Isolated Wind–Hydro Hybrid System using Permanent Magnet Synchronous Generators and Battery Storage with Fuzzy Logic Controller

C.F.Nicy[1],R.Punitharaji[2],G.Balaji [3]
[1]Student , [2]Assistant Professor, [3]Associate Professor
[1]PG scholar in Power Systems Engineering, Paavai Engineering college, Namakkal, TN, INDIA
[2]Assistant professor, EEE Department, Paavai Engineering College, Namakkal,TN, INDIA
[3]Associate Professor, EEE Department, Paavai Engineering College, Namakkal, TN, INDIA
[1]nicyfrancis99@gmail.com , [2]neethuraji@gmail.com, [3]balajimythili@gmail.com

***Abstract*- This paper deals with a new isolated wind–hydro hybrid generation system employing one permanent magnet synchronous generator driven by a variable speed wind turbine and another permanent magnet synchronous generator 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 controlled insulated-gate-bipolar-transistor-based voltage-source converters with a battery energy storage system at their dc link. The main objective of the control algorithm for the voltage source converters is to achieve better efficiency of the hybrid system using fuzzy logic controller. The proposed wind-hydro hybrid system has a capability of controlling the magnitude and the frequency of the load voltage. The proposed electromechanical system and a voltage and frequency controller are modeled and simulated in MATLAB using Simulink and Sim Power System set toolboxes at different aspects of the proposed system are studied .It also has the capability of harmonic elimination and reduction of peak oscillations of output voltage and current.**

***Index Terms*— Battery energy storage system (BESS), small hydro, Wind Energy Conversion System (WECS), Squirrel Cage Induction Generator (SCIG).Permanent Magnet Synchronous Generator(PMSG)**

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. Renewable energy sources are the natural energy resources that are inexhaustible, for example, wind, solar, geothermal, biomass, and small hydro generation [2]. Among the renewable energy sources, small hydro and wind energy have the ability to complement each other [3]. 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 way of how to control. The viability of isolated systems using renewable energy sources depends largely on regulations and stimulation measures.

For power generation by small or micro hydro as well as wind systems, the use of squirrel-cage induction generators (SCIGs) has been reported in literature [4]–[19].Although the potential for small hydroelectric systems depends on the availability of suitable water flow, where the source exists, it can provide cheap clean reliable electricity. Hydroelectric plants convert the kinetic energy of a water fall 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.

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 [12].

The grid-connected variable-speed wind-energy-conversion system (WECS) based on PMSG uses back-to-back connected power converters [13], [15].In such system the power converters 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 standalonesystems 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 [19]–[23].

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 side converter and load-side converter. The objectives of the machine 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 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.

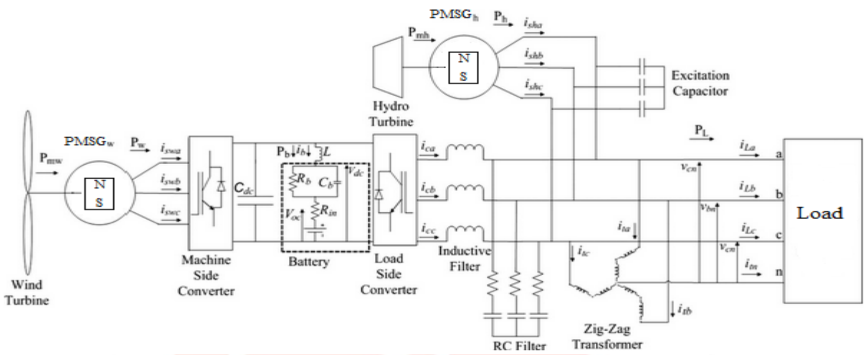

Figure.1. Wind Hydro Hybrid System

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

The development of new hydropower projects as well as the modernization of existing plants, while still significant, has been under increasing pressure for a variety of financial, environmental, social, and regulatory reasons. However, hydropower's role in integrating other renewable energy sources,especially wind energy, has the potential to grow both in extent and importance. While fluctuating power levels and transmission constraints have hampered ready adoption of wind energy to the utility grids worldwide, fluctuating water levels, growing pressures on water supplies, the need for flood controls, and environmental issues are just a few of the constraints that may limit future growth of hydroelectric production.

