Standalone Wind–Hydro Hybrid Generation System with Dump Power Control and Battery Energy Storage System (BESS)

[1]Yokeeswaran. R, [2]Pari. R
Assistant Professor, Department of EEE, V.S.B. Engineering College, Karur-639 111.

[3]Bharani Prakash.T
Assistant Professor, Department of EEE, V.S.B. Engineering College, Karur-639 111.

Abstract: *In this thesis deals with a new isolated wind-hydro hybrid generation system employing one Permanent Magnet Synchronous Generator (PMSG) driven by a variable-speed wind turbine and another PMSG driven by a constant-power hydro turbine feeding three-phase four-wire local loads. The proposed system utilizes two back-to-back-connected Pulse Width Modulation (PWM) controlled Insulated Gate Bipolar Transistor (IGBT) based Voltage-Source Converters (VSCs) with a Battery Energy Storage System (BESS) at their dc link. The proposed electromechanical system using PMSGs and a voltage and frequency controller are modelled and simulated in MATLAB using Simulink and Sim Power System set toolboxes, and different aspects of the proposed system are studied for various types of linear and nonlinear loads under varying wind-speed conditions. The performance of the proposed system is presented to demonstrate its Voltage and Frequency Control (VFC), harmonic elimination, and load balancing.*

Keywords: *Power Quality (PQ), Discrete Wavelet Transform, DOS-Transform, Time-Frequency Representation(TFR), Feature extraction, Classification.*

1. INTRODUCTION

Renewable energy sources have attracted attention worldwide due to soaring prices of fossil fuels. Renewable energy sources are considered to be important in improving the security of energy supplies by decreasing the dependence on fossil fuels and in reducing the emissions of greenhouse gases. The viability of isolated systems using renewable energy sources depends largely on regulations and stimulation measures. Renewable energy sources are the natural energy resources that are inexhaustible, for example, wind, solar, geothermal, biomass, and small hydro generation [1].

Among the renewable energy sources, small hydro and wind energy have the ability to complement each other [2]. For power generation by small or micro hydro as well as wind systems, the use of permanent magnet synchronous generators (PMSGs) has been reported in literature [3].The potential for small hydroelectric systems depends on the availability of suitable water flow, where the resource exists, it can provide cheap clean reliable electricity. Hydroelectric plants convert the kinetic energy of a waterfall into electric energy. The power available in a flow of water depends on the vertical distance the water falls (i.e., head) and the volume of flow of water in unit time.

The water powers a turbine, and its rotational movement is transferred through a shaft to an electric generator [1]. When PMSG is used for small or microhydro applications, its reactive power requirement is met by a capacitor bank at its stator terminals. As regards wind-turbine generators, these can be built either as constant-speed machines, which rotate at a fixed speed regardless of wind speed, or as variable-speed machines in which rotational speed varies in accordance with wind speed.

For fixed-speed wind turbines, energy-conversion efficiency is very low for widely varying wind speeds. In recent years, wind-turbine technology has switched from fixed speed to variable speed. The variable-speed machines have several advantages. They reduce mechanical stresses, dynamically compensate for torque and power pulsations, and improve power quality and system efficiency [2]. The grid-connected variable-speed wind-energy-conversion system (WECS) based on PMSG use back-to-back connected power converters [3], [5]. In such systems, the power converter decouples the PMSG from the grid, resulting in an improved reliability. In the case of grid-connected systems using renewable energy sources, the total active power can be fed to the grid.

For stand-alone systems supplying local loads, if the extracted power is more than the local loads (and losses), the excess power from the wind turbine is required to be diverted to a dump load or stored in the battery bank. Moreover, when the extracted power is less than the consumer load, the deficit power needs to be supplied from a storage element, e.g., a battery bank [9]. In the case of stand-alone or autonomous systems, the issues of voltage and frequency control (VFC) are very important. In [6]–[7], the authors have addressed the issues of VFC for stand-alone systems using PMSGs. Some work has also been reported for stand-alone WECSs using doubly fed induction generator [2], [3]. In [6], a battery-based controller is proposed for control of voltage and frequency in the isolated WECS.

