Simulation and Control of Pv-Wind-HydroHybrid Renewable Energy System and Possibility in Nepal

Er.Sujan Acharya

ABSTRACT : This paper presents a hybrid renewable energy system consisting of solar photovoltaic, wind energy system and micro hydro system that supplies electricity to isolated locations or remote areas that are far from the grid supply. The solar photovoltaic system is simulated with a power converter, the first one being a DC-DC converter with maximum power point tracking. The Wind power system is designed using Permanent Magnet Synchronous Generator (PMSG). The wind energy system has two power converters, AC-DC and DC-DC converters to obtain smooth and constant DC output to form a DC bus with the photovoltaic system output. The dc output from PV/Wind hybrid system is converted to ac via an inverter.

The micro hydro system is modeled to drive a synchronous generator. A static compensator is proposed to improve the load voltage and current profiles while also mitigating the harmonic contents of the voltage and current. This is achieved with the help of inverter that also generates active and reactive power to fulfill the load demand.

Index terms: Simulation, Hybrid, Renewable, Power, System, Grid,Compensation, Traction, Generation

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CHAPTER 1 INTRODUCTION

1.1.BACKGROUND

Unlike conventional energy sources, non-conventional energy sources are clean, reliable and abundant in then nature. This sort of energy systems cause less pollution, environmental degradation or global warming because of which these renewable energy systems are widely used. The current researches therefore are about harnessing renewable energy sources (RES) for generating electricity and supply power to rural consumers where grid connection is not available. Heavy dependence for energy on biomass resources has accelerated the depletion of natural resources and contributed to the degradation of natural environment. The country spends about 40 percent of its foreign currency reserve on the import of petroleum products. On the other hand, the country's vast resource of renewable hydropower energy remains virtually unexploited. Nepal needs to harness its vast hydropower potential and reduce its dependence on biomass in order to check the further degradation of the environment and reduce country's dependence on fossil fuel based energy. The power so generated can be used for setting up clean energy based industries which will significantly contribute to the economic development of the country.

The electric power consumption (kWh per capita) in Nepal was 90.95 in 2009, according to a World Bank report, published in 2010. The Electric power consumption (kWh per capita) in Nepal was reported at 77.01 in 2008, according to the World Bank. The main renewable energy sources In Nepal are hydropower, wind, solar, biomass and geothermal energy source.

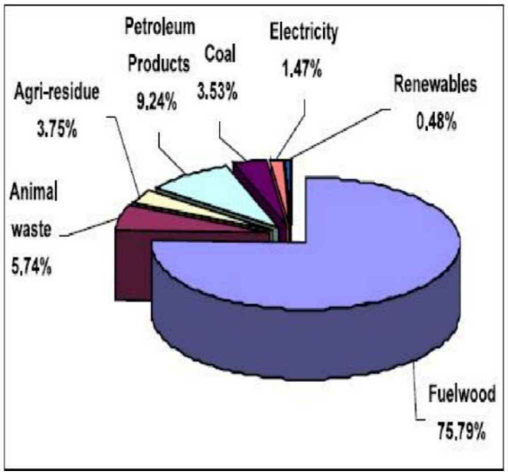


Fig 1.1: Energy Scenario in Nepal

Nepal is the world's second largest country rich in water resources. The geography gives the maximum advantages to install the clean energy source. Nepal has a huge hydropower potential. In fact, the perennial nature of Nepali rivers and the steep gradient of the country's topography provide ideal conditions for the development of some of the world's largest hydroelectric projects in Nepal. Current estimates are that Nepal has approximately 40,000 MW of economically feasible hydropower potential. However, the present situation is that Nepal has developed only approximately 600 MW of hydropower. Besides, the multipurpose, secondary and tertiary benefits have not been realized from the development of its rivers. Although bestowed with tremendous hydropower resources, only about 40% of Nepal's population has access to electricity. Most of the power plants in Nepal are run-of-river type with energy available in excess of the in-country demand during the monsoon season and deficit during the dry season.

The electricity demand in Nepal is increasing by about 7-9% per year. About 40 % of population in Nepal has access to electricity through the grid and off grid system. Nepal's Tenth Five Year Plan (2002–2007) aims to extend the electrification within country and export to India for mutual benefit. The new Hydropower Policy 2001 seeks to promote private sector investment in the sector of hydropower development and aims to expand electrification within the country and export.

The hydropower system in Nepal is dominated by run-of-river projects. There is only one seasonal storage project in the system. There is shortage of power during winter and spill during wet season. The load factor is quite low as the majority of the consumption is dominated by household use. This imbalance has clearly shown the need for storage projects.

Nepal's electricity generation is dominated by hydropower. Although bestowed with tremendous hydropower resources, only about 40% of Nepal's population has access to electricity. Most of the power plants in Nepal are run-of-river type with deficit of energy during the dry season as well as wet season. Hence there is a need of alternate resources to fulfill the deficit energy demand. . Among the current renewable technologies, Photovoltaic (PV) cells are one of the most capable ones. It has the biggest growth rate comparing to other technologies (8.3% per year) and the cost of PV cells per watt is reducing rapidly. As per an estimate by WECS (1995), 78% of the land area of Nepal lies in high potential solar insolation areas. The average solar radiation varies from 3.6 – 6.2 kWh/m /day, and the sun shines for about 300 days in a year.

The development of solar energy technology is thus reasonably favorable in many parts of the country. The output power of a Solar-PV cell is highly dependent on the ambient temperature and the sun irradiance. Also, in a given ambient condition a PV cell can deliver peak power only at a certain operating point. PV units extract power from the sun and it means that, unlike conventional generators, their output power cannot be controlled and increased by the operator. On the other hand, synchronous generators can control their output power using governor and excitation systems to some extent. Now, in a system with low penetration level of PV units this limitation is not important and PV units do not affect the dynamic of the system noticeably. On the other hand, in systems with high penetration level of PV modules this can result in some serious problems. Because PV power plants do not have environmental problems like conventional synchronous generators, they can be installed near the load centers. This helps to reduce the losses and installation and maintenance cost of the system.

