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SIMULATION AND MODELING OF INTEGRATED RENEWABLE ENERGY RESOURCES (HYDRO, SOLAR AND WIND ENERGY)

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Abstract— Renewable energy sources are likely to become prominent in the future due to less environmental impact and energy cost escalation. However, due to its intermittent essence, it encourages us to integrate various renewable energy resources to improve the reliability and quality of power supply to the consumer. Henceforth, this paper emphasizes the integration of various renewable energy sources (RES) such as - photovoltaic (PV), wind energy (WE) and hydro-electric grid (HEG) systems through software simulation. The purpose of this research was to compare the end user power quality and reliability between isolated mode and integrated mode operation of the power system through the result analysis in MATLAB simulation. In this qualitative study, the required data on wind and solar of a particular place, Samdrup Jongkhar (Bhutan) were collected in the form of satellite recorded data (NASA and SolarGIS). The result from this study highlights the nature of energy output from isolated-mode operated power plants and integrated power plant systems. From the result analysis, it has been shown that the quality and reliability of energy output from an integrated power system is much higher as compared to the isolated-mode operated power plant.

Keywords— Hybrid power system, Integration, solar PV, Wind power system, Hydropower system.

I. INTRODUCTION

Worldwide, the energy demand is rapidly and constantly increasing due to modernization. It has been expected that global energy consumption will increase more than 30% by the period of 2035. Therefore, the ceaseless supply of energy and the need for electricity has become inevitable to the life of every people. Nevertheless, the operation of only a single source of power plant resources such as hydropower plant, wind power plant, or solar power plant cannot fulfill the consumers demand throughout the years. It is because only one source of those renewable energies can lead to various substandard performance such as voltage sag and swell, non-reliable supply, poor power quality and even blackout during fault. Henceforth, the irregular nature and the unique operating characteristics of each renewable energy source encourage us to integrate them for better performance. Also, the integration of renewable energy sources in Bhutan is feasible as all those renewable energy sources have a potential of (50 GW solar, 30 GW hydro and 4GW wind energy generation.) [1] In this project, after considering non-depletable, site-dependent, non-polluting and potential sources of alternative energy options, the detailed integration of solar, wind and hydro energy sources are presented. The integration of more than one source of energy is very crucial since the integrated power system has got a unique feature that the system can respond as variations of energy needs throughout the day and seasonally. The core objectives of renewable energy integration are to advance the system structure, planning, and operation of the utility grid to: [2]

- Support in achieving renewable portfolio standards for renewable energy and improving energy efficiency.
- Improve the energy security, reliability, power quality and availability.
- Help in reducing the usage of non-renewable energy sources such as oil, coal and fossil fuel.

This paper vividly shows that the end-user energy quality and reliability have been comparatively improved when more than one source of renewable energy resources are integrated together.

II. MODELLING OF HYBRID POWER SYSTEM

In a hybrid renewable energy source, it consists of different energy sources such as solar PV, wind energy system, biomass and hydropower system. For modeling a hybrid energy system correctly, selecting the components and subsystem for optimal sizing of the entire system is the first step [3]. Modeling process help understand the different component in the system and it supports in decision making of a system. The accuracy and the efficiency of the model depend on the prediction of performance but due to its complexity, it is difficult to design a perfect model. A sufficiently appropriate model can be built, and the performance of individual components is modeled by deterministic or probabilistic approaches [4]. A method for modeling different energy systems is described below

2.1 ***SOLAR POWER SYSTEM***

2.1.1 ***PV system Modelling***

For the simulation of PV module, the geographical data from Global Solar Atlas for Dewathang (Jigme Namgyel Engineering College) has been used by considering the 10 hours sun rays a day. According to satellite data, the site has the potential and suitable for medium size commercial purpose PV system with 457.2 W/m^2 irradiation per day at the temperature of 20.6^0C having a nominal peak power of 95 watts from the single PV module.

Mathematical model of solar PV module is based on the fundamental building block like current source, diode, series and parallel resistors, which has been developed in a step-by-step procedure under MATLAB/Simulink system. Therefore, an initial understanding of solar PV cell performance and its equivalent circuit is very crucial and must be considered for the simulation.