In this paper, a new three-phase four-wire autonomous (or isolated) wind–small hydro hybrid system is proposed for

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 1, January- 2013

isolated locations, which cannot be connected to the grid and where the wind potential and hydro potential exist simultaneously. One such location in India is the Andaman and Nicobar group of islands [4]. The proposed system utilizes variable-speed wind-turbine-driven $PMSG_w$ (subscript w for wind), and a constant-speed/constant-power small hydro-turbine-driven $PMSG_h$ (subscript h for hydro). For the rest of this paper, the subscript w is used to denote the parameters and variables of the wind-turbine generator, and the subscript h is used to denote the parameters and variables of the hydro-turbine generator.

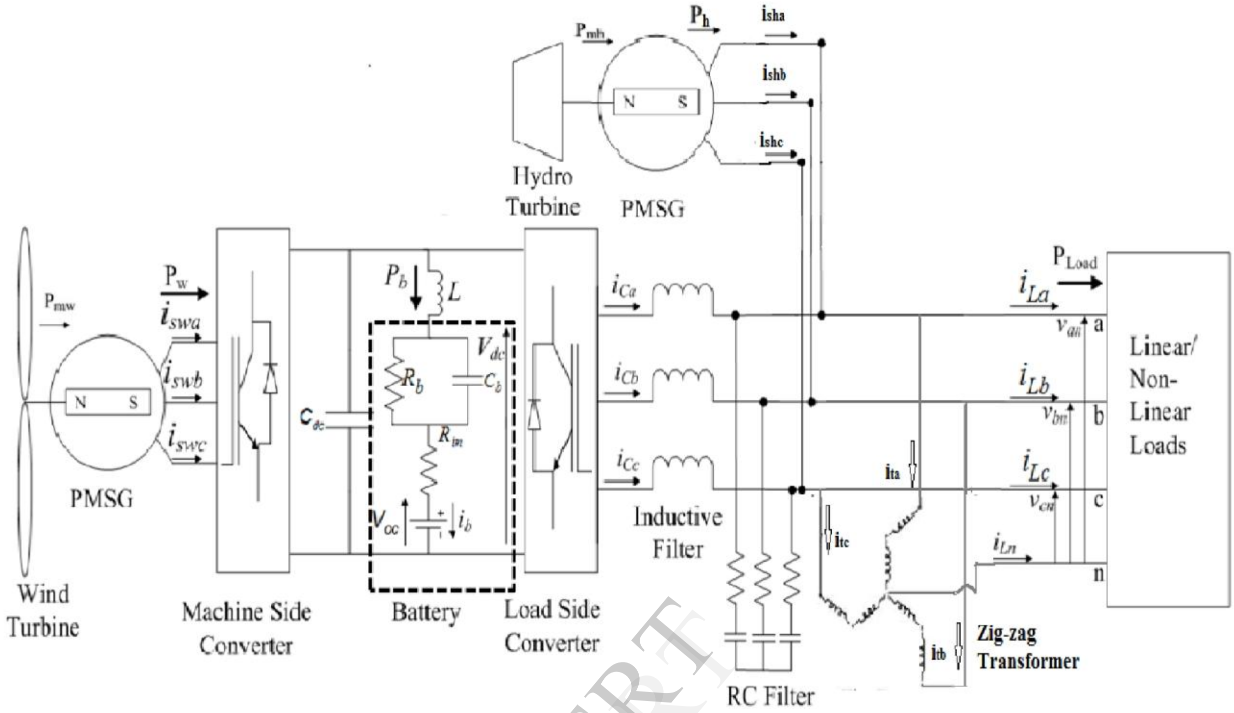

Fig. 1. Schematic diagram of WIND–HYDRO HYBRID SYSTEM.

A schematic diagram of a three-phase four-wire autonomous system is shown in Fig. 1. Two back-to-back-connected pulse- width modulation (PWM)-controlled insulated-gate-bipolar-transistor (IGBTs)-based voltage-source converters (VSCs) are connected between the stator windings of $PMSG_w$ and the stator windings of the $PMSG_h$ to facilitate bidirectional power flow. The stator windings of the $PMSG_h$ are connected to the load terminals. The two VSCs can be called as the machine ($PMSG_w$) side converter and the load-side converter.