1.2.BRIEF DESCRIPTION OF THE PROJECT

The proposed project discusses the possibility of using Hydro-Solar PV-Wind hybrid power system for low-cost electricity production in order to satisfy the energy load requirement of a particular area. With regards to several researches done in the field of hybrid power system, the use of optimum size of such hybrid power system can help to reduce the overall cost of generation without having the need to use a storage system alongside the inverter.

The Wind power system (AC-DC-AC) and PV system, which are complementary in operation with regards to timing, can help to generate active power while they cannot supply the reactive power demanded by the system load. This project is proposed to design a switching pattern of the inverter in such a way that it can convert the solar power into active power and generate reactive power within the inverter. This project also studies the possibility of operating the hydro generator to produce mainly reactive power and share with the PV-Wind system that generates active power. The main idea of the proposed project is to integrate the PV and Wind units into an isolated hydro generating unit.

The layout of the proposed system is presented in the block diagram below:

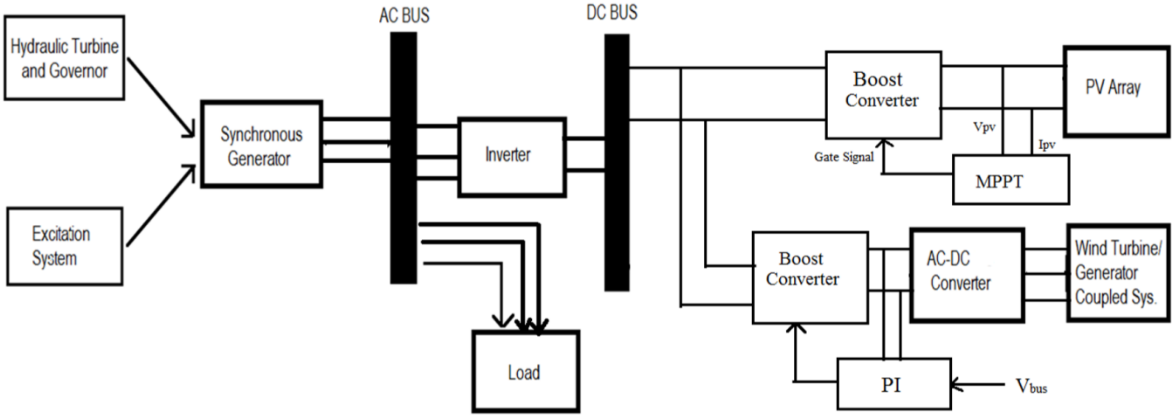


Fig 1.2: Block Diagram of the proposed Hybrid PV-Wind-Hydro System

The above shown block diagram of the proposed scheme under study consists of a PV solar unit, a Wind power system and a hydro unit. The Wind power system is connected to AC-DC converter to form a common DC bus with the PV system. A common inverter is accompanied with the system and a common AC bus is formed together with the hydro unit. The main concern of the project is to make balance between reactive power demand of the load and reactive power generation to maintain the system voltage within the acceptable values.

A MATLAB Simulink program is proposed for modeling the entire system. The simulation is done to incorporate control system for automatic regulation and extraction of required powers from the hybrid system. The conversion of solar energy to useable electrical energy requires several components such as PV array, and DC-toDC Converter (Boost converter). An array of solar cells converts solar energy into a usable amount of DC power. The wind system uses AC-DC converter and forms a common DC bus with the PV system. A 3-phase inverter is designed that converts the DC output power from the common DC bus of the PV-Wind System to AC power, while also generating the reactive power as per the load requirement within the inverter. The voltage is transformed to a suitable level by the converter and inverted to AC by a 3-phase inverter and then injected to the common bus. The reactive power is generated either by the synchronous generator or within the inverter as per the capacity and requirement.

1.3.LITERATURE REVIEWS

An extensive study on several papers, regarding the optimization of renewable energy for power generation and grid connection, published in journals were done.

Diaf et al. [2] proposed a hybrid PV-Wind system in which the AC power form the wind is directly supplied to the load via un-interruptible power supply (UPS). The excess power, if available, is used to charge the battery through an AC/DC converter. The power obtained from the PV is also used in charging the battery via a DC/DC converter. In case of peak load, power is supplied from battery to the load through a DC/ AC converter.

Hashimito et al. [3] discussed stand-alone wind-PV hybrid system with a secondary backup battery that ensures uninterruptable supply of electricity to a radio base station in an island. Their system consists of cylindrical PV modules mounted on wind generator pole to save installation space and cost. Relationship between system idle time and backup battery capacity was studied and battery bank was designed to bring the system idle time to zero.

Sharaf and El-sayed[4] discussed application of wind-PV hybrid system in a micro grid. Their system is consisted of a common DC and common AC collection bus interface. The system employs permanent magnet DC generator to convert the wind kinetic energy into DC power. The power obtained from PV, which is also DC, is connected to common DC bus.

Bakos[5] performed the feasibility study of wind-pumped hydro storage system assisted by diesel generator in case of power shortage. The system is designed as a wind farm which supplies to the load first. Excess energy if available is used for pumping water from lower tank to the higher reservoir so that the excess energy is stored as hydro potential energy. When wind farm is incapable of covering the whole load, the hydro system is called into operation and energy is supplied from both wind and hydro. If further energy deficiency exists, then deficit power is supplied by the diesel generator. The water reservoir acts as an energy storage so it is designed based on energy autonomy days. Monte Carlo analysis considering the linear characteristic of wind energy system and undamaged hydro system has been performed to verify the feasibility.

Bekele and Tedesse[6] suggested a PV-hydro-wind hybrid system which can supply uninterrupted electricity for a village in Ethiopia. HOMER was used to optimize six small hydropower potentials together with wind PV systems. Due to the limitations of HOMER to handle more than one hydro resource at a time, optimization was performed by taking a nominal hydropower with total sum capacity of all small sites. Besides the primary purpose of lighting, they have considered electricity for cooking and running flour mills along with TVs and radio in their load calculation.