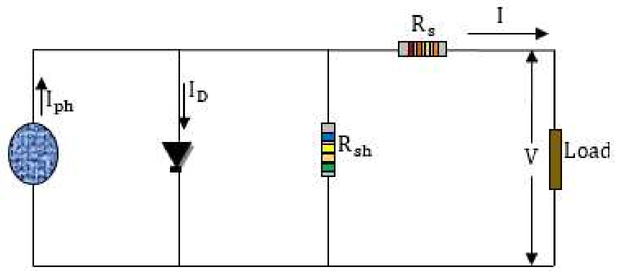

Fig. 1. Equivalent electrical circuit model of PV module.

In the PV cell model, there is a diode in parallel with respect to a controlled current source, and there is a series and shunt connected resister for considering the losses in the system. The terminal current **I** is equal to the amount of current generated by the light $\mathbf{I_{ph}}$ from PV cell, less than diode current $\mathbf{I_D}$ and shunt leakage current $\mathbf{I_{sh}}$.

Series resistance $\mathbf{R_s}$ represent the internal resistance of current flow and $\mathbf{R_{sh}}$ is inversely related to the leakage current to the ground. An ideal solar cell, $\mathbf{R_s}$= **0** (no series loss in the system) and $\mathbf{R_{sh}} = \infty$ (no leakage to ground).

2.1.2 ***Photovoltaic Array Model***

PV modules are a combination of a photovoltaic cell. It is connected in numbers of series and parallel to extend the voltage and current, respectively. The various number of PV module connections leads to the development of PV array system and its maximum power output will be given as mentioned below [5].

$$P_A = FF_A * V_A * I_A = M_P * M_S * P_M \qquad (1)$$

Were, $FF_A = \frac{V_{MPP} * I_{MPP}}{V_{OC} * I_{SC}}$

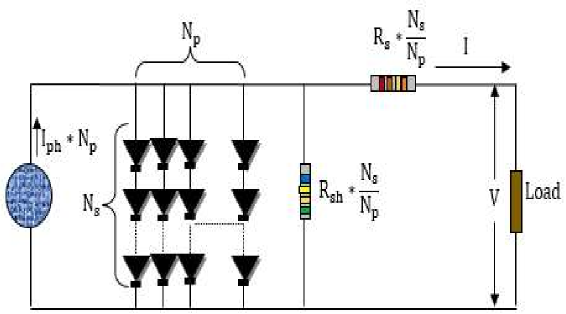

Fig. 2. Equivalent electrical circuit model of PV array

The PV array generates DC component output and it should be converted into AC component output using an inverter system, where the conversion efficiency of the inverter system will effect on the AC component output power. Henceforth, the maximum output of PV system can be expressed as shown below [5].

$P_S = \eta_{inv} * P_A$ (2)

Were, $\eta_{inv} = \frac{e_{AC}}{e_{DC}}$

The final PV module required the intake such as solar irradiance, working temperature and panel voltage in order to provide the PV output current and voltage.

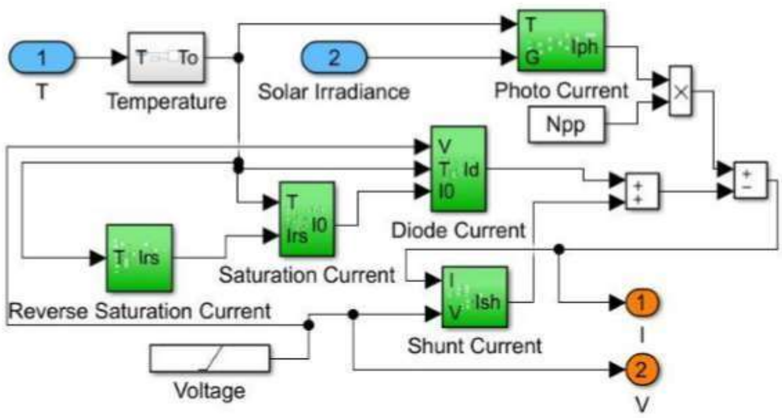

Fig. 3. Photovoltaic module model in Simulink

2.2 *WIND POWER SYSTEM MODELING*

2.2.1 *Wind Speed and Turbine Model*

Wind turbines produce kinetic energy with the assist from surrounding wind and it will lead to the production of useful power.