The system employs a battery energy storage system (BESS), which performs the function of load leveling in the wake of uncertainty in the wind speed and variable loads. The BESS is connected at the dc bus of the PWM converters. The advantage of using BESS on the dc bus of the PWM converters is that no additional converter is required for transfer of power to or from the battery. Further, the battery keeps the dc-bus voltage constant during load disturbances or load fluctuations. An inductor is connected in series with the BESS to remove ripples from the battery current.

A zigzag transformer is connected in parallel to the load for filtering zero-sequence components of the load currents. Further, the zigzag windings trap triplen harmonic (third, ninth, fifteenth, etc.) currents. As shown in Fig. 1, the zigzag transformer consists of three single-phase transformers with a turn ratio of 1 : 1. The zigzag transformer is to be located as near to the load as possible. The neutral terminal of the consumer loads is connected to the neutral terminal of the zigzag transformer.

The rest of this paper is organized as follows. In Section

The principle of operation of the proposed hybrid system is given in II. In Section III, a design procedure is presented for selection of various components of the proposed system. In Section IV, the developed MATLAB-based simulation is discussed for the proposed system. In Section V, the simulation results for the proposed system under linear load, nonlinear load, mixed load, balanced load, unbalanced load, and variable wind-speed conditions are presented and discussed verifying the validity of the proposed system. Finally, an appraisal of the proposed hybrid system is presented in the Section VI.

II. PRINCIPLE OF OPERATION

As already stated, the proposed system uses two back-to-back-connected PWM-controlled IGBT-based VSCs. These VSCs are referred to as the machine ($PMSG_w$) side converter and load-side converter. The objectives of the machine ($PMSG_w$) side converter are to provide the requisite magnetizing current to the $PMSG_w$ and to achieve MPT, and the objective of the load-side converter is VFC at the load terminals by maintaining active- and reactive-power balance.

For the hybrid system, a new control algorithm is proposed that has the capability of MPT, harmonic elimination, load leveling, load balancing, and neutral current compensation along with VFC. The objectives of the machine ($PMSG_w$) side converter are to provide the requisite magnetizing current to the $PMSG_w$ and to achieve MPT. In the conventional control of variable-speed SCIGs, the objective of the load-side converter (called as grid-side converter in the grid-connected systems) is to maintain the dc-bus voltage constant at the dc link of two back-to-back connected VSCs. Because in the proposed system the dc-bus voltage is kept constant by the battery, the control objective of the load-side converter is different, i.e., to maintain an active power balance in the system by transferring the excess power to the battery or for providing deficit power from the battery. Further, the load-side converter provides the requisite reactive power for the load. The reactive-power requirement of the $PMSG_h$ is provided by the excitation capacitors connected at its stator terminals.

A novel control strategy using indirect current control is proposed for the load-side converter. The control signals for switching of the load-side converter are generated from the error of the reference and the sensed stator currents of $PMSG_h$ rather than by the errors of the load-side converter currents. With this control strategy, the switching of the load-side converter is controlled to make the $PMSG_h$ currents balanced and sinusoidal at the nominal frequency. Any unbalance and harmonics in the load currents are compensated by the zigzag transformer and the load-side converter. The proposed control algorithm for load-side converter requires sensing of the load voltage and stator currents of $PMSG_h$. For the control purpose, sensing of load-side-converter currents and load currents is not required, thus reducing the requirement of current sensors for the control of load-side converter.

For the proposed system, there are three modes of operation. In the first mode, the required active power of the load is less than the power generated by the $PMSG_h$, and the excess power generated by the $PMSG_h$ is transferred to the BESS through the load-side converter. Moreover, the power generated by the $PMSG_w$ is transferred to the BESS. In the second mode, the required active power of the load is more than the power generated by the $PMSG_h$ but less than the total power generated by $PMSG_w$ and $PMSG_h$.

