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Paper Modeling of Wind-Solar Hybrid Power System for Off-Grid in Nepal and a Case Study

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Abstract:
The adaptation of renewable energy has been increasing in a very encouraging way all over the world. Among various renewable energy resources, wind and solar energy are the promising sources of alternative energy. Wind and solar photovoltaic (PV) have been employed in parallel as a hybrid system for better electricity service. This paper presents a case study and modeling of wind-solar hybrid system in Hriharpur Gadi village, Sindhuli District, Nepal. The hybrid system yields 110kWh of energy per day meeting the village's electricity demand of 87 kWh per day. Moreover, the hybrid power system with battery storage system is modeled using MATLAB simulator. Further, improvising in the existing modeling has been presented to enhance the efficiency and effectiveness of the system.

Keywords: Wind Energy, Solar Photovoltaic, Battery, Hybrid Power System

1 Introduction

Hasty draining of fossil fuel is alarming the condition of energy crisis. Renewable energy sources are the potential sources to this problem. They are far superior in terms of sustainability and environmentally friendly race. Going renewable has many advantages, including energy security and self-reliance in energy. It also upgrades the socio-economic condition of rural lives. In the future, it is unquestionable that a large proportion of energy used will be derived from renewable sources.

1.1 Background

In the context of Nepal, hydropower is a prominent source of energy. Nepal is abundantly rich in hydro resources but construction and commission of bigger hydropower takes ample capital investment and considerably longer time. In rural areas, the outlays for grid-connection are higher due to low population density. However, the preference of diesel generator could be reliable and most economical alternatives but due to various environmental issues and its shorter useful life, it cannot be the best option. The electricity demand in Nepal is increasing by about 7-9 % per year [1]. In order to address electricity demand at shorter period of time, other available renewable resources like wind plant and solar plant could be utilized.

1.1.1 Hybrid System

For uninterrupted power supply in the rural area, battery bank or a diesel or both can be placed as a back-up. In this case, the system has only battery bank as a back-up source. This type of hybrid system is basically adopted to electrify the remotely located villages, without national grid connections. When the system is properly designed and operated, all the advantages of this kind of system can be harnessed. Sizing of the system, control system, and operational strategies, are all interlinked. Figure 1 shows the bock diagram of a wind-PV hybrid system. It consists of wind system, PV system, battery bank system for storage purposes, inverter and dump load for the consumption of the excessive power after consuming by the loads.

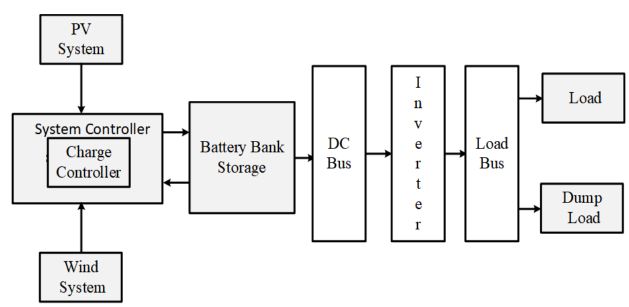

Figure 1: Block diagram of a Wind-PV hybrid System

The major components of PV hybrid system are depicted in Figure 2. Dump load is used in order to achieve stability during the period when production is actually greater than demand, during any anomaly or deliberate cases. Battery bank can play a vital role in the system.

Figure 3 shows the architecture of wind system. Battery back-up system can be used to enhance the system performance, reliability, cost of energy (COE) reduction. When the production is surplus, battery charging can be done, whereas during low production and high demand time, it could supply the power.