Hydropower provides unique benefits rarely found in other sources of energy. These benefits can be attributed to the electricity itself or to side-benefits, often associated with reservoir development. Fuzzy systems become popular because it implements human reasoning that can be programmed into fuzzy logic language i.e. membership but designing a fuzzy system is not an easy task because the good performance of fuzzy system depends upon the accuracy of membership function and rules.

Determining appropriate membership functions and rules are major constraints in fuzzy systems for adaptive Neuro - based fuzzy inference system.

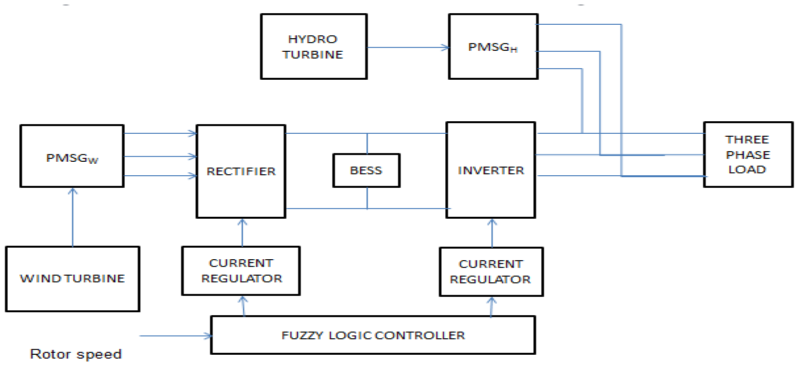

Figure.2. Block Diagram of Proposed System

A. Wind Turbine

The turbines can only operate within a very narrow speed range above the synchronous speed, and this requires the turbine blades to rotate at a nearly constant speed. Control of active power above the rated speed is dealt with by a stall control. A blade pitch control, as applied to variable speed wind turbines, is not used for wind turbines.The turbine is used to convert wind energy into mechanical energy.The simple induction machines used for turbines consume reactive power.

To supply the required reactive power of the induction machine, shunt capacitor banks are installed at the turbine terminals. No other controls are typically used at the turbine level (aside from soft starter during energisation).

B. Battery Energy Storage System

There are a number of battery technologies for storage use on a utility-scale. Lead acid is the dominant battery type, although other batteries—such as sodium sulphur and lithium-ion—are also available. Batteries are electrochemical cells composed of two electrodes separated by an electrolyte. When a battery is discharging, ions from the first electrode (anode) are released into the solution, and oxides are deposited on the second electrode (cathode). To recharge the battery, the electrical charge is reversed, returning the battery to its original condition.

C. Permanent Magnet Synchronous Generator

A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. Synchronous generators are the majority source of commercial electrical energy. They are commonly used to convert the mechanical power output of steam turbines, gas turbines, reciprocating engines, hydro turbines and wind turbines into electrical power for the grid.

In the majority of designs the rotating assembly in the center of the generator the "rotor" contains the magnet, and the "stator" is the stationary armature that is electrically connected to a load. A set of three conductors make up the armature winding in standard utility equipment, constituting three phases of a power circuit—that correspond to the three wires we are accustomed to see on transmission lines. The phases are wound such that they are 120 degrees apart spatially on the stator, providing for a uniform force or torque on the generator rotor. The uniformity of the torque arises because the magnetic fields resulting from the induced currents in the three conductors of the armature winding combine spatially in such a way as to resemble the magnetic field of a single, rotating magnet. This stator magnetic field or "stator field" appears as a steady rotating field and spins at the same frequency as the rotor when the rotor contains a single dipole magnetic field. The two fields move in "synchronicity" and maintain a fixed position relative to each other as they spin.

Permanent magnet generators do not require a DC supply for the excitation circuit, nor do they have slipringsand contact brushes. However, large permanent magnets are costly which restricts the economic rating of the machine. The flux density of high performance permanent magnets is limited. The air gap flux is not controllable, so the voltage of the machine cannot be easily regulated. A persistent magnetic field imposes safety issues during assembly, field service or repair. High performance permanent magnets, themselves, have structural and thermal issues. Torque current MMF vectorially combines with the persistent flux of permanent magnets, which leads to higher air-gap flux density and eventually, core saturation. In this permanent magnet alternator the speed is directly proportional to the output voltage of the alternator.

IV. SIMULATION MODEL

The main circuit of Wind Hydro using fuzzy controller have simulated by using MATLAB. MATLAB (Matrix Laboratory) is a numerical system computing environment and fourth generation programming language. Developed by Math Works, MATLAB allows matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran. Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing capabilities.