Saheb-Koussa et al. [7] presented results of techno-economic analysis of PV/wind/diesel hybrid system. For all the six sites they studied, they found out that stand alone PV is a better solution considering the economic aspects. But there would be deficit during the winter season, and using a hybrid system overcome this effect.

Their study suggested that hybrid system would be

reliable but is not economic.

Fadaeenejad et al. [8] studied PV-wind-battery hybrid and PV-wind-diesel- battery hybrid with aim of rural electrification in Malaysia. For optimization of HRES iHOGA software developed by Dr. Rodolfo, Dufo-Lopez has been used. This study suggested PV-wind-battery hybrid as a better option. In a similar analysis, Goodbodyet al.23 performed the study on integration of renewable energy systems in Ireland. System optimization was carried using HOMER, diurnal and seasonal variation of load was taken into consideration for optimization. This study has also considered space heating in the application of HRES and cost of fuel to do so, but the capital, maintenance or replacement cost is not taken into account due to limitations of HOMER. Ireland has high wind potential so wind energy was found to feature in most of stand-alone or grid connected hybrid systems. Biogas harvesting with large biodigester was suggested to be cost-efficient for large community. Even though some regions simulated contains hydropower in the optimal design, the installation was found to be difficult in those regions because of the geographical constraints.

Akikur et al. [9] carried a study on standalone solar and hybrid systems. Solar-wind hybrid, solar-hydro hybrid, solar-wind-diesel hybrid and solar-wind-dieselhydro/biogas hybrid have been discussed, and viability and significance of solar energy (both in standalone and hybrid form) in global electrification have been shown in this study.

Djamel and Abdallah[10] discussed power quality control of grid connected windsolar hybrid system that employs a battery connected in the common DC bus. Though the system is said to be grid connected much has not been discussed. A fixed speed wind turbine has been employed so power control on high wind speed has been done by stall control. Power control in PV has been done by employing MPPT tracking that uses perturb and observe (P&O) method.

Meshram et al. [11] proposed a hypothetical grid connected solar-hydro hybrid system. As solar energy is abundant in summer, grid connected solar system supplies the power while hydro system is cutoff during operation. Similarly during rainy season when water is abundant, grid connected hydro system is brought in operation and solar system is cut off. During other season the system operates in hybrid mode. The proposed system has 10kW solar capacity and 7.5 kW hydro capacity.11

kV AC line is used to transmit the electricity form production site; it is then connected to 132 kV, 2500 MNA grid line through step down transformer, before supplying to customer supply; it is stepped down to 415 V for household usage.

Ismail et al.[12] performed a feasibility study and techno-economic analysis of a PV system with batteries and micro turbine- micro turbine acting as backup supply in the system. Component sizing and optimization have been performed by iterative method to minimize cost of energy (COE) production. Comparison of standalone PV, micro turbine and hybrid system is also performed in this study. The study found that COE of standalone micro turbine was cheaper with very small difference. Sensitivity analysis of the system has also been performed by considering project life time, cost of natural gas, PV panels, battery bank, bidirectional inverter and charge regulator. The sensitivity analysis result showed hybrid system as the better alternative. In similar study Daud and Ismail designed and analyzed a PV-wind-diesel hybrid system for a family house in Palestine considering efficiency, reliability along with the dumped electric power. A software that is capable of changing the variable of hybrid energy system was developed to perform the analysis. High quantity of dump energy was found during the simulation because the system is designed for the worst case. In order to utilize the dump energy power supply to street light, water pumping has been suggested. Economic analysis of this system in terms of COE hybrid system lags behind purchasing grid electricity. The study concludes that if remote location, subsidy levels, cost of renewable energy equipment and environmental effects are taken into account then hybrid systems justify their use.

In another study, the same authors analyzed PV-battery-diesel hybrid system which concluded the hybrid system as best alternative when the diesel generator is used as backup source. Kalantar and Mousavi also performed similar kind of study and proposed wind-solar-micro turbine-battery hybrid system. In their system the microturbine and battery act as a backup power supply during energy deficiency.

1.4.OBJECTIVES

1. To develop the MATLAB Simulink model of the overall Solar PV-WindHydro hybrid system.
2. To develop the control logic for inverter to convert DC power obtained from solar PV-Wind (AC-DC) to AC active power and to generate reactive power within the inverter.
3. To develop the control logic for hydro unit to generate deficit amount of active power and reactive power required for the load.

1.5.METHODOLOGY

1. Study and investigate different papers, articles, research works and reports related to hybrid system including renewable resources and hydro power plant.
2. Learn and practice various Simulink models in MATLAB software so to familiarize in the particular tools and techniques required for the report simulation and modeling.
3. Investigate and learn about the PV solar grid system in detail and prepare its Simulink model for the final simulation.
4. Investigate and learn about the Wind power system in detail and prepare its Simulink model for the final simulation.
5. Prepare the mathematical and Simulink model of the inverter with modifications as per requirement for the project.
6. Model the inverter for reactive power fulfillment of the system.
7. Develop a Simulink model for isolated hydro generating unit using synchronous generator.
8. Set up a complete plan and control mechanism for automatic operation of the overall system and Simulink model of the proposed system in MATLAB simulation.