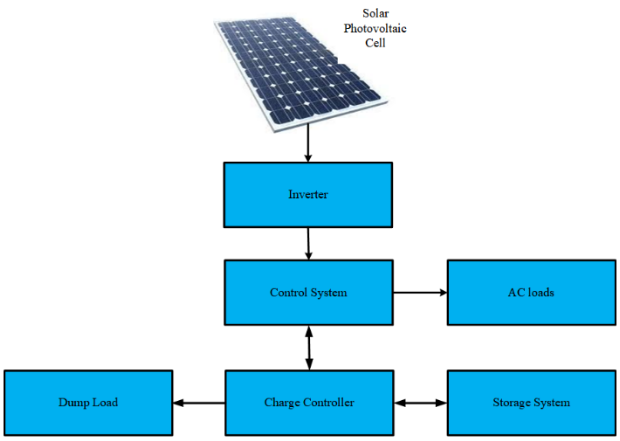

Figure 2: Architecture of PV hybrid system

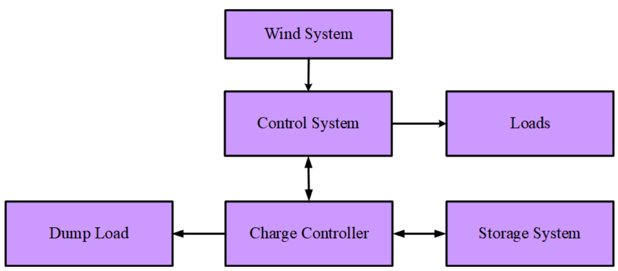

Figure 3: Architecture of Wind hybrid system

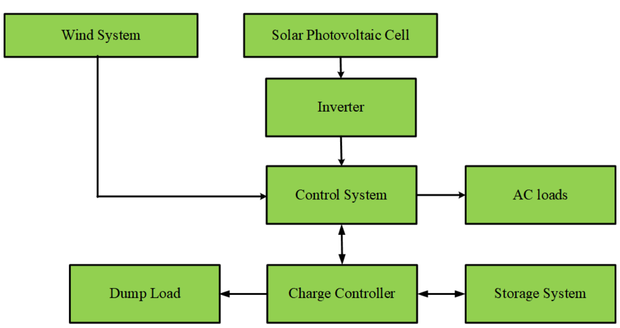

Figure 4: Architecture of Wind-PV hybrid system

The solar and wind can be the best solution for rural electrification and its architecture is shown in Figure 4. It can provide uninterruptible power supply in rural areas with battery bank as a backup with high reliability and low maintenance.

Nepal has a high potential for wind energy. Average wind speed of Nepal is 6 m/s. Wind could be a very good alternative source of energy in rural areas of Nepal. Available wind power plant installed till date in Nepal are Mustang, Morang, Dhading, Makwanpur, Pyuthan and many more. According to alternative energy promotion center (AEPC) data of 2003, the wind power potential area is about 6074 sq. km with wind power density greater than 300 watt/m2. From the total area of 6074 sq. km only 10% has been analyzed and it has been found that more than 3,000 MW of electricity could be generated with consideration of the installed capacity of 5 MW/km^2.The commercially viable wind potential of the country is estimated to be only about 448 MW. This analysis shows that 3000 MW of electricity could be generated from wind energy with consideration of 10% of the area within the boundary of 10 km from current national grid and with more than 300 W/m^2 wind power density in Nepal [2-5].

Similarly, according to wind energy conversion system, 78% of the total land of Nepal has high potential solar insulation area. The average solar radiation varies from (3.6-6.2) kWh/m/day and the sun shines for about 300 days in a year.

Hybrid system can be suitable for both grid connected and off-grid connected system as well. The sources, sun and wind have the opposite cycle and their intensities vary during the same day or in the same seasons. During summer, wind speed is low and sun intensity is high whereas during winter, wind speed is high and sun intensity is low. Even during the same day, in different regions of the world or in the same periods of the year, there is the opposite pattern of wind and solar resources and these opposite pattern increases the reliability of the system. Moreover, it also reduces the size of battery bank making the hybrid solar-wind system commensurably cheaper. [6-9]

1.1.2 Modeling of Hybrid System

Various wind-solar modeling techniques are suggested by researches for modeling the component of a hybrid wind-solar renewable energy system. The different kinds of the components regarding wind-solar hybrid system is discussed below.