Thus, portion of the power generated by $PMSG_w$ is supplied to the load through the load-side converter and remaining power is stored in BESS. In the third mode, the required active power of the load is more than the total power generated by $PMSG_w$ and $PMSG_h$. Thus, the deficit power is supplied by the BESS, and the power generated by $PMSG_w$ and the deficit met by BESS are supplied to the load through the load-side converter.

III. DESIGN OF PMSG-BASED WIND -HYDRO HYBRID SYSTEM

The system is designed for an isolated location with the load varying from 30 to 90 kW at a lagging power factor (PF) of 0.8. The average load of the system is considered to be 60 kW. The following subsections describe the procedure for selection of ratings for SCIGs, battery voltage, battery capacity, machine-side converter, load-side converter, specifications of wind turbine, and gear ratio.

A. Selection of Rating of SCIGs

The wind-hydro hybrid system being considered has a wind turbine of 55 kW and a hydro turbine of 35 kW. Both turbines are coupled to SCIGs. The rating of the $PMSG_w$ is equal to the rating of the wind turbine, which is 55 kW. The rating of the $PMSG_h$ should be equal to the rating of the hydro turbine, which is 35 kW. Commercially available SCIG whose rating is close to 35 kW is of 37.3 kW rating. Hence, the rating of $PMSG_h$ is taken as 37.3 kW. The parameters of the turbines and SCIGs are given in the Appendix.

B. Selection of Voltage of DC Link and Battery Design

The dc-bus voltage (V_{dc}) must be more than the peak of the line voltage for satisfactory PWM control,

$$V_{dc} > 2\ (2/3) V_{ac}\ m_a \qquad (1)$$

where m_a is the modulation index normally with a maximum value of one and V_{ac} is the rms value of the line voltage on the ac side of the PWM converter. In this case, there are two PWM converters connected to the dc bus; therefore, the constraint on the dc-bus voltage is from the ac voltages of both the converters. The maximum rms value of the line voltage at $PMSG_w$ terminals as well as the rms value of the line voltage at the load terminals is 415 V. Substituting this value in (2), V_{dc} should be more than 677.7 V. The voltage of the dc link and the battery bank is selected as 700 V. Considering the ability of the proposed system to supply electricity to a load of 60 kW for 10 h, the design storage capacity of the battery bank is taken as 600 kW · h. The commercially available battery bank consists of cells of 12 V. The nominal capacity of each cell is taken as 150 Ah. To achieve a dc-bus voltage of 700 V through series connected cells of 12 V, the battery bank should have (700/12) = 59 number of cells in series. Since the storage capacity of this combination is 150 A · h, and the total ampere hour required is (600 kW · h/700 V) = 857 A · h, the number of such sets required to be connected in parallel would be (857 A · h/150 A · h) = 5.71 or 6 (selected). Thus, the battery bank consists of six parallel-connected sets of 59 series-connected battery cells.

Thevenin's model is used to describe the energy storage of the battery in which the parallel combination of capacitance (C_b) and resistance (R_b) in series with internal resistance (R_{in}) and an ideal voltage source of voltage 700 V are used for modeling the battery in which the equivalent capacitance C_b.

C. Selection of Rating of Machine ($PMSG_w$) Side Converter

The maximum active-power flow through the machine- side converter P_{sw} = 55 kW, and the maximum reactive- power flow provided from the machine-side converter (Q_{sw}) is calculated as

$$_2Q_{sw} = V_{msc}/(2\pi f L_m) = 18.4 \text{ kvar} \qquad (2)$$

where V_{msc} is the maximum line voltage generated at the $SCIG_w$ terminals, which is 415 V, at a frequency (f) of 50 Hz generated at a wind speed of 11.2 m/s.