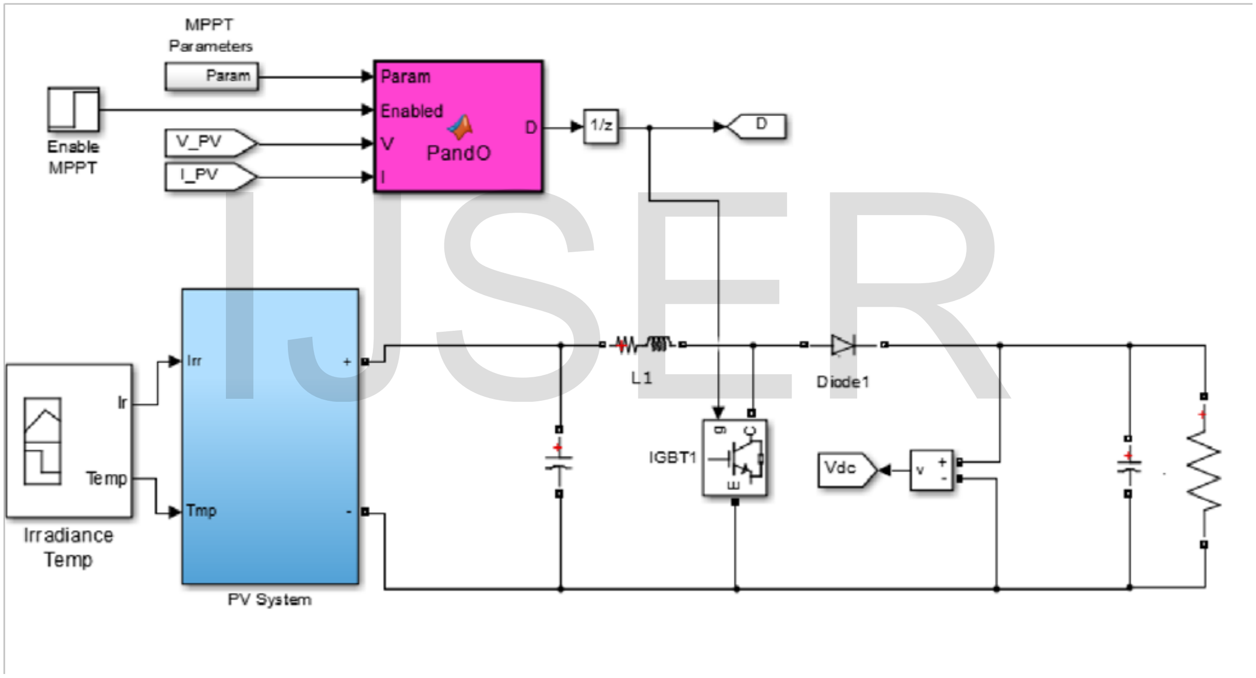
CHAPTER 2

DESCRIPTION AND ANALYSIS OF MATLAB SIMULINK MODEL

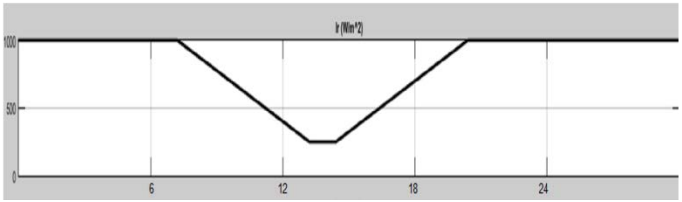
2.1 PV Modeling with MPPT and Boost Converter

The modeling of the PV sub system in the project is done on the basis of the equivalent model of the solar cell with series and parallel resistances as present in the MATLAB blocks.

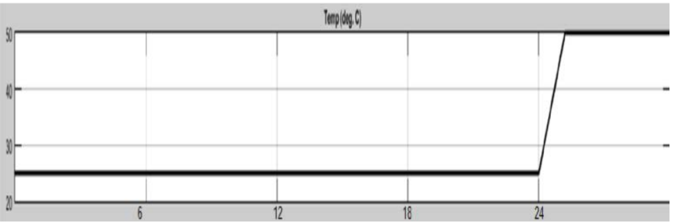
Hence the MPPT block was coded using the user defined functional block in MATLAB. Perturbation and observation algorithm was applied for the above MPPT coding due to its simple structure and fewer parameters requirement to track the maximum power point. MPPT block generated required duty cycle to track maximum power point.



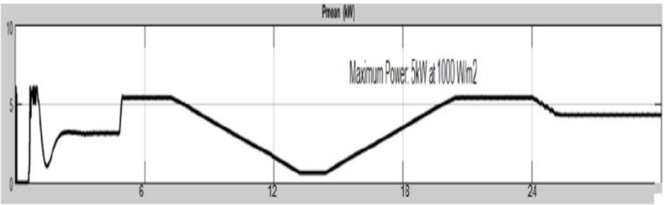
Model 2.1.1: PV System with MPPT and Buck Converter



Plot 2.1.1: Input Solar Irradiance (in Wm^2)



Plot 2.1.2: Input Temperature (in deg C)



Plot 2.1.3: Output Power (in kW)

The simulation was run for 30 seconds with variable values of irradiance. For the maximum irradiance value (ie at STC), the corresponding values of power generated by the PVsystem is ~5kW.

