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MPT BASED AUTONOMOUS WIND HYDRO HYBRID SYSTEM USING SCIG AND DFIG

Hinduja D[1], Balaji G (Asst.Professor)[2]
[1,2]Department of EEE, PAAVAI Engineering College, Namakkal, India

***Abstract* -** A new isolated wind hydro hybrid generation system, employing a DFIG driven by a variable speed wind turbine and a SCIG driven by a constant power hydro turbine are feeding three phase four wire local loads. The system mainly uses a rectifier and a PWM controlled IGBT based VSC with a BESS at their DC link. The main objective of the rectifier is to convert the AC power generated by the wind system to DC and the control algorithm for the VSC is to control the magnitude and the frequency of the system load voltage. This system has the capability of bidirectional active and reactive power flow, by which it controls the magnitude and the frequency of the load voltage. Here pitch angle control is used to achieve MPT. Wind turbine, hydro turbine, MPT controller, and a voltage and frequency controller are modeled and simulated in MATLAB and different aspects of the proposed system are studied for various types of loads, and under varying wind speed conditions. The performance of the proposed system is presented to demonstrate its capability of MPT, voltage and frequency control, harmonic elimination, and load balancing using MATLAB Simulink.

***Index Terms* -** Double Fed Induction Generator (DFIG), Squirrel Cage Induction Motor (SCIG), Maximum Power Tracking (MPT), Battery Energy Storage System (BESS), Voltage Source Converter (VSC), Insulated Gate Bipolar Transistor (IGBT), Pulse Width Modulation (PWM)

I. INTRODUCTION

The combination of different but complementary energy generation systems based on renewable energies or mixed is known as hybrid system. The conventional energy sources are limited and have pollution to the environment. For this reason more attention has been paid to the utilization of renewable energy sources. Wind energy is the fastest growing and most promising renewable energy source. During last two decades, the high penetration of wind turbines in the power system has been closely related to the advancement of the wind turbine technology and the controlling technology/methodology.

Systems with hydroelectric generation can use the free stored hydro energy in the system reservoirs to meet demand, thus avoiding fuel expenses with thermal units. Hybrid power systems are designed for the generation and use of electrical power. They are independent of a large, centralized electricity grid and incorporate more than one type of power source. 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 (i.e., discharge).

The water powers a turbine, and its rotational movement is transferred through a shaft to an electric generator. When SCIG is used for small or micro hydro applications, its reactive power requirement is met by a capacitor bank at its stator terminals. The SCIG has advantages like being simple, low cost, rugged, maintenance free, absence of dc, brushless, etc., as compared with the conventional synchronous generator for hydro applications.

In the case of grid connected systems using renewable energy sources, the total active power can be fed to the grid. For standalone 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. In the case of standalone or autonomous systems, the issues of Voltage and Frequency Control (VFC) are very important. The issues of VFC for standalone systems using SCIGs are well known. Some work has also been reported for standalone WECSs using doubly fed induction generator. A battery based controller is proposed for control of voltage and frequency in the isolated wind energy conversion systems. However, Maximum Power Tracking (MPT) could not be realized in this battery based isolated system employing SCIG operated at fixed speed. There is a load controller for VFC at the stator terminals, and the controller transfers excess power from the hydropower generator to a dump load, whenever the load is less than the generated power.

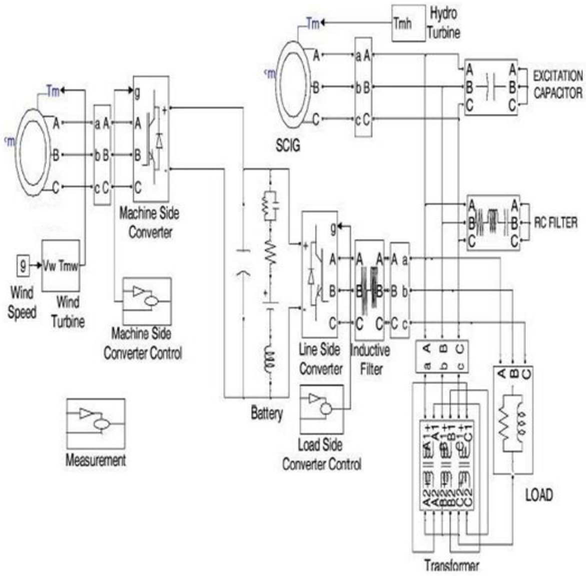

Fig.1. Schematic diagram of wind hydro hybrid system

In this paper, a new three phase four wire autonomous (or isolated) wind hydro hybrid system is proposed for isolated locations where the wind potential and hydro potential exist simultaneously. One such location in India is the Andaman and Nicobar group of islands. The proposed system utilizes variable speed Wind turbine driven DFIG and a constant speed/constant power small hydro turbine driven SCIG. Two back to back connected PWM controlled IGBTs based VSCs are connected between the stator windings of DFIG and the stator windings of the SCIG to facilitate bidirectional power flow. The stator windings of the SCIG are connected to the load terminals. The two VSCs can be called as the machine side converter and the load side converter.