Modeling of Wind Energy System

The actual mathematical modeling of wind energy conversion system consists of the wind turbine dynamics as well as generator modeling. Power production through the wind turbine can be determined by wind power equation. The turbine is characterized by non-dimensional performance as a function of tip speed quantitative relation. A wind turbine model extracts the mechanical power from the wind power and it can be written by

$$P_{mech} = 0.5\rho A v^3 c_P(\lambda, \beta) \quad (1)$$

where ρ, A, and v mean the air density, the rotor swept area by the blades, and the wind speed, respectively and c_P

depends on the tip speed ratio, λ, and pitch-angle, β, and is represented by

$$c_P = 0.645\left\{0.00912\lambda + \frac{-5 - 0.4(2.5+\beta) + 116\Lambda}{e^{21\Lambda}}\right\} \quad (2)$$

Where

$$\Lambda = \frac{1}{\lambda + 0.08(2.5+\beta)} - \frac{0.035}{1 + (2.5+\beta)^3} \quad (3)$$

According to (2), the maximum c_P and optimum λ is 0.5 and 9.95, respectively.

A two-mass shaft considering the mechanical dynamics is modelled by

$$J\frac{d\omega_r}{dt} = T_m - K_r\omega_r - T_e \quad (4)$$

where J, K_r, ω_r, T_m, and T_e mean the momentum of inertia, rotor damping coefficient, generator rotating speed, mechanical torque, and electromagnetic torque, respectively.

Modeling of Solar Photovoltaic System

The output of the PV completely depends on solar radiation. Hourly solar radiation on a fixed inclined surface (I_T) can be determined as

$$I_T = I_b I_b + I_d R_d + (I_b + I_d)R_r \quad (5)$$

where I_T is the solar radiation on an incident surface; I_b is the direct normal and diffuse; I_d is the solar radiations; R_b is the tilt factors for the beam; R_d is the tilt factors for the diffuse; and R_r is the reflected part of the solar radiations.

PV power output with respect to area is evaluated by

$$P = I_T A_{PV} \eta_{PV} \quad (6)$$

A_{PV} and η_{PV} are PV system area and efficiency, respectively.

The PV system efficiency is defined as

$$\eta_{PV} = \eta_M \eta_{PC}[1 - \beta(T_C - T_R)\#(7)$$

where η_M is the module efficiency, η_{PC} is the power conditioning efficiency, T_C is the monthly average cell temperature, T_R is the reference temperature and β is the array efficiency temperature coefficient.

In the ideal equivalent circuit of PV cell, a current source is connected in parallel with diode connected PV cell with load, voltage, and current equation of cell which is calculated by

$$I_{PV} = I_{PH} - I\left(e^{\frac{QV_{PV}}{kT}} - 1\right) \quad (9)$$

where I_{PV} is the PV current (A), I is the diode reverse saturation current (A), Q is the electron charge, k is the Boltzmann Constant and T is the cell temperature.

1.2 Paper Layout

In this paper, the proposed system of wind-solar hybrid system has been developed under the case study in Hariharpur Gadi village, Sindhuli District, Nepal.

In Section-2, the description of the site along with the solar and wind components is discussed. In Section-3, the modeling of wind-solar system done in MATLAB is explained. The simulation results are discussed in Section-4. Scope for improvisation and conclusion is explained in Section-5 and Section-6, respectively.

2 Description of Site

In this paper, we present a case study and modeling of wind-solar hybrid system with installed capacity of 20 kW wind turbines complimented by 15kWp solar photovoltaic (PV) panels with battery storage system in Chisapani, Hariharpur Gadi village, Sindhuli District, Nepal. The site is located N $27^0 21' 8.34''$ and E 85^0 27' 44.28'', at 355-meter elevation as shown in Figure 5.

Figure 5: Geographical image of the Site

With the target of electrifying 83 households, the hybrid wind-solar system was developed in the year 2017 December 12, which was financed by Asian Development Bank. The present perceived ease of use (PEU) demand is 6 kW. The hybrid system yields 110 kWh of energy per day, meeting the village's electricity demand of 87 kWh per day (15% demands from PEU). Considering losses maximum daily energy demand of the hybrid system is 99 kWh/day. The minimum energy from wind Turbine (50% of total demand) is 14.07 MWh/year and the minimum energy from Solar PV Plant (50% of total demand) is 14.07 MWh/year. The total annual energy demand of Chisapani village is 28.14 MWh/year.