The V A rating (VA_{msc}) of the machine-side converter is calculated as$\sqrt{}_2 VA_{msc} = P_{sw} + Q_2 = 55_2 + 18.4_2$ = 58 kVA, and the$_{sw}$ maximum rms machine-side converter current as

$$\sqrt{} I_{sw} = VA_{msc}/(3V_{msc}) = 80.7 \text{ A}. \qquad (3)$$

The voltage and current ratings of the switching devices (IGBTs) are decided by the maximum voltage across the device and the maximum current through it. In view of (2), the voltage rating of the switching devices is decided by the dc-link voltage, whose maximum value is 750 V. Taking a 25% margin, the voltage rating of the switching devices of the machine-side converter should be more than 1.25 ∗ 750 V, i.e., 937.5 V. The maximum current through the switching device is $1.25\{I_{r(p-p)msc} + I_{(peak)msc}\}$[2], where $I_{(peak)msc}$ is the peak line current through the machine-side converter, and $I_{r(p-p)msc}$ is the peak-to-peak ripple current in the machine- side converter, and 1.25 is the safety margin taken for design. For design purpose, the ripple in the machine-side converter current is assumed to be 5% of $I_{(peak)msc}$.

D. Selection of Rating of Load-Side Converter

The rating of the load-side converter is determined by the case when the connected load is at its maximum value, i.e., 90 kW at 0.8 lagging PF. The reactive power of the load is supplied by the load-side converter. Hence, the reactive-power flow through load-side converter (Q_{lsc}) is equal to the reactive-power demand of the load (Q_L). At a load of 90 kW at 0.8 lagging power factor, $Q_{lsc} = Q_L = (90/0.8) * 0.6 = 67.5$ kvar.

For the design purpose, safety margin is taken as 1.25. Thus, the maximum current through the switching device = 1.25 ∗ (11.1 + 221.3) = 290.5 A. In view of (24), the voltage rating of the switching devices is decided by the dc-link voltage, whose maximum value is 750 V. Taking a 25% margin, the voltage rating of the switching devices of the load-side converter should be more than 1.25 ∗750 V, i.e., 937.5 V. From the previous calculation, the maximum voltage across the device may be 937.5 V, and the current through the device may be 290.5 A. The commercially available rating for switching device (IGBT) higher than 937.5 V and 290.5 A is 1200 V and 300 A, respectively. Therefore, the rating of the switching devices (IGBTs) of the load-side converter is decided to be 1200 V and 300 A.

IV. MATLAB-BASED MODELING

A simulation model is developed in MATLAB using Simulink and Sim Power System set toolboxes. The simulation is carried out on MATLAB version 7 with ode3 solver. The electrical system is simulated using Sim Power System. The different loads are modelled using resistive and inductive elements and diode-rectifier-fed resistive loads combined with an LC filter. The unbalanced load is modelled using breakers in individual phases. The developed MATLAB 2009 model for the wind-hydro hybrid system is shown in Fig. 2.

V. RESULTS AND DISCUSSION

The performance of the wind-hydro hybrid system with the proposed control algorithm is demonstrated under different dynamic conditions as shown in Figs.4-8.

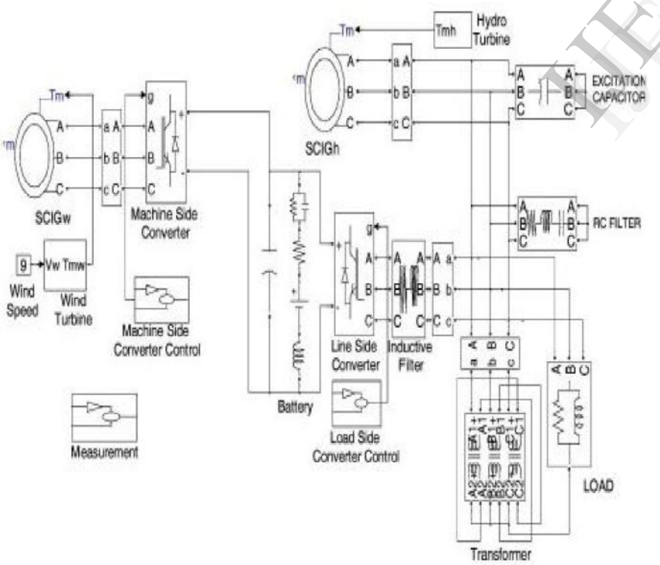

Fig.2. Test system of wind-hydo hybrid system

Moreover, performance of the wind-hydro hybrid system is studied with various electrical loads. Figures 4, 5, 6 shows the voltage, current and power profiles across the wind, hydro and load. Figure 4 shows voltage profile across wind, hydro and load. Voltage across the wind is 0.98pu (410V). Voltage across is 0.98pu (410V) and voltage across load is 0.97pu (408V).