The system employs a 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.

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. 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 side converter are to provide the requisite magnetizing current to the DFIG and to achieve MPT. In the conventional control of variable speed DFIGs, the objective of the load side converter 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 SCIG 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 and the sensed stator currents of SCIG 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 SCIG 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 SCIG. 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 this 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 SCIG, and the excess power generated by the SCIG is transferred to the BESS through the load side converter. Moreover, the power generated by the DFIG is transferred to the BESS. In the second mode, the required active power of the load is more than the power generated by the SCIG but less than the total power generated by DFIG and SCIG. Thus, portion of the power generated by DFIG 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 DFIG and SCIG. Thus, the deficit power is supplied by the BESS, and the power generated by DFIG and the deficit met by BESS are supplied to the load through the load side converter.

II. PRINCIPLE OF OPERATION

To achieve MPT, the DFIG is required to be operated at optimal tip speed ratio. The tip speed ratio determines the DFIG rotor speed set point for a given wind speed. Speed and the mechanical power generated at this speed lies on the maximum power line of the turbine. The operating principle of the controller for the machine side converter is based on the decoupled control of d and q axes stator currents of the DFIG with the d axis aligned to rotor flux axis. The reference value for the d axis or reactive component of the stator current is generated from the required magnetizing flux for the DFIG. The reference value for the q axis or active component of the stator current is generated from error of the desired speed which is shown in Fig 2.

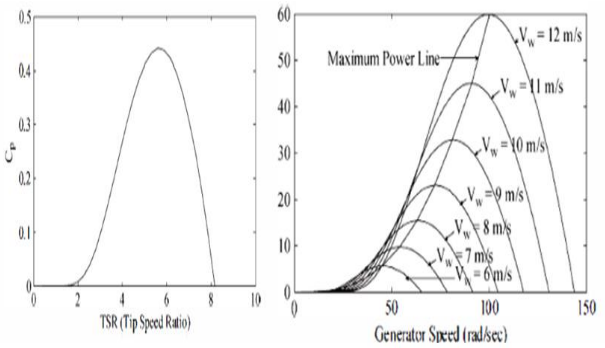

Fig.2. MPT of wind power

As the wind speed varies, the rotor speed set point changes, and the difference in the reference rotor speed and the sensed rotor speed is fed to the controller for the machine side converter, also referred to as the speed controller. The output of the speed controller gives the reference q axis stator current for DFIG. The reference d-q stator currents are transformed to the reference three phase stator currents and compared with the sensed three phase stator currents to generate control signals for the machine side converter.

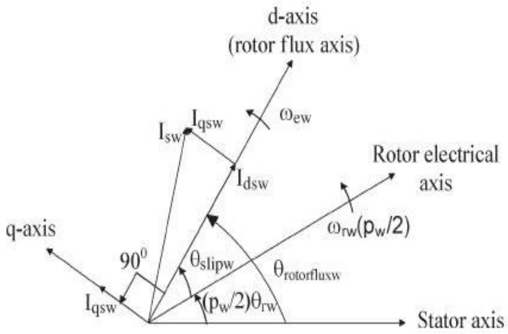

Fig.3. Phasor Diagram

Further, for maintaining the load frequency constant, it is also essential that any surplus active power in the system is diverted to the battery. Alternatively, the battery system should be able to supply any deficit in the generated power. Similarly, the magnitude of the load voltage is maintained constant in the system by balancing the reactive power requirement of the load through the load side converter.

III. DESIGN OF 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 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 SCIG, DFIG, battery voltage, battery capacity, machine side converter, load side converter, specifications of wind turbine, and gear ratio.
The hybrid system being considered has a wind turbine of 55 kW and a hydro turbine of 35 kW. Both turbines are coupled. The rating of the DFIG is equal to the rating of the wind turbine, which is 55 kW. The rating of the SCIG should be equal to the rating of the hydro turbine, which is 35 kW.
The dc bus voltage (Vdc) must be more than the peak of the line voltage for satisfactory PWM control as Vdc>2*2(2/3)Vac where m is the modulation index normally with a maximum value of one and Vac 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; the constraint on dc bus voltage is from the ac voltages of both converters. The maximum rms value of the line voltage at DFIG terminals as well as the rms value of the line voltage at the load terminals is 415 V. Substituting this value, Vdc should be more than 677.7 V. Thus Vdc selected as 700 V, considering the ability of the 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 kWh.