2.1 Component Feature

The total transmission and distribution lengths are extended about 2920m. The three phase lines are extended up to 1120m length whereas single phase lines are lengthened about 1800m.The conductor proposed here is ACSR (Aluminum conductor Steel Reinforced). The cable used are dog type and rabbit type. The dog cable has total length of 2800m in which 1400m is phase wire and 1400 m are neutral wire. The rabbit type cable has total length of 5180m in which 3710m is phase wire and 1470m is neutral wire. The length of dog and rabbit cable were determined to be 3080m and 5698m respectively, considering the voltage drop of 10 %. Similarly, the service cable is 6 mm^2 with length of 1660m. The voltage level is 400V for three phase lines and 230V for single phase lines. The 26 number of MS Tubular Pole has been used with 9m length and MS pole has 43 numbers with 8m length. The insulator employed was medium and large Shackle type insulator with total of 124 and 66 in number. The stay set consist total of 17 number of stay plate of dimension 300mm*300mm*6mm. The stay set accessories includes thimble/stay wire, stranded/turnbuckle and stay rod of diameter 16mm, length 1.8m etc. Plate earthing system is employed, using copper plate with dimension 600mm*600mm*3mm with 6 numbers. It includes 2 extra plates each for equipment body earthing and neutral earthing at power house. There are 14 number of lightning arrestors used having rating of 0.5kV, 1.5kA. The miniature circuit breaker (MCB) for households has rating of 1A SP 230V with 83 number. The energy meter is single phase 2 wire, 230V, 5A Static Type and 83 in number. Figure 6 shows the block diagram consisting of various components in the wind-solar hybrid system.

The major system components used in Hybrid system are shown in Table 1. Tables 2 and 3 depict the data for solar and wind power systems, respectively.

The load curve for the household demand of the village is depicted in Figure 7 where peak load demand is around 10.6 kW at approximately 21 o'clock at night time.

Consequently, the contribution factor is nearly unity. Similarly, Figure 8 illustrates the load curve for the business and street light power demand. In this case, the