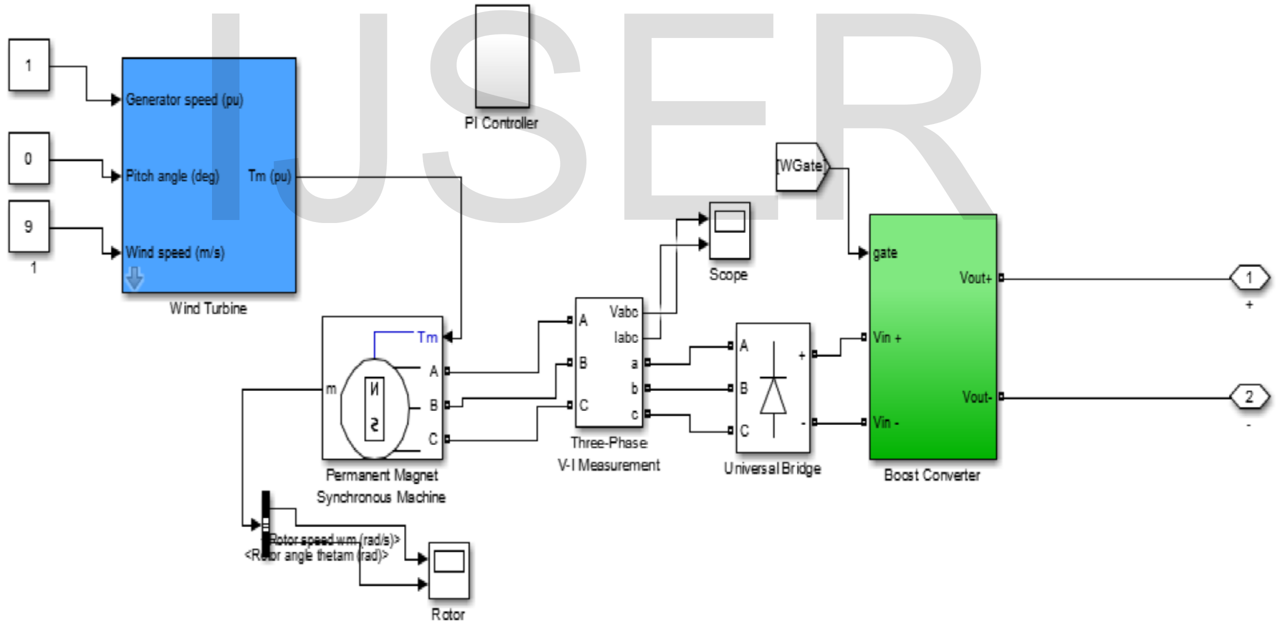
2.2WIND POWER SYSTEM MODELING

In order to design the Wind Power system, a permanent magnet synchronous machine has been used which is driven by a wind turbine, taken from the MATLAB inbuilt block. A constant wind speed of 9 m/s is supplied to the wind turbine which then generates torque to feed to the synchronous machine.

The AC output of the synchronous machine is then converted to a DC output through a universal bridge. The universal bridge converts the AC output from the synchronous generator, but is accompanied by fluctuations.

The buck converter is used so as to maintain constant voltage at the output, so as to feed to a common DC bus system, with voltage in balance with the bus.

A PI controller has been used to maintain the constant bus voltage, which acts as a MPP to the synchronous machine system as it generates a gate signal that controls the buck converter to produce a desired output DC voltage of 600 V.



Model 2.2.1: Wind Power System Modeling

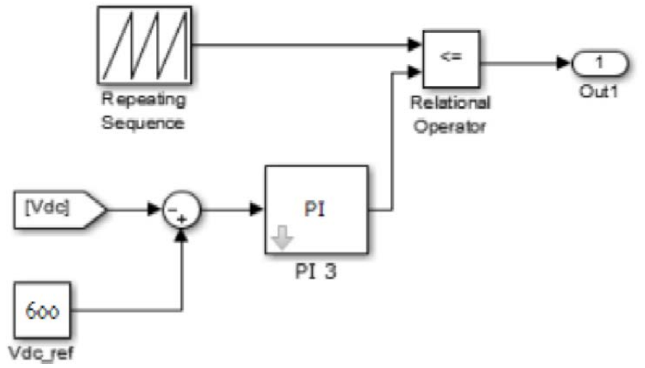


Fig 2.2.1: PI Controller (MPP) for Wind Power System

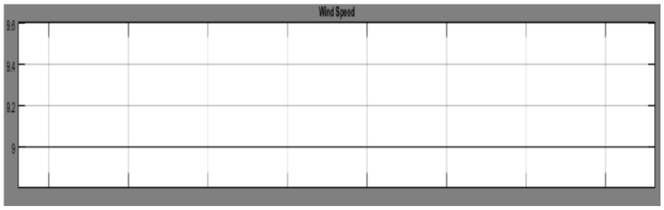


Fig 2.2.1: Wind Speed (m/s)

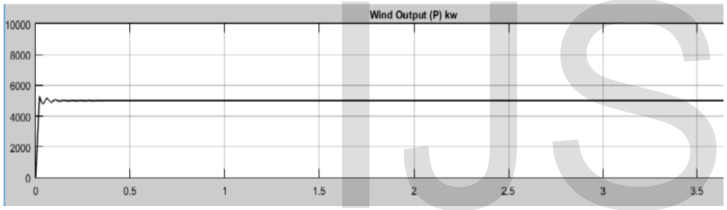


Fig 2.2.2: Wind Power Output (kW)

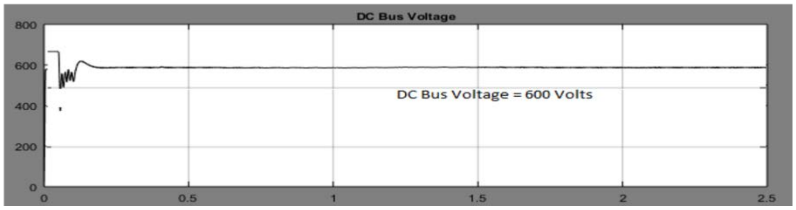


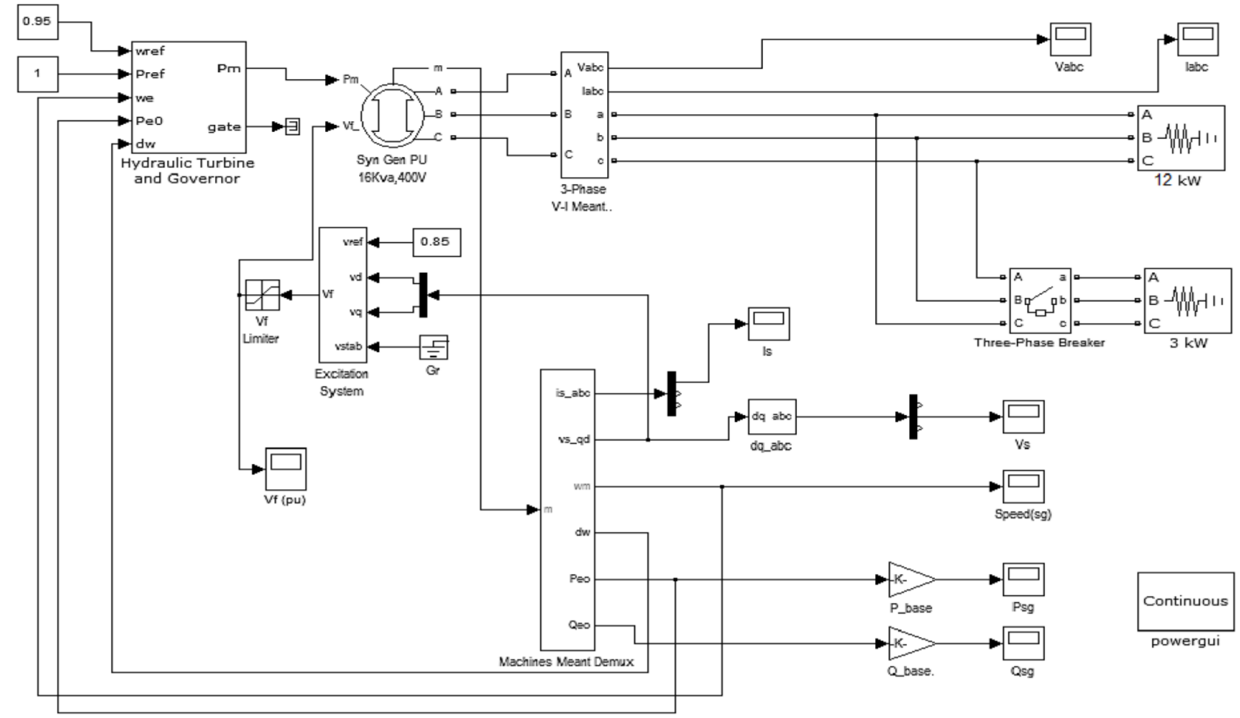
Fig 2.3.3: DC Bus voltage (V)

