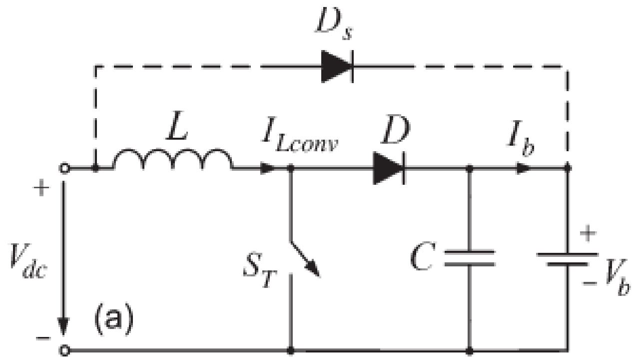

Figure4: Boost converter diagram.

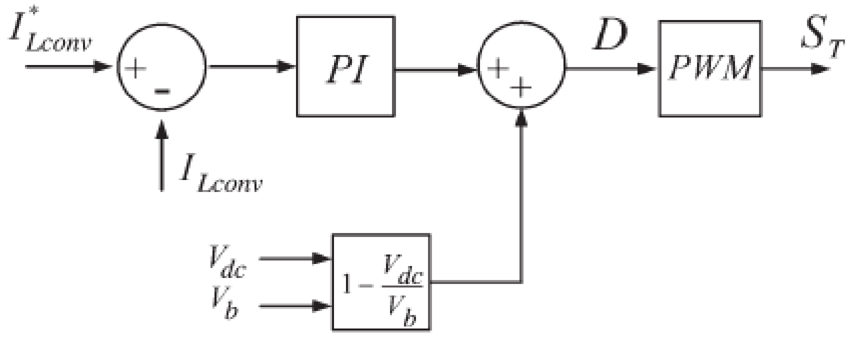

Figure 5: Boost converter control diagram.

D. **ENERGY STORAGE SYSTEM:**

The energy storage system is composed of a single-phase MOSFET inverter and a bank of LABs 12 V each (gel type) connected in series to provide the desired value of the inverter battery voltage. The LAB is able to supplement the power provided to the load by the wind turbine, when the wind speed is too low. The equivalent electrical model of the LAB contains a con-trolled voltage source (E_b), connected in series with the internal resistance (R_{int}) and the LAB voltage (V_b). It is known that the E_b voltage depends on the charging condition, battery nature, and temperature, and it is relationship:

$$E_b = E_{b0} - \frac{K.Q}{Q - \int_0^t I_b dt} \quad 17$$

$$SOC_{[\%]} = SOC_{0[\%]} + \left(\frac{I}{Q_n}\int_0^t I_b dt\right) \quad 18$$

If the LAB is fully charged, *SOC* = 1, and if the battery is discharged at the maximum value, *SOC* = *SOC*min. For instance, the maximum recommended discharge for LABs used in such applications is 80%; thus, *SOC*min = 0.2. As the full discharge is not recommended for LABs, a *SOC*min = 20%will be considered in the regulator's implementation.