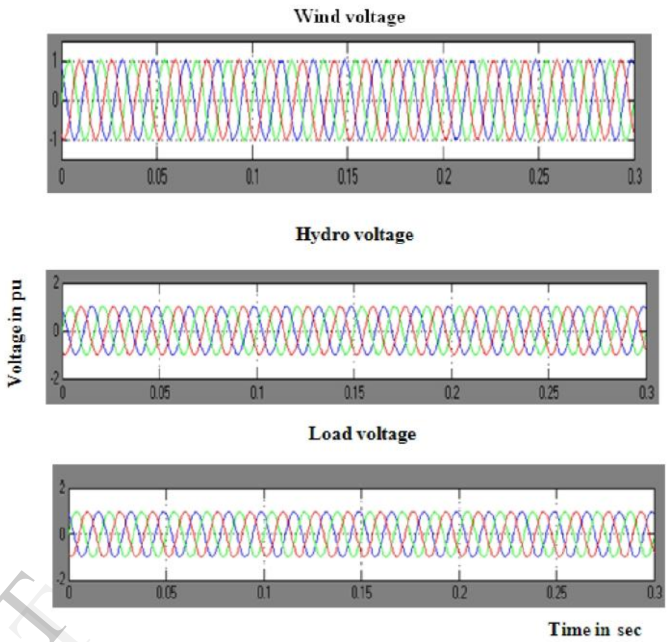

Fig.3. Voltage profile across wind, hydro and load

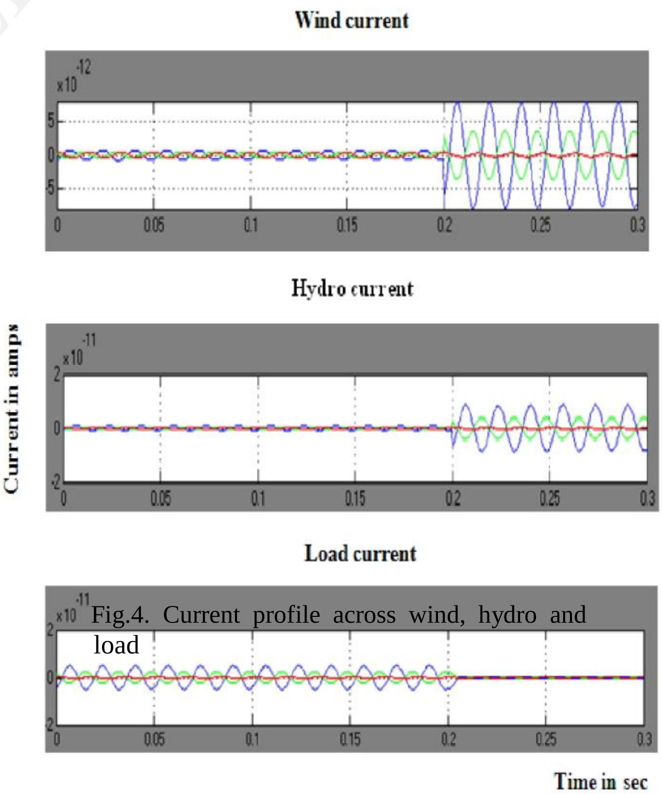

Fig.4. Current profile across wind, hydro and load

The performance of the wind-hydro hybrid system with the proposed control algorithm is demonstrated under different dynamic conditions as shown in Figs.4-8. Moreover, performance of the wind-hydro hybrid system is studied with various electrical loads. Figures 4, 5, 6 shows the voltage, current and power profiles across the wind, hydro and load. Figure 4 shows voltage profile across wind, hydro and load. Voltage across the wind is 0.98pu (410V). Voltage across is 0.98pu (410V) and voltage across load is 0.97pu (408V).