2.3. SYNCHRONOUS GENERATOR MODELING

The hydro unit including the synchronous generator, hydraulic turbine and governor was operated for the following schemes.

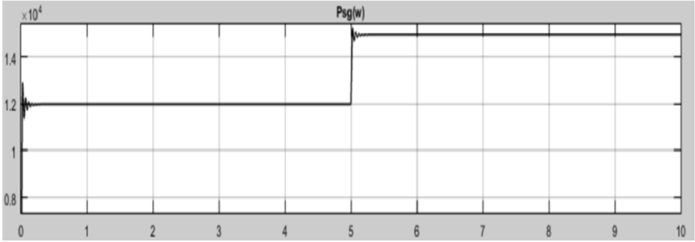
Turbine Speed Control upon Load Variation

The main objective of this simulation is to check the governor action to control the turbine speed upon variation in load. For this purpose, there's provision for two resistive loads that are connected to the 20KVA, 400V 3 phase synchronous generator through a 3 phase breaker switch. The circuitry is designed in such a way that the generator powers only the 12 KW load in the initial 5 seconds. And, after the breaker switch is made ON after 5 seconds, the generator is to power the 3KW load as well. Here the reference values taken are 1, 0.95 and 0.85 for input power to turbine (Pref), speed (wref) and field winding voltage (vref) respectively. Also the field winding voltage (Vf) is limited in the range of -2.5 to +2.5.

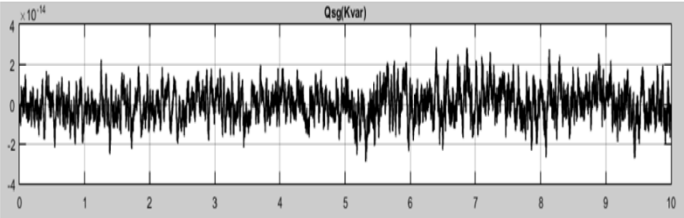


Model 2.4.1: Synchronous Generator with Governor and Excitation System

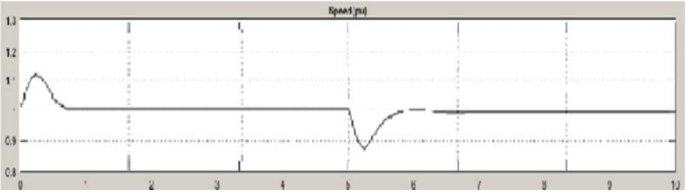
Results and Analysis



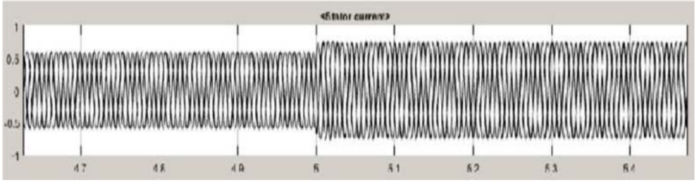
Plot 2.4.1: Active Power (W)from SG



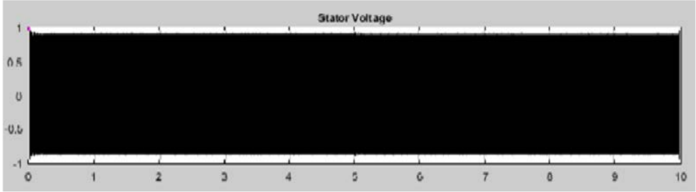
Plot 2.4.2: Reactive Power (kVar) from SG



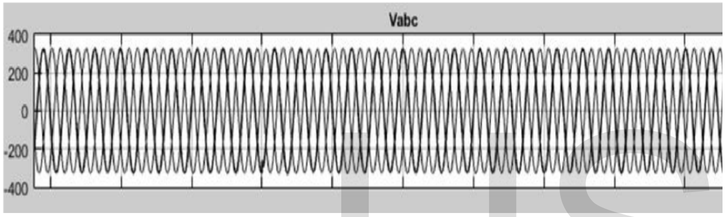
Plot 2.4.3: Turbine Speed (pu)



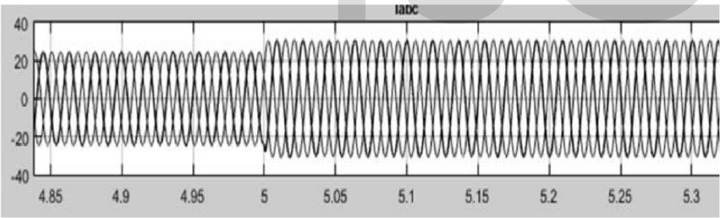
Plot 2.4.4: Stator Current(Is) Expanded view



Plot 2.4.5: Stator Voltage (Vs)



Plot 2.4.6: Load Voltage (Vabc in volts)