III. SIMULATOIN RESULTS

A. 1 kw Load switching, at constant wind speed:

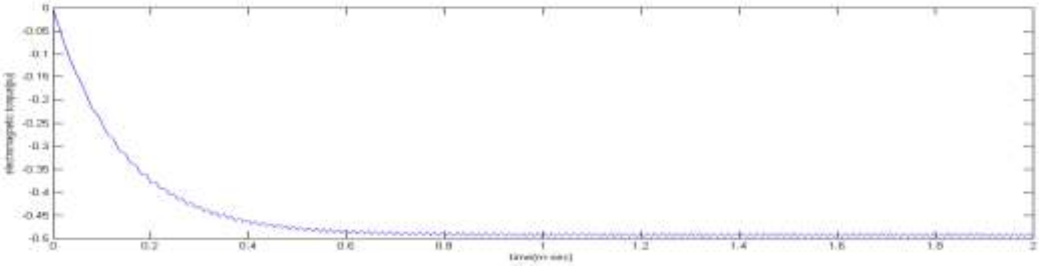

Figure.6:electromagnetic torque at constant wind speed

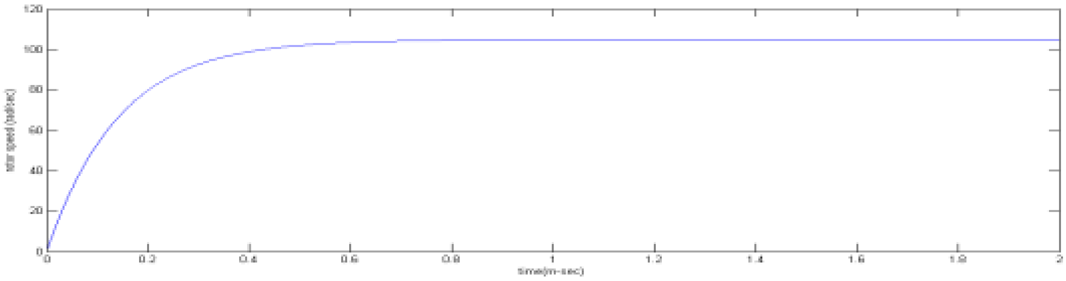

Figure.7:rotor speed at constant wind speed

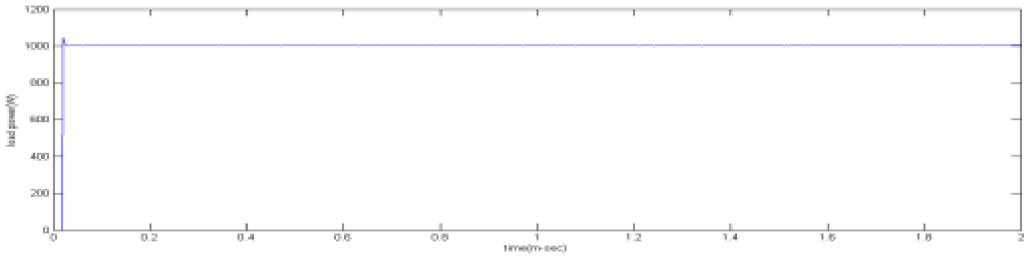

Figure.8:1kw load switching power at conatant wind speed

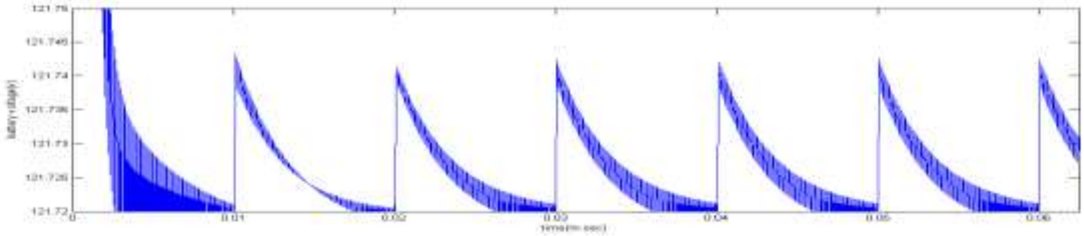

Figure9: Battery voltage at constant wind speed