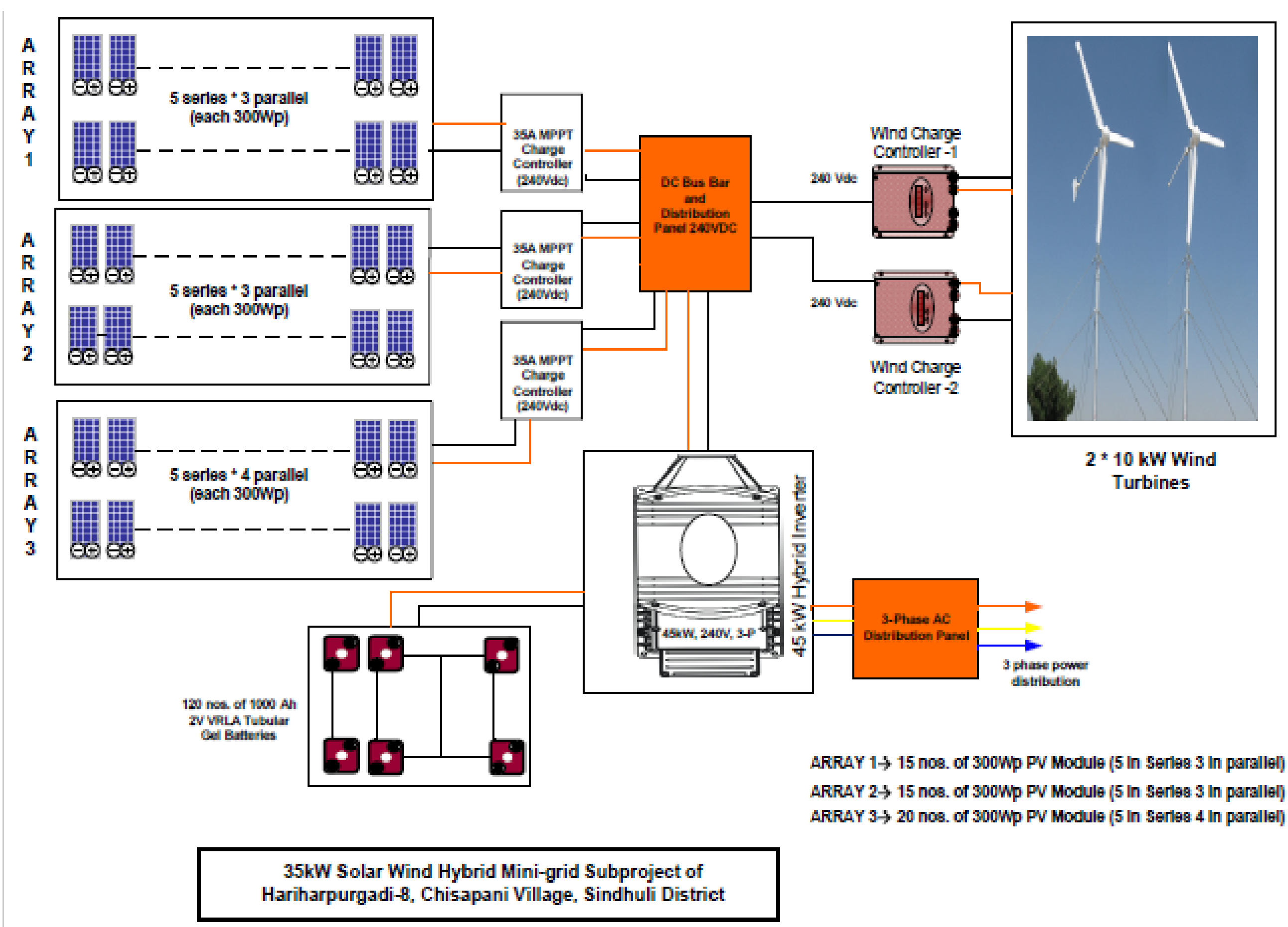

Figure 6: Block diagram of wind-solar hybrid system (*Source: AEPC, Nepal*)

Table 1: Components used in Hybrid system

Components	QTY	Unit	Total
Wind Turbine	2	10 kW	20 kW
Solar PV Modules	50	300 Wp	15 kWp
VRLA Tub Gel Batteries	120	2 V/ 100 Ah	240 V/ 1000 Ah
DC/AC Inverter	1	45 kVA	45kVA

Source: AEPC, Nepal

Table 2: Solar Power System data

DOD of Battery	70%
Days of Autonomous	2 days
Peak Sunshine hours	5 hrs.
Coulombic efficiency	90%
Inverter efficiency	94%
De-rating factor	5%
Horizontal Irradiance	5.18 kWh/m^2/day
Tilted (27^0) irradiance	5.75 kW/m^2/day
Average temperature	14.6^0 C
Other losses (e.g. Cable)	7%
Average daily production	60 kWh

Table 3: Wind power System data

Average Wind Speed at 10m height	3.21m/s
Spot measurement	6-8m/s
Average daily wind production	49 kWh