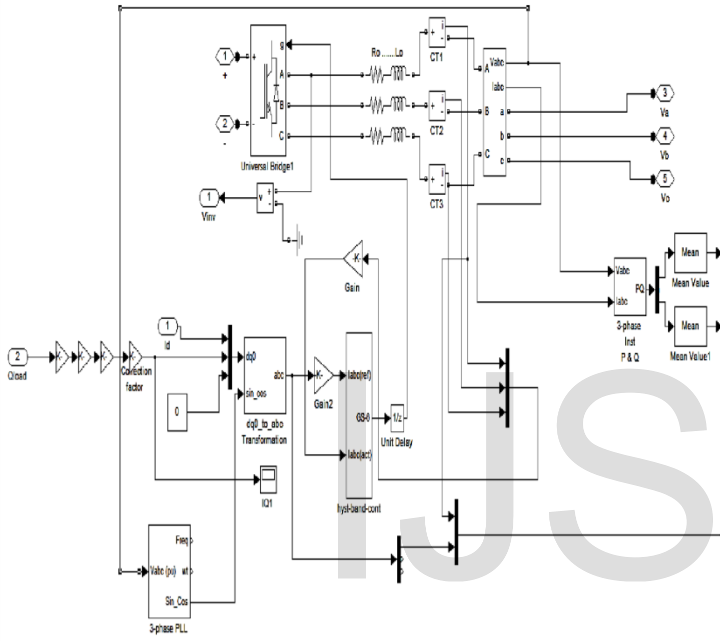
Plot 2.4.7: Load Current (Expanded in Amps)

The power generated by the synchronous generator increased from 12kW to 15kW as the load was increased after 5 seconds. Throughout the operation, a constant speed of 1 pu and a constant terminal voltage of 0.85 pu was observed apart from the initial running time and the breaker switching instant. Thus, the governing action is controlled.

2.4. INVERTER MODELING

The inverter used in the simulation of our project is a voltage source inverter with a dc capacitor with a constant dc voltage across it in dc side of the inverter. We have used Hysteresis band current control technique. It is basically an instantaneous feedback current control method where the actual current through the inverter branch continuously tracks the reference current within a limited hysteresis band.

The actual current signal is compared with the given current signal of the inverter by hysteresis current control. If the actual current signal exceeds the given current signal a certain range, we can change the switching state of the inverter to control the change of actual current signal in order to track the given current signal. Hysteresis current control has series of advantages such as quick response, internal current limiting capacity and stability.



Model 2.5.1: Inverter

Id and Iq current input to the inverter sub-system is converted to equivalent Iabc. Phase Locked Loop (PLL) system is used to synchronize on a set of variable frequency, three-phase sinusoidal signals. This converted Iabc is the reference value of current. Actual value of current obtained from inverter is again used as feedback and compared with reference value. By comparing these values, Hysteresis band controller generates pulse which is fed to Universal Bridge. Universal Bridge implements a universal three-phase power converter that consists of three power switches connected in a bridge configuration.

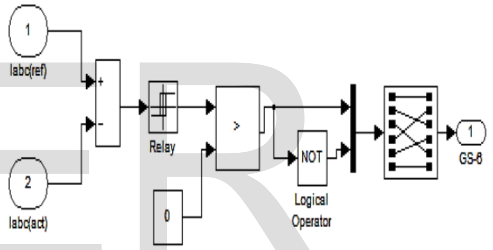
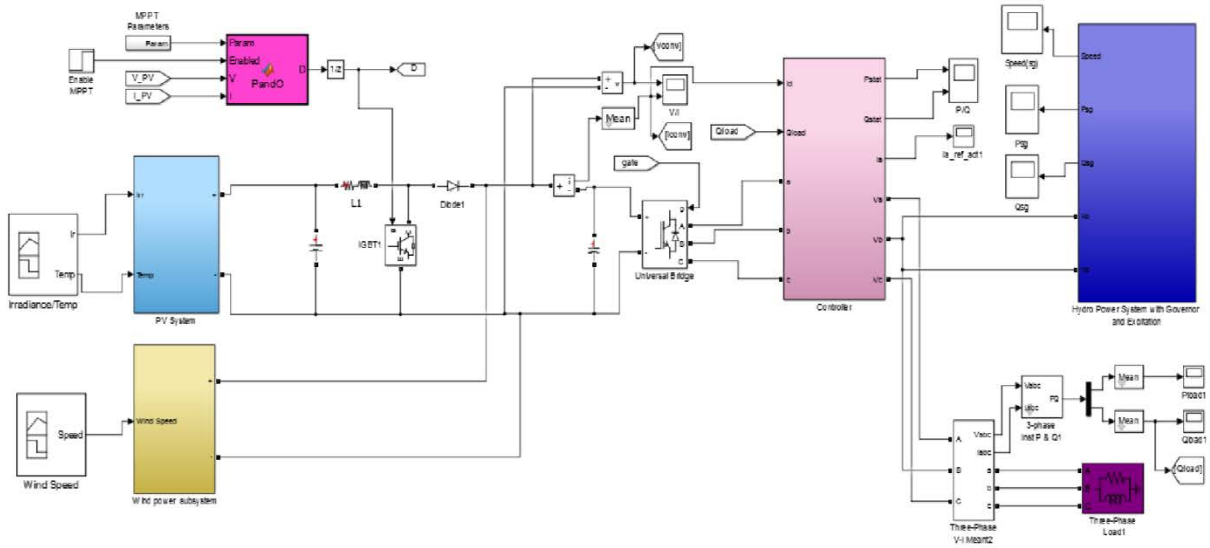


Fig 2.5.2: Block Diagram Model of Hysteresis Band current control

2.5. Overall system block diagram and modeling

The overall system consisting of PV, Wind, and Hydro system is interconnected with the help of inverter and the output is then supplied to the loads.



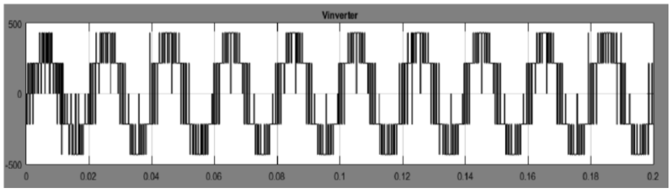
Model 2.5.1: Overall system block Diagram

A 16 kW active load and 5 kVar reactive load is used to analyze the operation of the overall system.