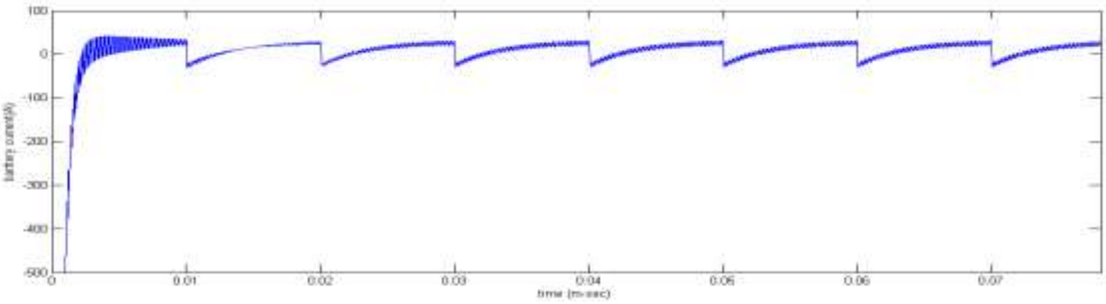

Figure.10:Battery current at constant wind speed

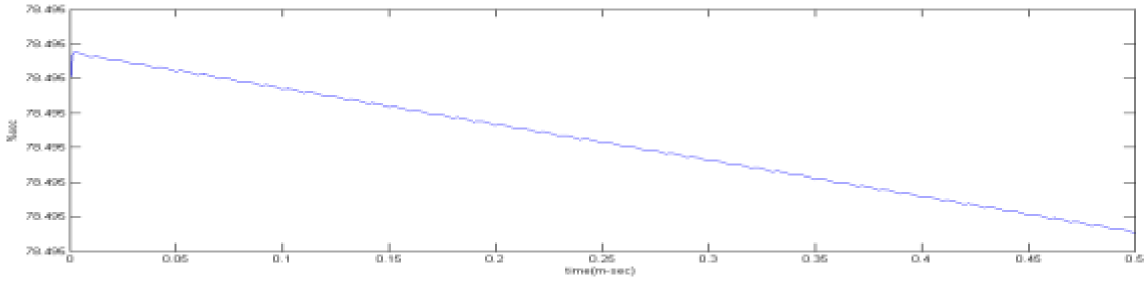

Figure11:% sate of charge at constant wind speed

B. 1kw Load switching at variable wind speed:

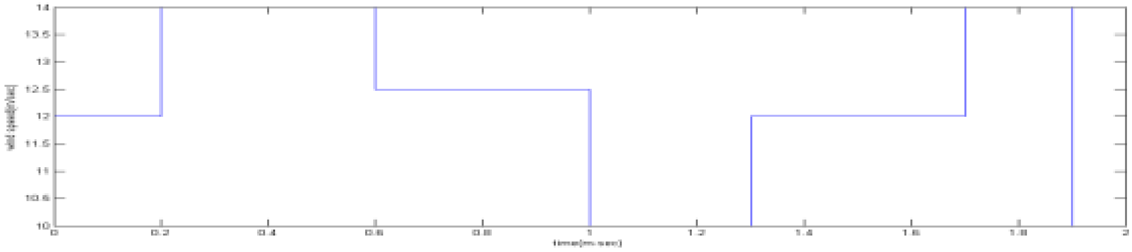

Figure.12: variation of the wind speed

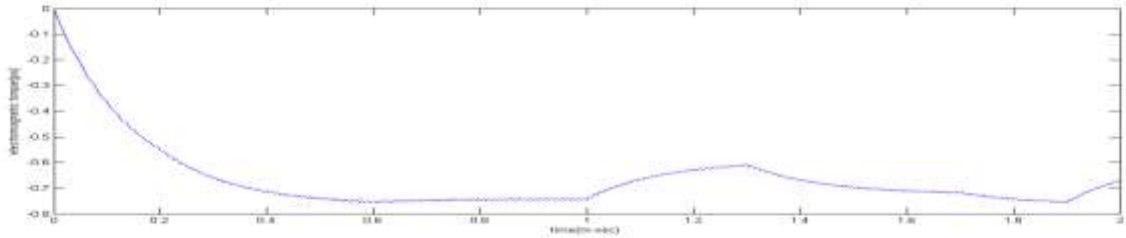

Figure13:Electromagnetic torque at variable wind speed

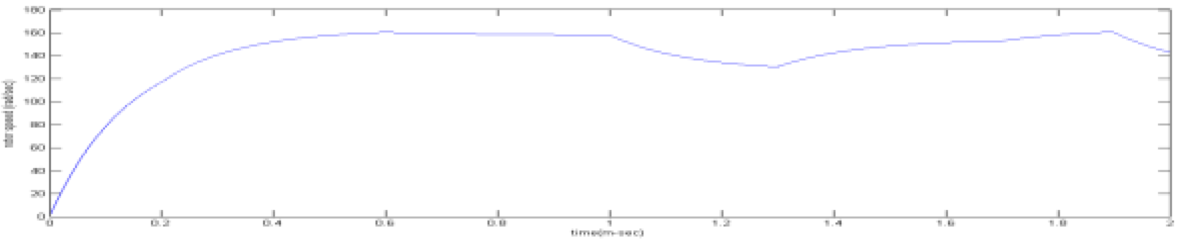