The commercially available battery bank consists of cells of 12V. 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 Ah, and the total ampere hour required is (600 kWh/700 V) = 857 Ah, the number of such sets required to be connected in parallel would be (857 Ah/150 Ah) = 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.

IV. CONTROL ALGORITHM

The objectives of the machine side converter are to achieve MPT and to provide the required magnetizing current to the DFIG, and the objective of the load side converter is to control the magnitude and the frequency of the load voltage. The detailed control algorithm for the two converters is described in the following sections.

Control of Machine Side Converter

The objectives of the machine side converter are to achieve optimum torque for MPT and to provide the required magnetizing current to the DFIG. *The control strategy for the machine side converter control explained below:* Speed Control Loop for MPT and Reference q axis Stator Current Generation: In the proposed algorithm, the rotor position (θ_{rw}) and the wind speed are sensed. The rotor speed (ω_{rw}) is determined from its rotor position (θ_{rw}). The tip speed ratio (λ_w) for a wind turbine of radius rw and gear ratio ηw at a wind speed of V_w is defined as

$$\lambda_w = (\omega_{rw}\, r_w)/\, \eta_w V_w$$

For MPT in the wind turbine generator system, the DFIG should operate at the optimum tip speed ratio (λ^*_w). Thus, the reference rotor speed (ω^*_{rw}) for MPT is generated as

$$\omega^*_{rw} = \lambda^*_w\, \eta_w V_w / r_w$$

Control of Load Side Converter

The objectives of the load side converter are to maintain rated voltage and frequency at the load terminals irrespective of connected load. The power balance in the system is maintained by diverting the surplus power generated to the battery or by supplying power from the battery in case of deficit between generated power and load requirement. Similarly, the required reactive power for the load is supplied by the load side converter to maintain constant value of the load voltage.

Pitch Angle Control

The pitch angle reference, θ_{ref}, is controlled by three values, they are:

Wind speed: Ideally, the pitch angle reference can be obtained from the curve of the pitch angle versus wind speed. This control strategy is simple as the wind speed is directly measured. However, this is not an appropriate procedure, since it is not possible to measure the wind speed precisely.

Generator rotor speed:The controlling rotor speed is compared with its reference. The error signal is then sent to the PI controller and produces the reference value of the pitch angle.

Generator power: The error signal of the generator power is sent to a PI controller. The PI controller produces the reference pitch angle. Here the pitch angle reference is controlled by the input value, generator power. Reference power and generated power is compared and the error signal is given to the PI controller. The output of the PI controller produces reference pitch angle.For high wind speeds the extracted wind power has to be limited via blade pitching. This is realized by means of a speed controller, regulating the speed $\omega_{gen,meas}$ to its rated value $\omega_{gen,rated}$. The speed is controlled by a PI controller, which outputs a reference pitch signal θ_{ref} to the pitch system. In order to get a realistic response in the pitch angle control system, the servomechanism model accounts for a servo time constant T_{Servo} and the limitation of both the pitch angle (0 to 30 deg) and its gradient (± 10 deg/s). The reference pitch angle θ_{ref} is compared to the actual pitch angle θ and then the erro r is corrected by the servo mechanism.

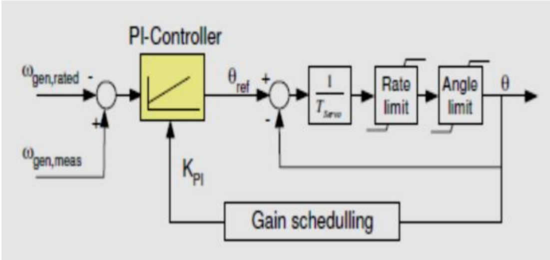

Fig.4. Pitch Angle Control Model

The blade angle control is thus only active, if the speed exceeds rated speed. Since speed and power are coupled via the MPT, this implies indirectly that the power is limited to its rated value, too. Furthermore, a gain scheduling control of the pitch angle is implemented in order to compensate for the existing non linear aerodynamic characteristics. The aerodynamic sensitivity dP/dθ of the system depends on the operating conditions (the set point power value, the wind speed or the pitch angle). The total gain of the system in the speed control loop K_{system}, can be expressed as a proportional gain K_{PI} in the PI controller times the aerodynamic sensitivity of the system dP/dθ.