Power of wind turbine, P_m is express as;

$$P_m = 0.5\ C_p\ (\lambda, \beta)\ \rho\ A v^3 \quad (3)$$

In this research, pitch angle β = 0 and tip speed ratio λ = 6.325 to attain the maximum value of power coefficient C_p.

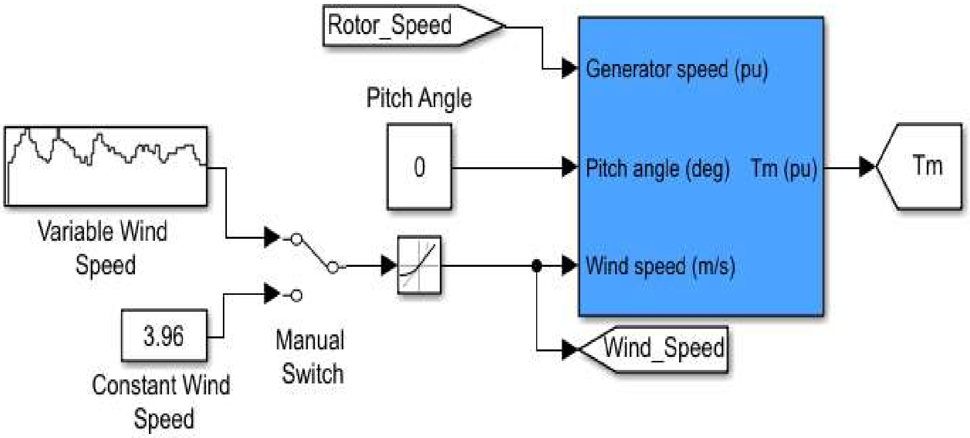

Fig. 4. SIMULINK model of wind Speed and Turbine

2.2.2 *Model of PMSG Wind Turbine*

The torque generated by a wind turbine is from wind power. The torque is transferred to the rotor with the help of a generator shaft. The generator produces electrical torque. The main difference between electrical torque from a generator and mechanical torque from a turbine is that it determines whether the mechanical system accelerates, decelerates, or remain constant [6].

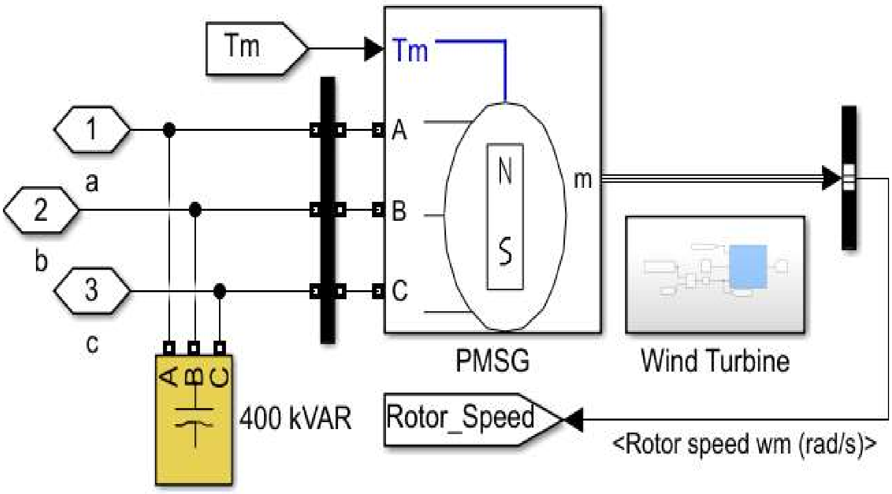

Fig.5. SIMULINK model of Permanent Magnet Synchronous Generator (PMSG)

2.3 *HYDROPOWER SYSTEM MODELING*

Hydropower is a renewable energy source, that converts the kinetic energy of water flowing from higher elevation to lower elevation into electricity using hydraulic turbines. Hydraulic turbines are of two basic types: impulse turbines (Pelton, Turgo and Crossflow turbine) and reaction turbines (Kaplan & Francis turbine). The type of selection of the turbine depends upon the net head available at the site and the discharge of the water. The power generated from hydropower is given by the following equation:

$$P = \eta \times g \times Q \times H \quad (4)$$

Were,

- ✓ P = Power generated in kW
- ✓ η = Overall efficiency of the plant
- ✓ g = Acceleration due to gravity in m/s^2
- ✓ Q = Discharge in m^3/s
- ✓ H = Head in meter