Figure14:Rotor speed at variable wind speed

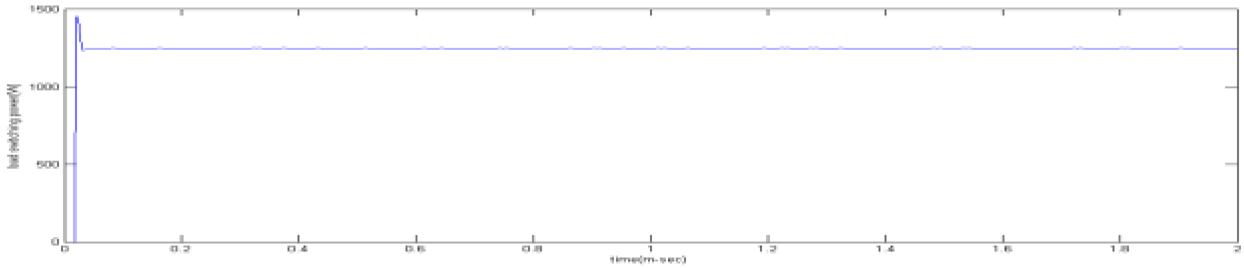

Figure15:1kw load switching power at variable wind speed

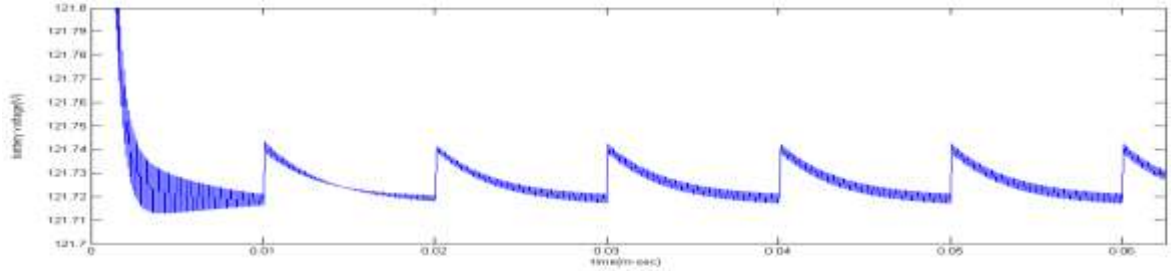

Figure16:battery voltage at variable wind spped

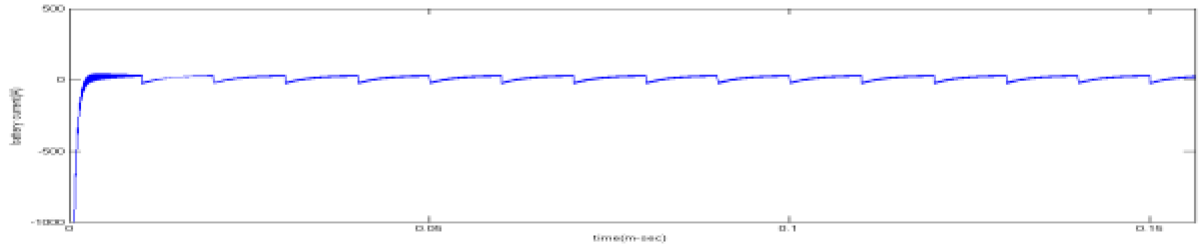

Figure.17:battery current at variable wind speed

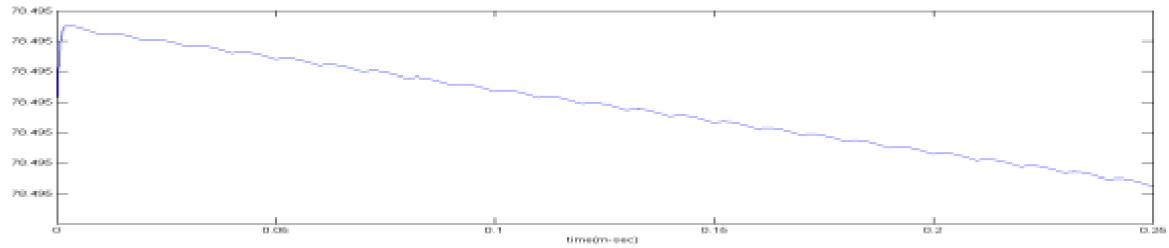

Figure.18:% sate of charge at variable wind speed

2kw load switching:

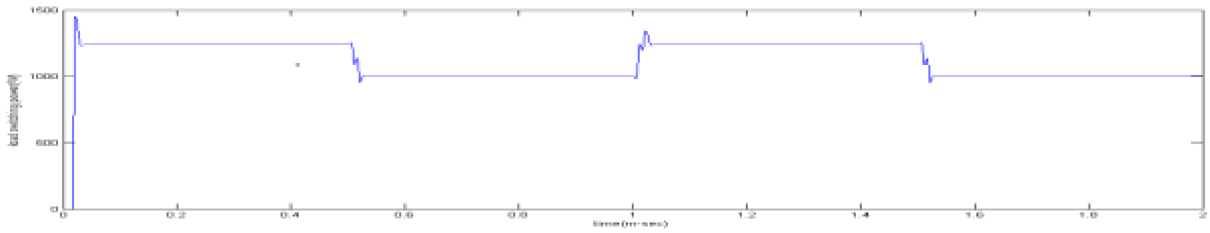

Figure19:2kw load switching power at variable wind speed

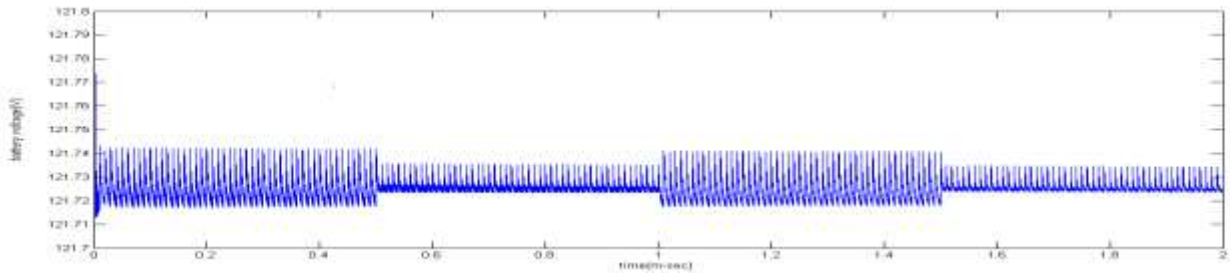

Figure20: battery voltage at variable wind spped

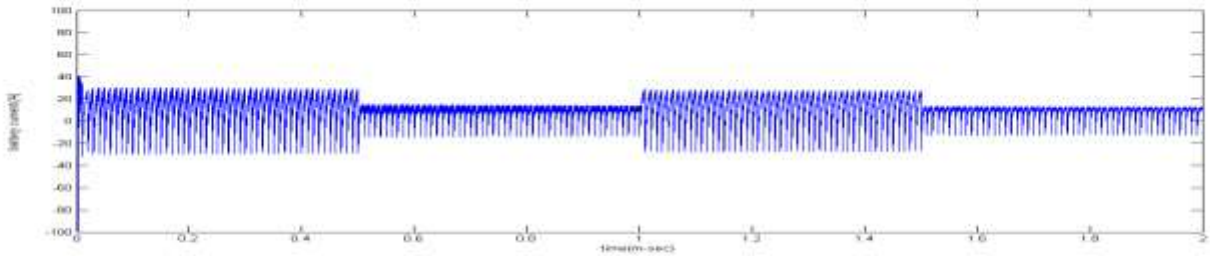

Figure21: battery current at variable wind speed

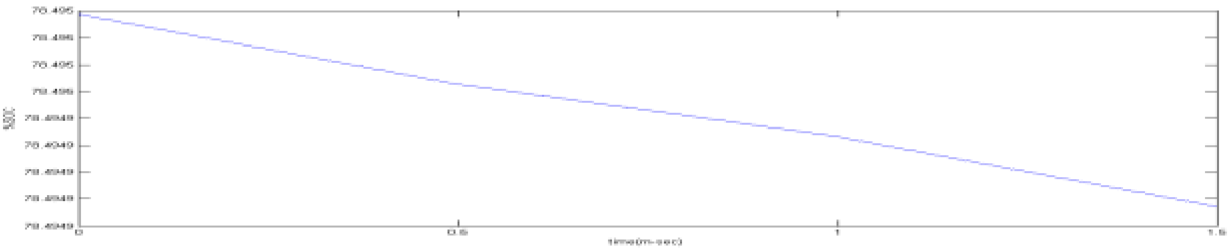

Figure22:% sate of charge at variable wind speed

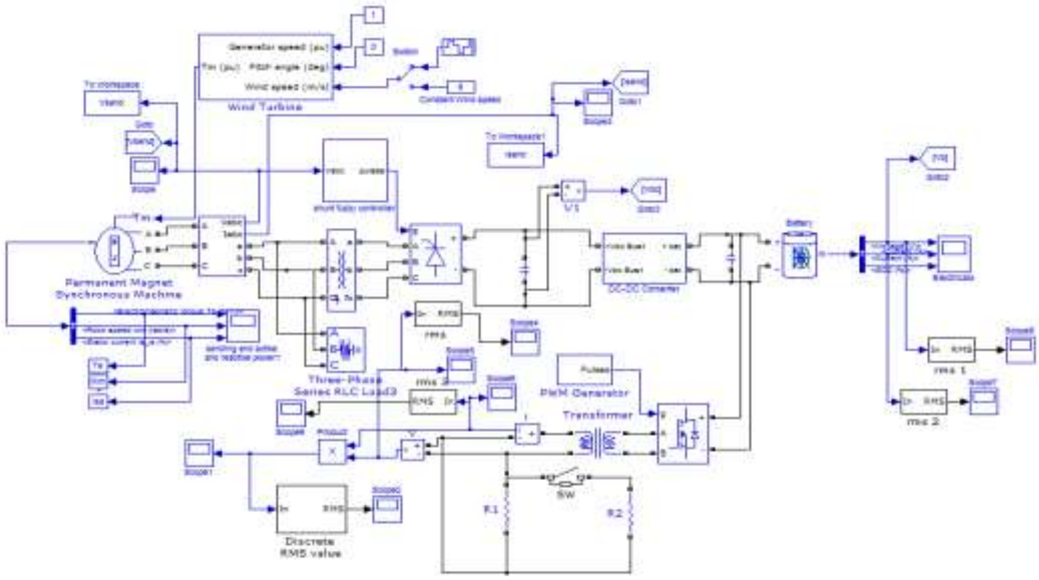

Figure23: simulation diagram of proposed stand alone wind turbine.

IV. CONCLUSION

The control strategy developed on standalone wind turbine generator along with energy storage systems has been analyzed .Here the energy storage system, with a role to stabilize the output voltage in autonomous applications. The energy generated by the wind turbine sufficiently supplied to the loads by developed control technique. To avoid frequency mismatching between generator and the utility loads generated power would be converted to AC to DC by using rectifier circuit. For the purpose of getting maximum energy from the wind fuzzy logic control was implemented to generate the switching signals to the DC-DC converter. The output from the DC-DC converter supplied to the load through the inverter. It is concluded that the developed control strategy for the stand alone wind turbine generator including with battery was achieve all the requirements to operate the loads without interruptions even though wind is varied.

V. FUTURE SCOPE

The presented simulink model setup has done experimentally using wind turbine emulator that drives the PMSG. This emulator is able to reproduce the steady and dynamic behaviour of a real wind turbine. To implement the real time control system hardware system will be required it can have following devices like micro controllers, comparators and microprocessors.

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