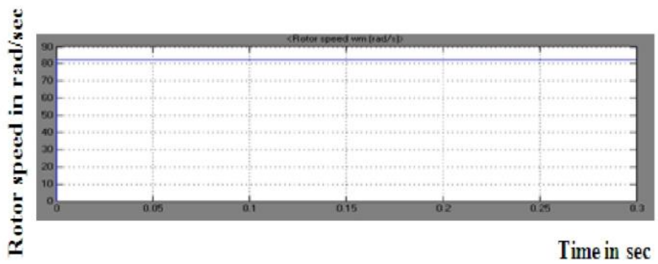

Fig.5. Rotor speed of PMSG motor

Figure 4 shows current profile across the wind,hydro and load. Wind current is initially $0.05*10^{-12}$ after 0.2 sec it will reduced to $5*10^{-12}$ Amps. Hydro current is initially $0.01*10^{-11}$ after 0.2 sec it will reduced to $1*10^{-11}$ amps. Load current is $0.5*10^{-11}$ rise up to $0.1*10^{-12}$ amps.

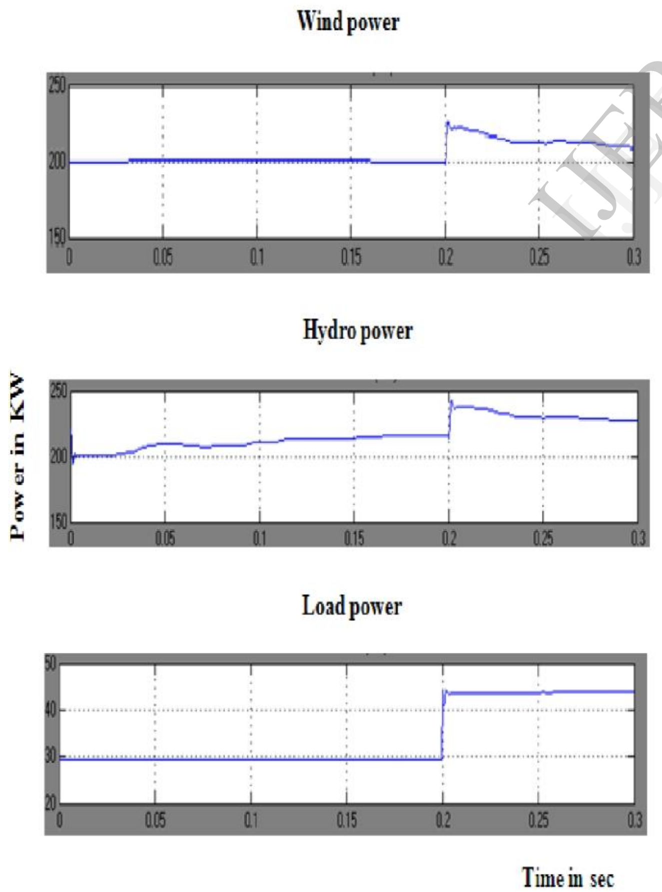

Fig.6. Power profile across wind, hydro and load

Figure 6 shows power profile of the wind,hydro and load. The power of the wind is initially varied from 200KW and after 0.2 seconds it will rise up to to 220KW. The hydro power is initially 200KW after 0.2 seconds it will rise up to 240KW and the load power is 45KW. Figure 7 shows electromagnetic torque of PMSG.