2.3.1 HYDROPOWER PLANT MODEL DEVELOPMENT USING MATLAB/SIMULINK

The hydropower plant model is simulated in MATLAB/Simulink environment and analysis of voltage, current and power in standalone mode is carried out. It is then integrated with a solar-wind hybrid system in later part after considering it as one of the research objectives.

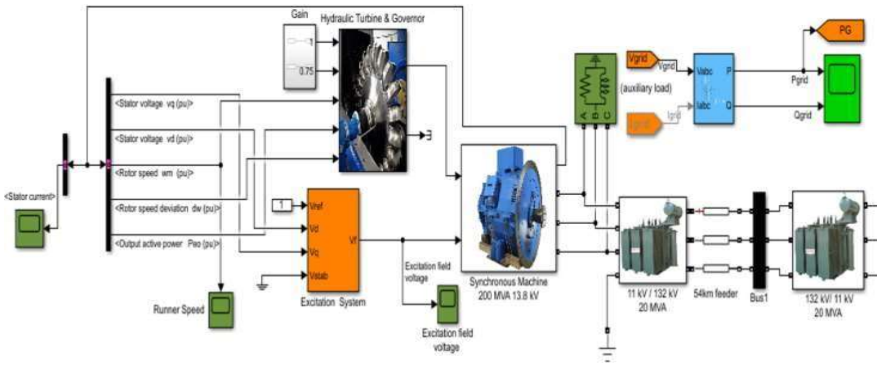

Fig. 6. MATLAB/Simulink model of Hydro Power Plant

2.4 *INTEGRATION OF RENEWABLE ENERGY SOURCES*

In this paper, the proposed system consists of renewable energy sources such as solar and wind energy connected to the utility grid. Such integration is highly recommended for the reliable supply of energy to the end-user since during peak summer, energy production from solar plants is abundantly available whereas, during rainy days, the power output from solar plants will either shut down or minimum. Similarly, wind energy sources are weather dependent and intermittent in nature and hydropower plants too will vary their output seasonally. Therefore, in the research, the parallel combination of all those mentioned renewable energy sources is developed for continuous power flow to the consumer. Figure 7 illustrate the architecture of renewable energy sources such as solar and wind plant integrated to the utility grid system.

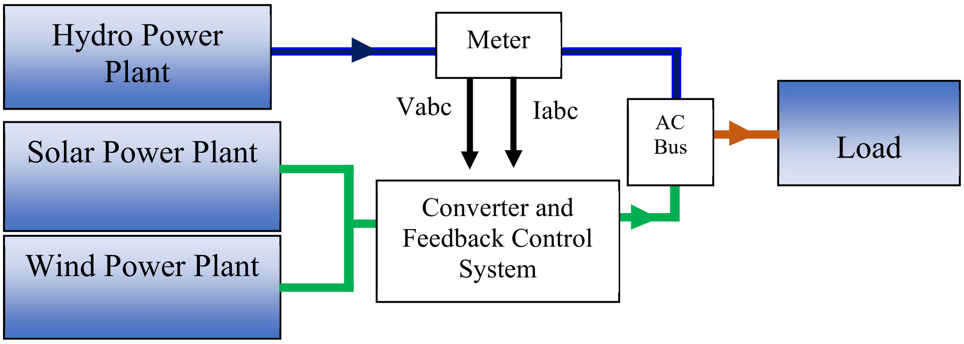

Fig. 7. Architecture of Renewable Energy Sources System

In the model, various renewable energy sources are connected to a common AC bus through necessary converting, controlling and feedback system and feed to the load. The Simulink model of integrated power system is shown below.