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 ode 3 solver. The electrical system is simulated using Sim Power System.

Considering the turbine as a black box, its input is wind speed and its output is shaft speed. Since the shaft speed is determined by the control algorithm applied to wind turbines and wind speed .The performance of the wind turbine not only depends on its hardware but also wind turbine control technique impacts on the performance of the wind turbines. Figure 3 shows simulation model of wind hydro hybrid system.

The hybrid system has wind power plant and hydro power plant as subsystems.The output of the subsystems is connected with the grid as shown in figure 3.Figure 4 and Figure 5 shows the simulink blocks of subsytems.

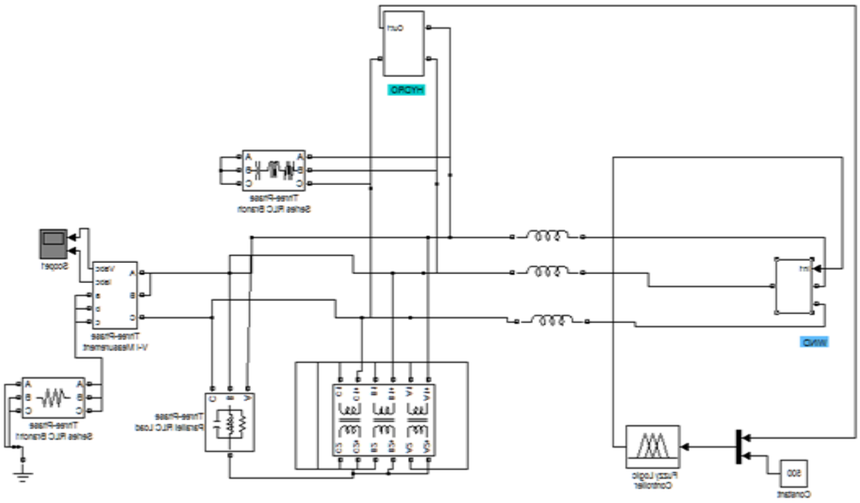

Figure.3.Wind Hydro Hybrid System

A. Wind Power Plant

The wind setup consists of generator,turbine,rectifier and inverter in which dc link and battery enrgy storage in between them.The feed back signal output from the fuzzy logic controller is given as the input to the PWM current regulator which regulates pulses for the gate of IGBT converters of loadside and machineside as shown in figure 4.

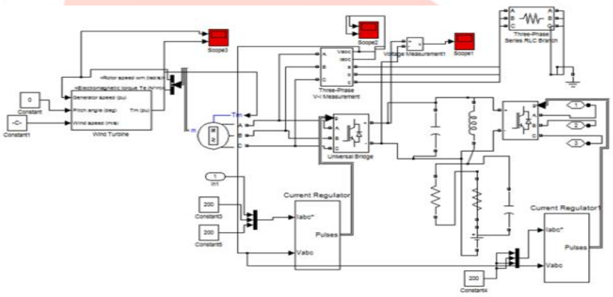

Figure.4. Wind Power Plant Simulink Model

B. Hydro Power Plant

The hydro setup includes generator and turbine and the output of the generator is given to the grid connected to the system.The error speed and the change in speed error(i.e derivative of error speed) is given as the input of the fuzzy controller.The following Figure 5 shows hydro power plant system.

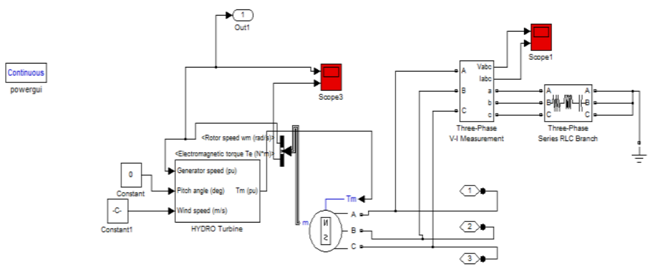

Figure.5. Hydro Power Plant Simulink

V.CONTROL OF HYBRID SYSTEM

A. Design of Fuzzy Controller

Fuzzy logic provides an alternative way to represent linguistic and subjective attributes of the real world in computing. It is able to be applied to control systems and other applications in order to improve the efficiency and simplicity of the design process. Fuzzy logic controller has used in the proposed system for better efficiency and fast response.