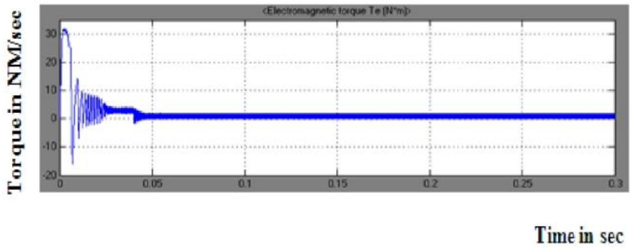

Figure 7 Electromagnetic torque

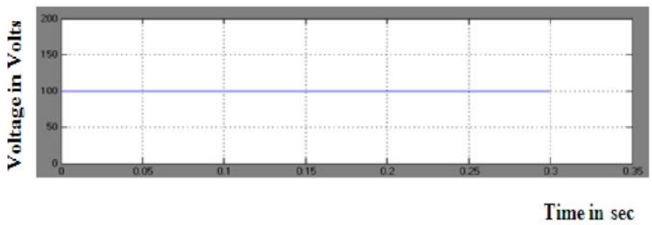

Figure 8. Voltage across the battery

Figure 8 shows the voltage across the battery. The dc voltage across the battery is 100V. Figure 9 shows the frequency across the load. The load frequency is 50Hz.

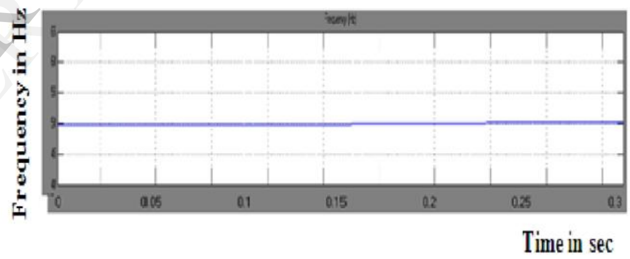

Figure 9 Frequency across load

VI.CONCLUSION

Among the renewable energy sources, hydro and wind energy have the ability to complement each other. Further, there are many isolated locations which cannot be connected to the grid and where the wind potential and hydro potential exist simultaneously. For such locations, a new three-phase four wire autonomous wind-hydro hybrid system, using one PMSG driven by wind turbine and another PMSG driven by hydro turbine along with BESS, has been modelled and simulated in MATLAB using Simulink and Sim Power System tool boxes. The design procedure for selection of various components has been demonstrated for the proposed hybrid system. The performance of the proposed hybrid system has been demonstrated with balanced/unbalanced non linear load, and with linear load under varying wind speed conditions.

It has been demonstrated that the proposed hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency. Moreover, the performance of the proposed system is presented to demonstrate its voltage and frequency control, neutral-current compensation, harmonics elimination, and load balancing.

REFERENCES

[1] Alejandro Rolan, Alvaro Luna, Gerardo Vazquez, and Daniel Aguilar. (2009) 'Modelling of a Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator', IEEE International Symposium on Industrial Electronics Seoul Olympic Parktel, Seoul, Korea,Vol. 6, No.4, pp. 434-442.

[2] Castronuovo, E.D. and Pecas, J. A. (2004) 'Bounding Active Power Generation of a Wind-Hydro Power Plant', in Proceeding, 8th Conference, Probabilistic Methods Application, Power System, AMES, IA,Vol.7, No.8, pp. 705–710.

[3] Murthy, S. S. Singh, B. Goel, P. K. and Tiwari, S. K. (2007) 'A Comparative Study of Fixed Speed and Variable Speed Wind Energy Conversion Systems Feeding the Grid', in Proceeding, IEEE PEDS, Vol.13,No.5, pp. 736–743.

[4] Rajveer Mittal, Sandu, K.S. and Jain, D.K. (2009) 'Isolated Operation of Variable Speed Driven PMSG for Wind Energy Conversion System', IACSIT International Journal of Engineering and Technology Vol. 1, No.3, ISSN: 1793-8236.

[5] Singh, B. and Kasal, G. K. (2008) 'Voltage and Frequency Controller for a Three-Phase Four-Wire Autonomous Wind Energy Conversion System', IEEE Transaction Energy Conversion., Vol. 23, No. 2, pp. 505–518.

[6] Tamas.L and Szekely,Z. (2008) 'Modeling and Simulation of an Induction Drive with Application to a Small Wind Turbine Generator',in Proceeding. IEEE International Conference. Automobile Quality Test. Robot, May 22–25, pp. 429–433.

[7] Yang, T.C. (2008) 'Initial Study of using Rechargeable Batteries in Wind Power Generation with Variable Speed Induction Generators', IET Renewable Power Generation., Vol. 2, No. 2, pp. 89–101.