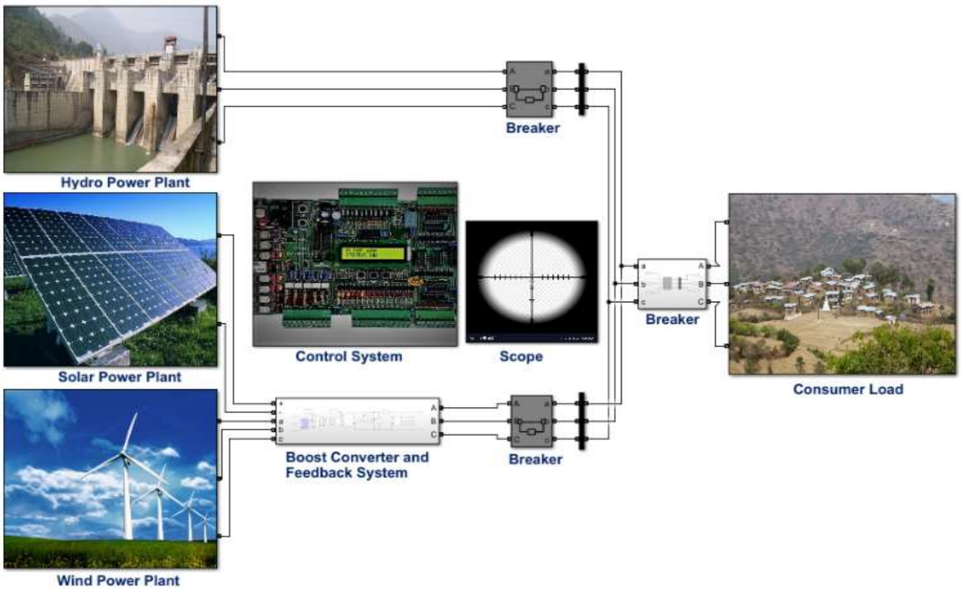

Fig. 8. MATLAB/Simulink Model of Integrated Power System

III. RESULT AND DISCUSSION

Research objectives such as power quality analysis and reliability enhancement in the integrated power system as compared to an isolated operating power plant are discussed in this chapter. The simulation result that has been evaluated from the integrated renewable energy resources with the usage of MATLAB/Simulink is also explained in this section.

3.1 Power Quality Analysis

Power quality analysis in this paper has been done based on FFT analysis. FFT analysis is one of the best electrical properties to analyze the power quality in the system since this method will clearly depict the characteristics and types of the output signal generated from the various power system.
The figure is shown below clearly explained that the level of harmonics distortion present in output energy from the isolated-mode operated power system is much higher than the integrated power system.

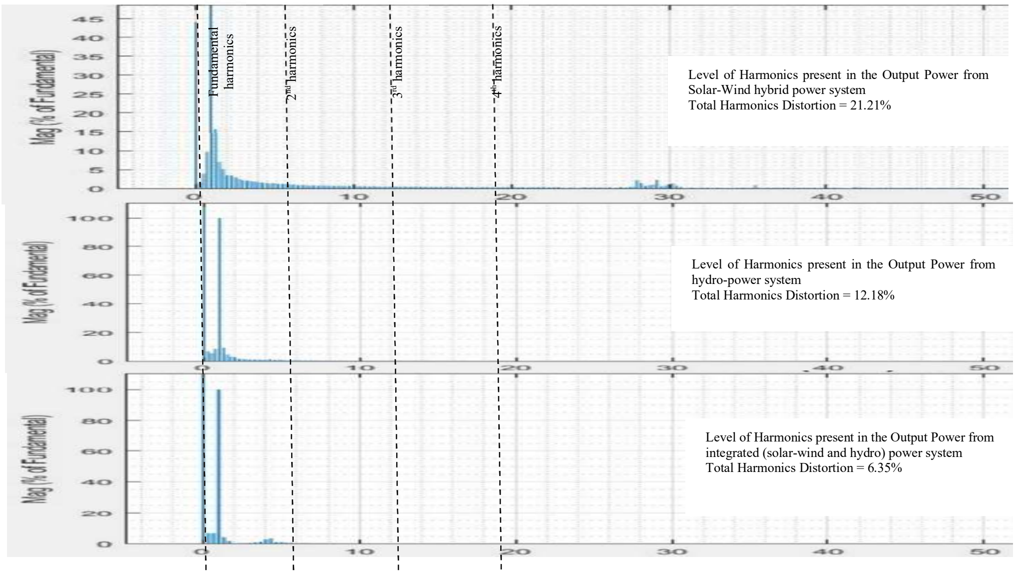

Fig. 9. Harmonics level presents a comparison among various power system structure