Here fuzzy controller is designed with two inputs i.e. generator speed and its derivative and a single output. The advantage of this controller is that it doesn't required detailed information about the system. Mamdani Fuzzy Model is use for the purposed fuzzy controller and "if-Then" rules use for inference engine. There is fuzzy variable corresponding to each controller input and these inputs are fuzzified by using five membership function. Proper membership functions are defined for output variables too. Membership functions for input variables and its derivative are given as Figure 6

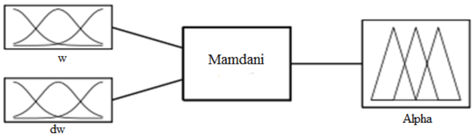

Figure.6. Two input single output FLC

B. Fuzzy Sub Blocks

In order to improve the transient efficiency of power system fuzzy controllers has been designed to regulate the voltage and current. The difference between speed error and its derivative are taken as input for fuzzy adjuster.

The error and change of error are used as numerical value from the real system. Five fuzzy sets i.e. NL (Negative low), NM (Negative Medium), PM (Positive Medium), PL (Positive low), Z(Zero) are chosen to convert this numerical values into linguistic variables. The membership functions of input and output variables of current regulator have been shown in Figure 6.The output of the fuzzy block is given to the current regulator.

The membership functions of input and output variables of current regulator are used to obtain feedback signal for PWM generator. Here we consider five membership functions for accuracy. Thus better efficiency and fast response is obtained for the proposed system.

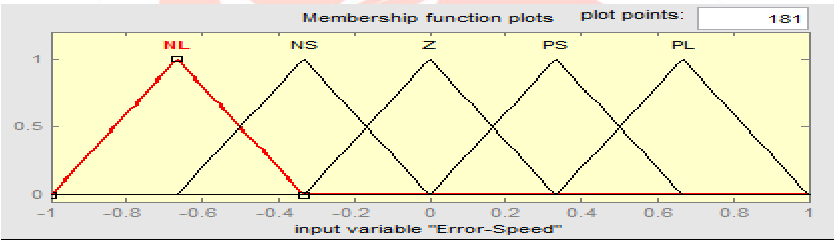

Figure.7. Input variable 1

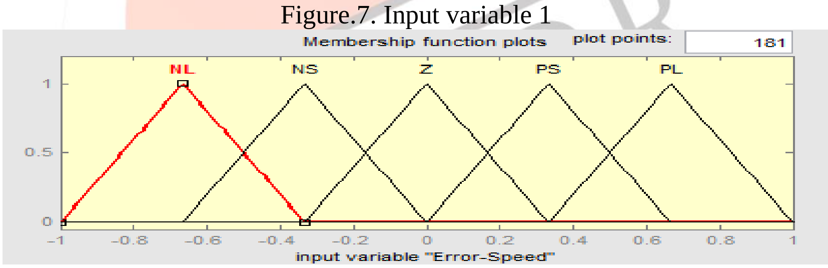

Figure.8. Input Variable 2

VI. RESULTS AND DISCUSSIONS

The performance of wind hydro hybrid system has discussed from the following diagrams. The output voltage and current waveforms obtained under 1000Ω resistive load is shown below. Figure 8 and Figure 9 shows output load voltage and output load current of the proposed system. The peak oscillations are reduced with the help of fuzzy logic controller and thus the magnitude of voltage and current has controlled as shown in figures.