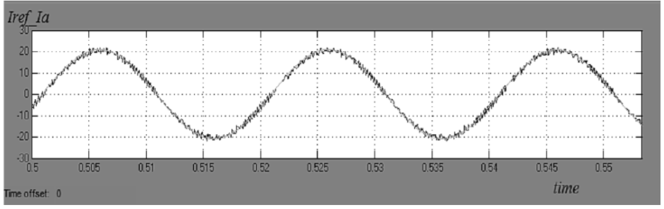
The system is designed so as to provide all the active power from the PV and Wind system and the remaining active power from the hydro unit.

Similarly, the reactive power required by the load is fed by the inverter.

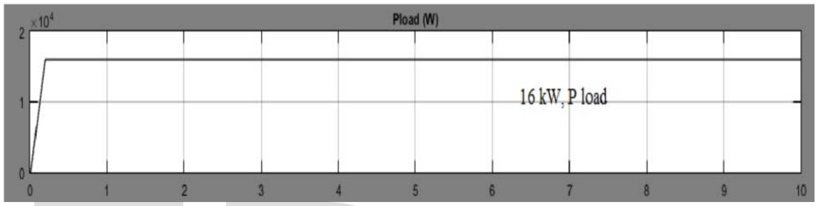
Results and Analysis:



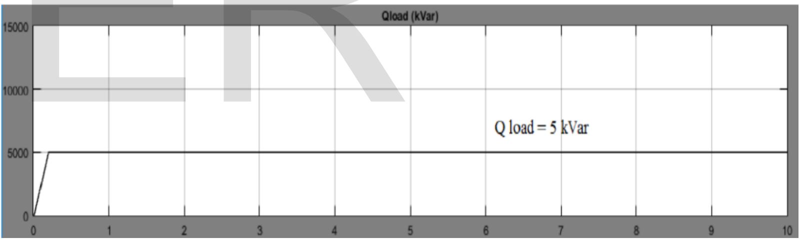
Plot 2.5.2: Inverter Output (V)



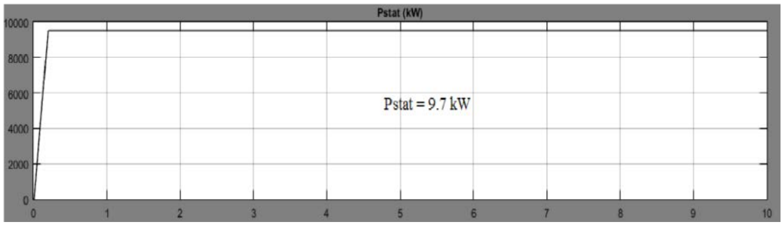
Plot 2.5.3: Reference Current (Iref_Ia in Amps)



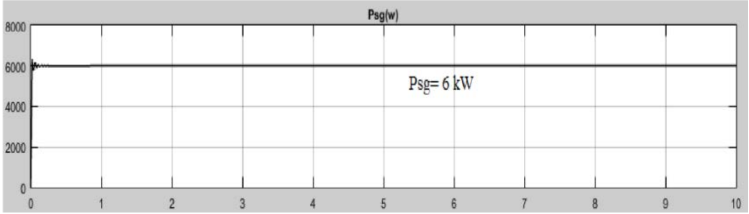
Plot 2.5.4: Active Power Supplied to the Load (kW)



Plot 2.5.5: Reactive Power Supplied to the Load (kVar)



Plot 2.5.6: Active Power Supplied from PV-Wind System (kW)



Plot 2.5.7: Active Power Supplied from the Hydro Unit (kW)

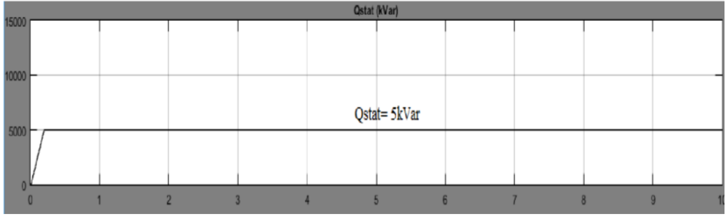


Fig 2.5.8: Reactive Power Supplied by the Inverter (kVar)

Table 8.6.1: Balance sheet of active and reactive power between the synchronous generator, infinite bus, Inverter and (16+j5.7) kVA load.

Source/Sinks	**Readings**
Pinv(W)	9700
Qinv(VAR)	6300
Psg(W)	5500
Qsg(VAR)	0 (at 1 pu)
Pload(W)	16000
Qload(VAR)	5700
Unbalance of P(W)	0.0
Unbalance of Q (VAR)	0.0

Thus the maximum active power is extracted from the PV and Wind system and reactive power is generated by the inverter .The deficit amount of power is supplied by SG. Therefore there is a perfect balance betweenactive power generation and consumption in the scheme resulting a constant speed operation of the synchronous generator at 1 pu.

CHAPTER 3

CONCLUSION AND RECOMMENDATION

The scope of hybrid power system is on rise, mostly in developing countries like Nepal, where the power consumption has rose up to a great level. In order to fulfill the demand of a particular area, expansion of a power system might not be possible, because of which the hybrid power system can come to action.

This MATLAB simulation project analyzes the way in which a PV-hydro-wind system can be incorporated and load demands of active and reactive power can be fulfilled. Similarly, the reactive power required to the load is also generated within the inverter, thereby providing effectiveness and flexibility in operation of the overall system.

Despite the conclusion, successfully, there are several methods that can be incorporated within the system, to make it more reliable. These can be:

1. Using induction generator for the wind power

system, as it is low in cost.

2. Incorporating AC systems (Wind and Hydro)

   together, so as to reduce additional cost for AC-DC converter as used with the wind system.

3. Designing a common MPPT system for the PV/Wind system.
4. Performing a detail analysis together with faults on either of the power systems used.
5. Designing the system in grid tied mode and supplying additional generated power to grid.
6. Using power saving devices like batteries.

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