According to IEEE Standard 519 – 1992**,** it has been said that the point of common coupling (PCC) in an integrated power system can have total voltage harmonics up to 5.0 % and total current harmonics in the system up to 8.0%. The comparison of the result from this study is done with the IEEE standard in order to verify that the result from this study was within the standard of IEEE conditions and values. The table below shows the percentage of harmonics present in the various power system parameters such as current, voltage and power.

TABLE 1. Level of harmonics present in various power plant

	Solar-Wind Hybrid Power Plant Harmonics Present (%)	Hydro Power Plant Harmonics Present (%)	After Integration (Point of Common Coupling) Harmonics (%)
Voltage	11.09	7.83	4.05
Current	14.51	8.88	4.36
Active Power	21.21	12.18	6.35
Reactive Power	16.75	10.72	4.06

After analysis through FFT, it has been shown that the electric signal generates from an integrated power system has got higher energy quality as compared to a hybrid power plant and grid alone operated output signal. The table below shows the THD reduction (in %) in the integrated power system as compared to isolated-mode operated power system.

TABLE 2: % level reduction of harmonics present when various energy sources are integrated together

Voltage harmonics Reduction	**14.87 %**
Current harmonics Reduction	**19.03 %**
Active power harmonics Reduction	**27.04 %**
Reactive power harmonics Reduction	**23.41 %**

3.2 System Reliability Analysis

In the research, system reliability is computed based on the Monte Carlo algorithm technique. It is based on a probabilistic reliability evaluation approach where the reliability index and loss of load probability LOLP have been evaluated. LOLP based reliability analysis in the system has been done based on various renewable energy sources mixture in the generating system.