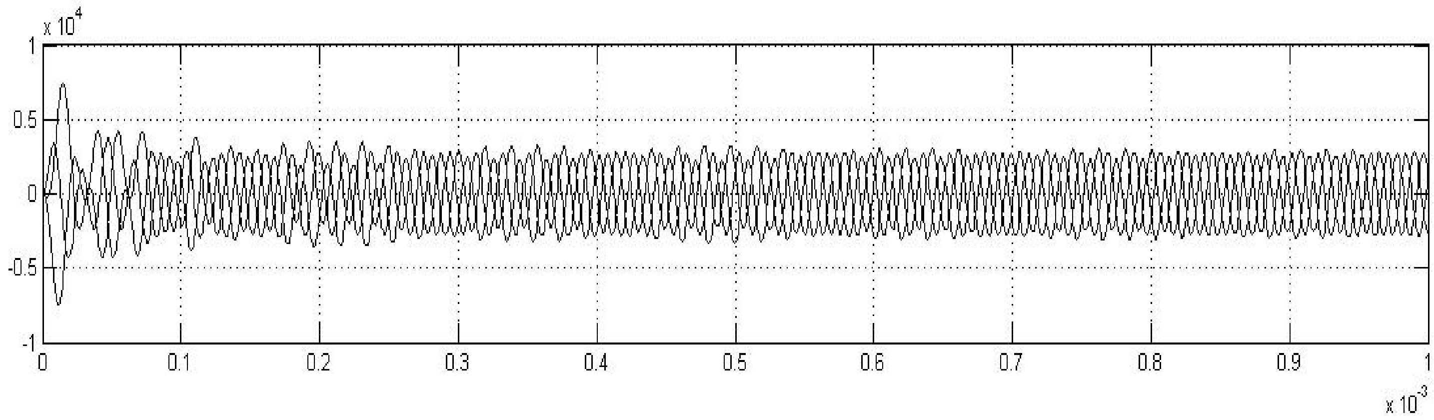

Figure.8. Output Voltage

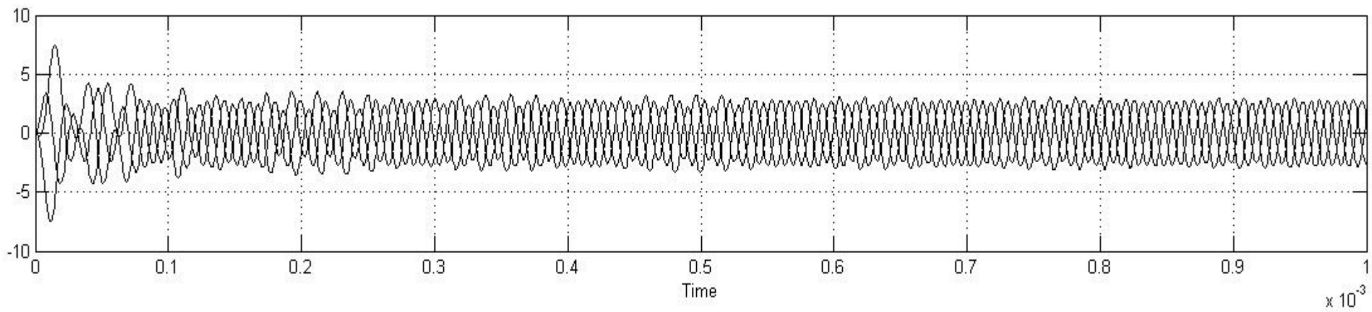

Figure.9. Output Current

The rotor speed and electromagnetic torque waveforms obtained from the hydro power plant generators are shown in figure 10 and figure 11 from which the fuzzy logic controller takes input as error speed and change in error speed.