$$K_{system} = K_{PI}\, dP/d\theta = K_{basis}\, [dP/d\theta]^{-1}\, dP/d\theta$$

The sensitivity function can be approximated to increase linear with the pitch angle. Thus, the more sensitive the system is, which is at higher wind speeds and so at larger pitch angles, the smaller the gain for the controller should be and vice versa. The total gain of the system K_{system} is thus kept constant by changing K_{PI} in such a way that it counteracts the variation of the aerodynamic sensitivity dP/dθ by the reciprocal sensitivity function.

$$K_{PI} = K_{basis}\, [dP/d\theta]^{-1}$$

K_{basis} is the constant designed proportional gain of the PI controller. The control parameters are found by means of the Ziegler Nichols method. However, the parameters can also be determined analytically, as it is carried out in.

V. 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 MATLAB 7.11 (Release 2010b). The developed MATLAB model for the wind hydro hybrid system is shown in Fig.4. The design procedure for selection of various components has been explained for the hybrid system. It has been explained that the hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency. Moreover, it has shown the capability of MPT, neutral current compensation, harmonics limitation, and load balancing.

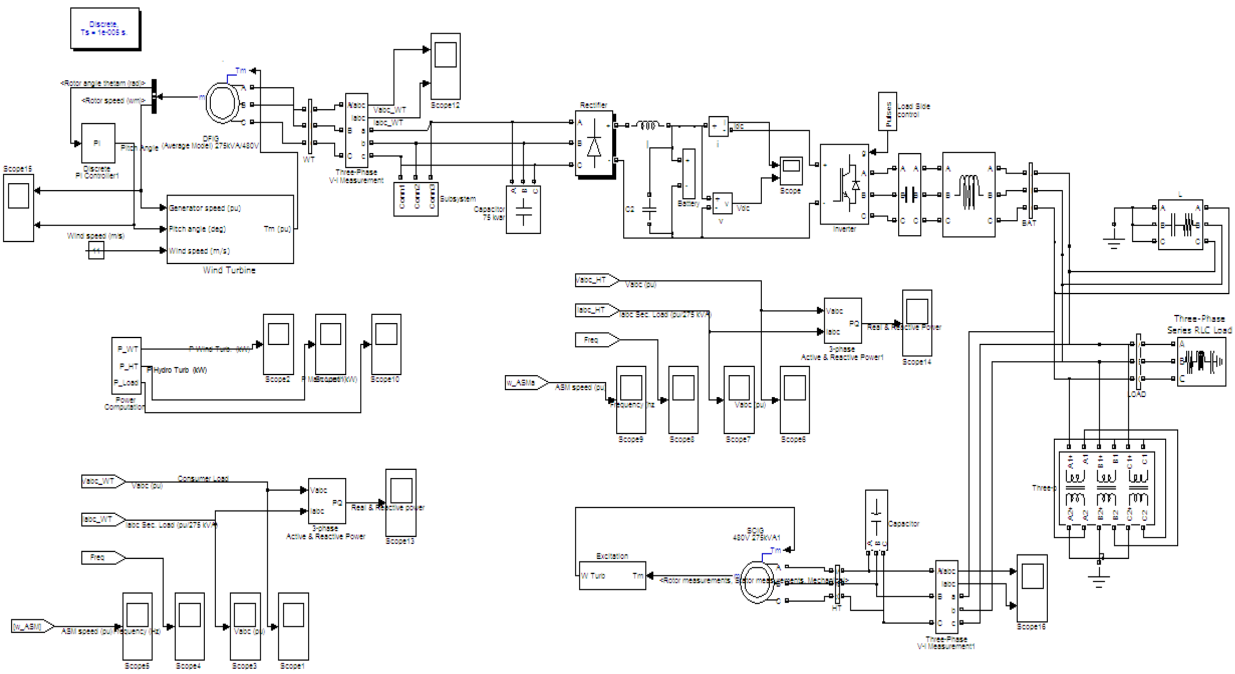

Fig.5. Wind hydro hybrid system

VI. RESULTS AND DISCUSSION

The performance of wind hydro hybrid system has been discussed from the following diagrams. The power generated by the wind turbine and hydro turbine are supplied to the load. Moreover, the power fluctuation is transferred to or from the BESS. The output voltage and current are obtained as sinusoidal because the peak oscillations are reduced with the help of PI controller and thus the magnitude of voltage and current has controlled. The output voltage and current waveforms are obtained under 1000Ω resistive load which are shown below.