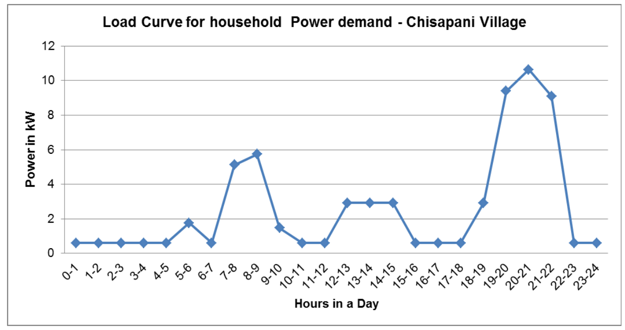

Figure 7: Load curve for household power demand

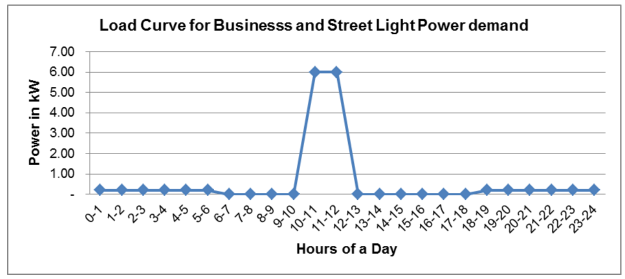

Figure 8: Load Curve for Business and Street Light Power Demand

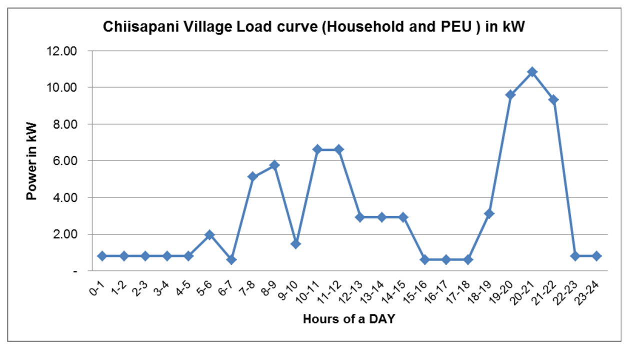

Figure 9: Load curve of Chisapani Village

peak demand is exactly 6 kw at 11-12 hour of a day. As a result, the contribution factor is nearly zero. In the case of the load curve for Chisapani village, the peak demand is at 21 hours of a day as shown in Figure 9.

The minimum energy from solar is 14.07 MWh/yr and wind is 14.07 MWh/yr with 50% share. Thus, a total of 100% energy supply from wind solar hybrid is 20.14MWh/yr.

3 Modeling

The simulation modeling of hybrid wind-solar system of Chisapani Village is done in MATLAB 2016 as shown in Figure 10.

In the model system, the solar array is of 15 kW along with consisting of 2 units of a 10-kW wind turbine. Solar array is connected to dc link capacitor through boost converter whose duty cycle is given by the maximum power point tracking point (MPPT) controller. A PMSG wind turbine is connected to dc link capacitor through machine side converter. The whole power from solar PV and wind turbine is supplied to the local distribution through the inverter

4 Simulation results

The below Figures show the simulation results for a model system of wind-solar hybrid system. Figure 11 illustrates the active power output from the PMSG wind. turbine where the output power is 15 kW. Similarly, the output power produced by the solar PV system is 15 kW as shown in Figure 12. Figure 13 shows the total active power that is generated by the wind-solar hybrid system which is 30 kW. In order to calculate the active power from the solar PV system, irradiance, temperature, voltage and current should be considered that is shown in Figure 14. The irradiance and temperature for solar PV system