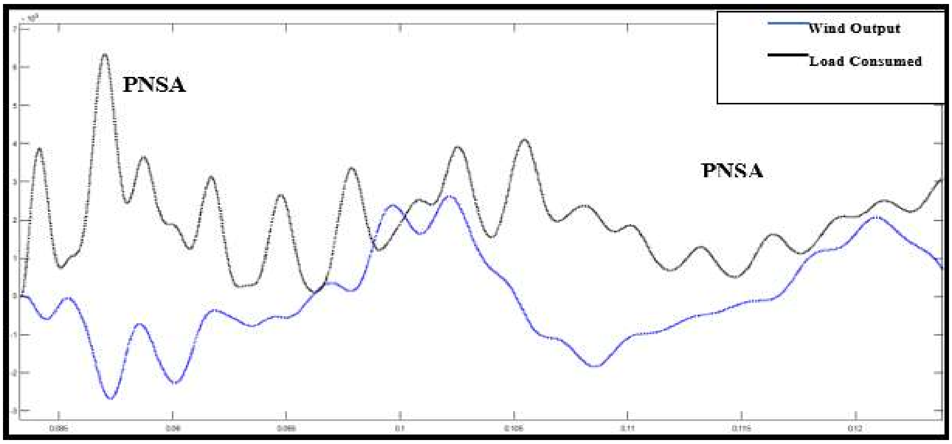

Fig. 10. Wind Output vs. Load Consumed pattern using Monte Carlo Technique

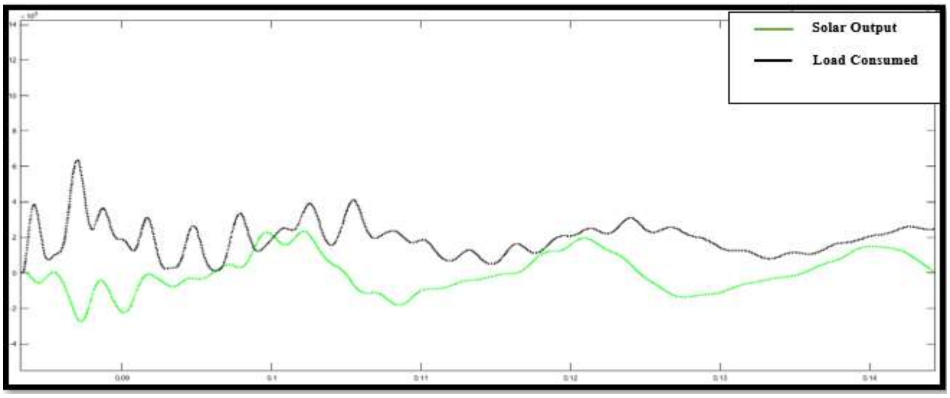

Fig. 11. Solar Output vs. Load Consumed pattern using Monte Carlo Technique

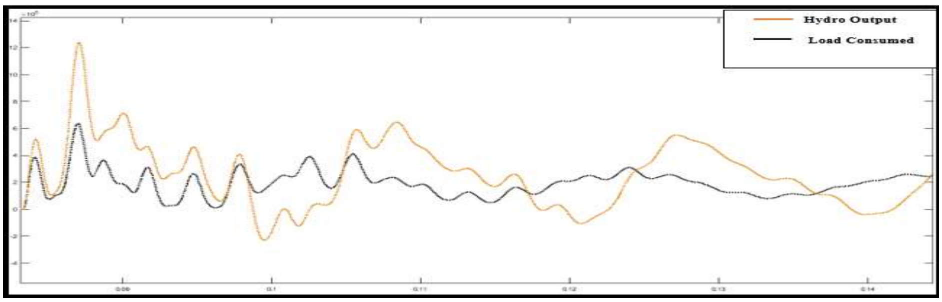

Fig. 12. Hydro Output vs. Load Consumed pattern using Monte Carlo Technique

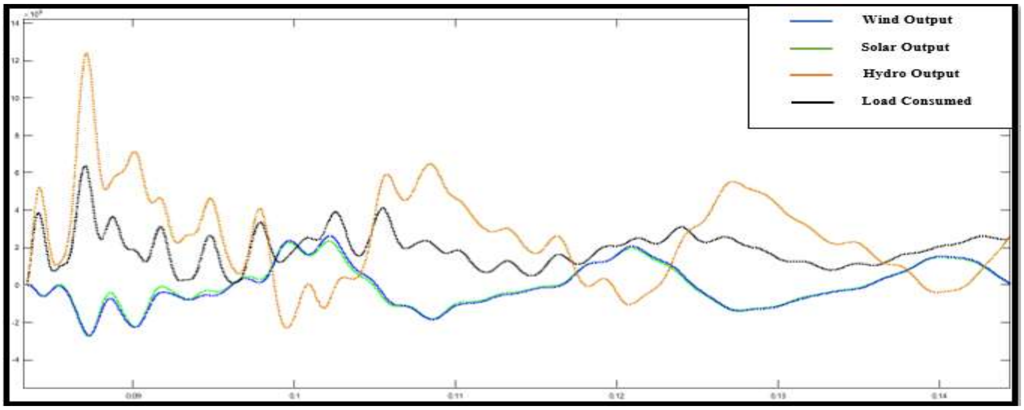

Fig. 13. Integrated Power System Output vs. Load pattern using Monte Carlo Technique

From the figure shown above, its clearly shown that the combination of solar, wind and hydropower plant energy supply fulfills the maximum number of hours for the load demand as compared to an isolated-mode operated power plant. This means that the reliable supply of power is enhanced in the case of the integrated power system.

IV. CONCLUSION

In this study, the integration of various renewable energy resources into the utility grid was discussed. Due to fluctuation and intermittent in nature, renewable energy sources like solar, wind and hydropower plant are recommended to integrate each other for the improvement of power system quality and reliability in this research. The result obtains in this study clearly depict that the quality and reliability of output energy for load demand is much higher if more than one source of energy resources are interconnected together.

From the result obtained in this study, we can draw a conclusion that integrated power systems (solar, wind and hydro-power plant) will be able to supply continuous and less distorted, higher quality energy to the load consumers when compared to using only one source of a power plant. Therefore, as load demand continue increasing, the need for a reliable power supply is very crucial, and an integrated power system is one of the best ways to fulfill all needs of load demand in the power system structure.

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