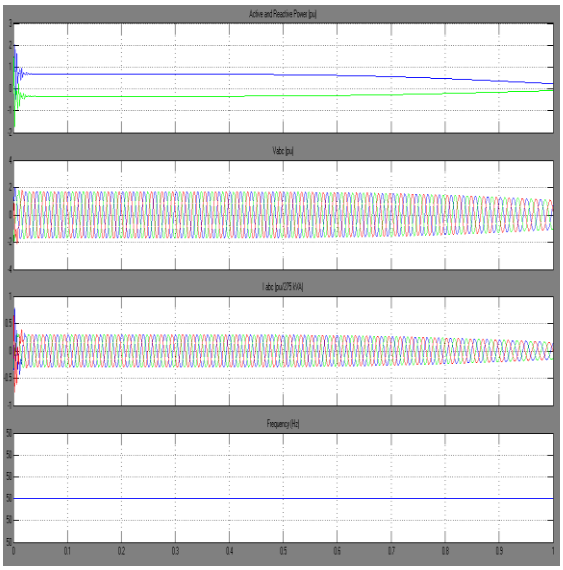

Fig.6. Outputs of wind system

While considering the active and reactive power of the wind energy conversion system, the active power output in positive quantity where the reactive power in negative quantity. The frequency of the wind plant is maintained with nominal frequency (50Hz) to connect the system with the power grid. The proposed control strategy can make the wind generator to supply maximum power to the grid and also supply the necessary reactive power to maintain the terminal voltage of the grid constant.

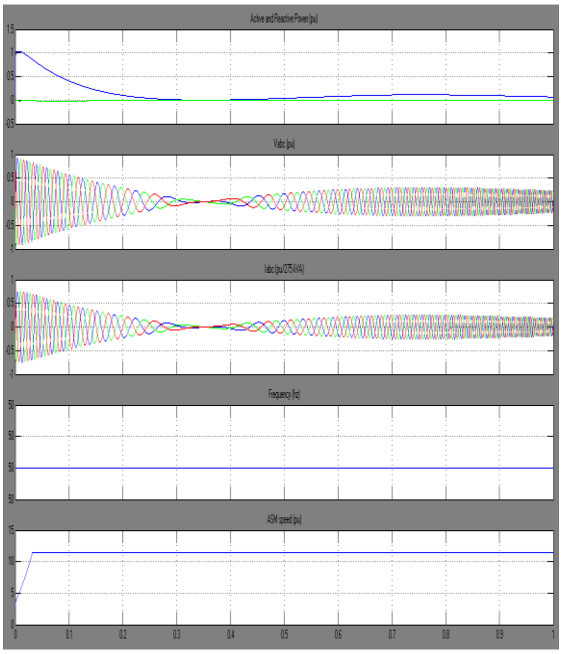

Fig.7. Outputs of Hydro System

The Hydro power is useful to overcome the power demand which cannot be fulfilled by the wind power plant when the wind source is not available. The power generated by the system is more than the required active power for the electrical loads; the battery is absorbing the excess power to maintain the frequency of the load voltage in constant value. Further the reactive power required by the load is also supplied by the load side converter to maintain the magnitude of the load voltage constant. Thus, under these conditions, both the magnitude and the frequency of the load voltage are maintained constant value. The power generated by the system is less than the required power for the electrical loads; the battery is supplying the deficit power. Therefore, the battery power (discharging) is decreased to maintain the load constant.

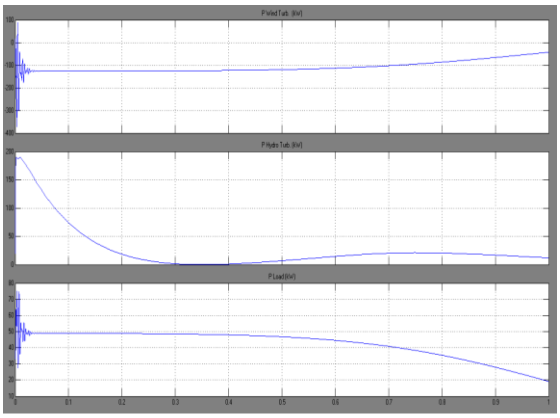

Fig.7. Power outputs

VII. CONCLUSION AND FUTURE SCOPE

Among the renewable energy sources, small 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 generator driven by wind turbine and another generator driven by hydro turbine along with BESS, has been modeled and simulated in MATLAB using Simulink. The design procedure for selection of various components has been explained for the proposed hybrid system. The performance of the proposed hybrid system produced with better efficiency with PI controller which is used to obtain maximum power from the WECS. Moreover it shows the capability of harmonic elimination. Furthermore, the same problem will be taken for the future work to get good system efficiency with only one controller in operation to meet the future demand.

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