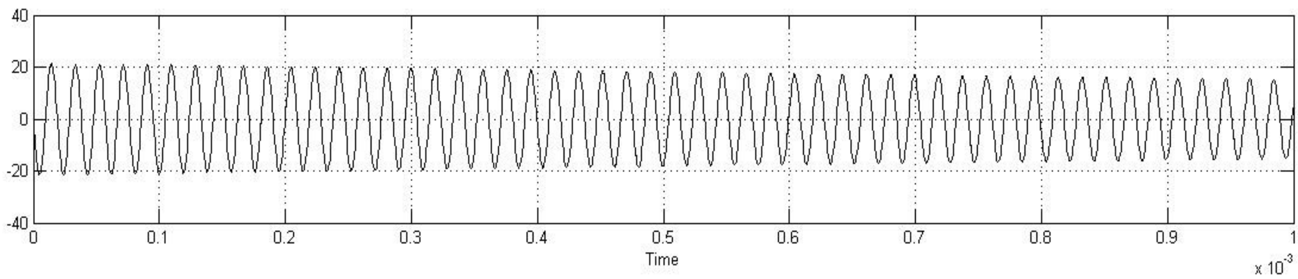

Figure.10. Rotor Speed

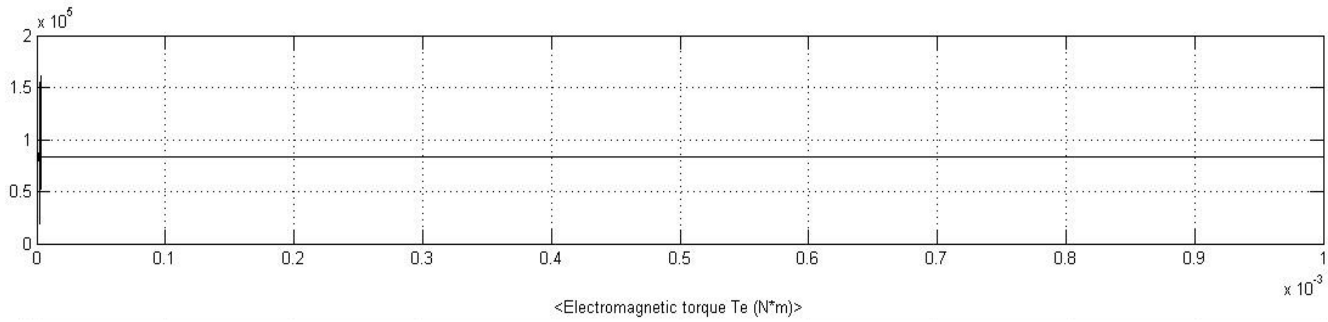

Figure.11. Electromagnetic Torque Output

The wave forms are obtained from hydro power plant as the output voltage and current which is connected with the grid consists of harmonics. Figure 12 and Figure 13 shows the output waveforms obtained from hydro power plant.

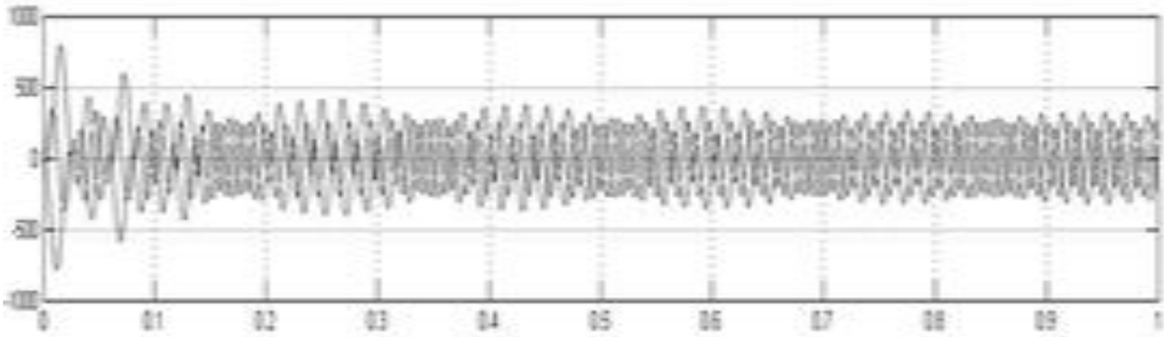

Figure.12. Hydro Plant Voltage

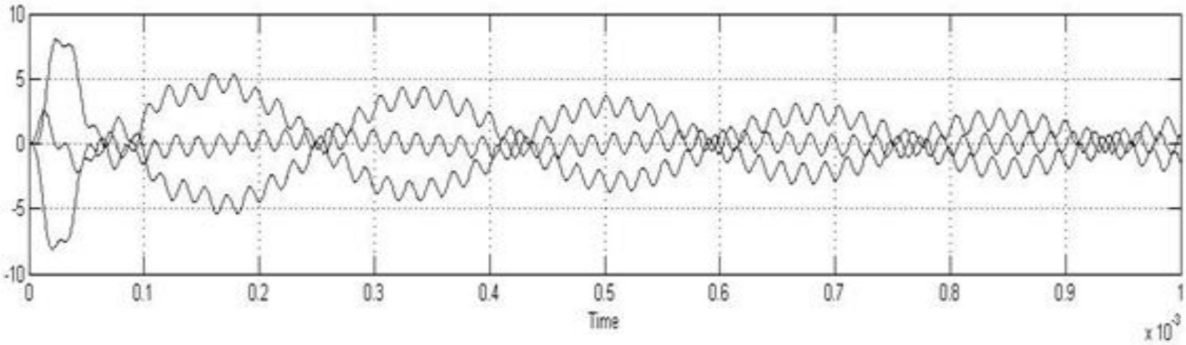

Figure.13. Hydro Plant Current

VII. CONCLUSION

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 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 better efficiency and fast response. Fuzzy logic controller with five membership function is used to obtain fast response and accuracy of the system. Moreover it shows the capability of harmonic elimination.

VIII. REFERENCES

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