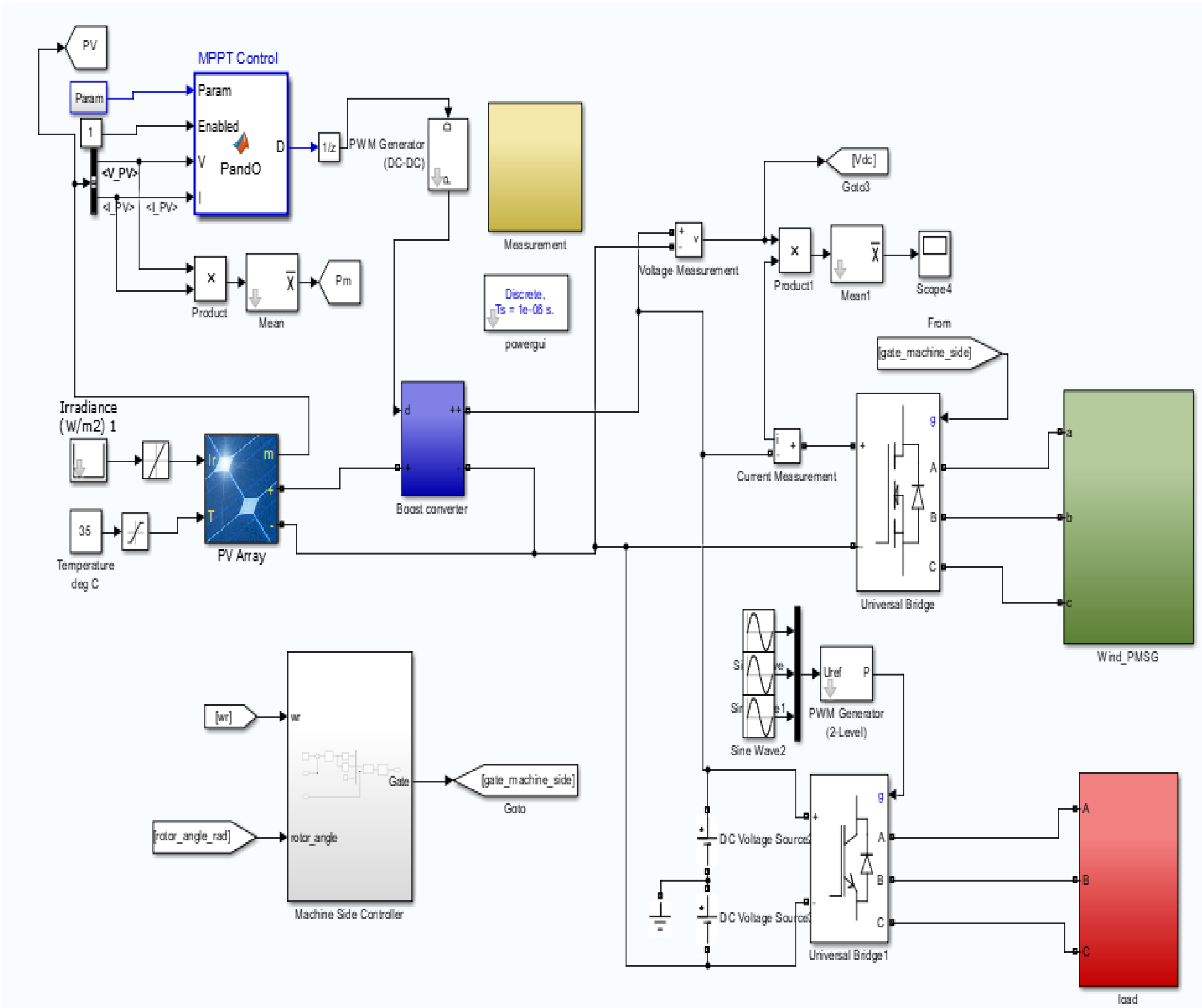

Figure 10: MATLAB Simulink Modeling of Hybrid System

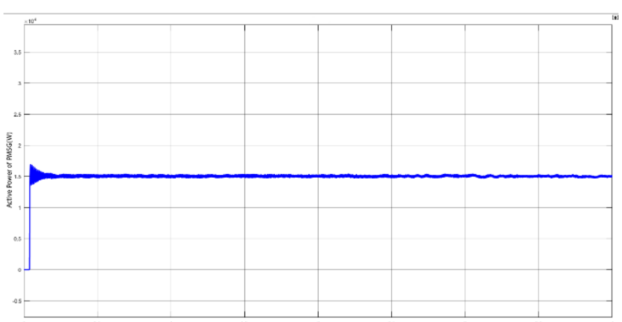

Figure 11: Active power at PMSG wind turbine

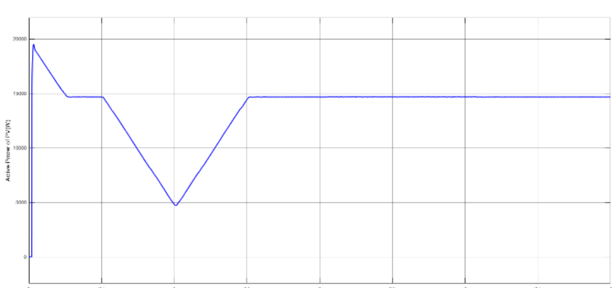

Figure 12: Active power at Solar PV system

are 750 W/m^2 and 35°C respectively. In addition, the voltage is 290 V whereas the current is 50 A. It is seen that it is the initialization condition is before the time of 1.5 s. After this time period, the hybrid system behaves in a normal condition as shown in all Figures.

Figure 10 shows the voltage across the capacitor for solar PV converter system which is 1 p.u. and the slight fluctuation occurs which is acceptable in this case. Figure 11 depicts the active and reactive powers at the load. The load consumes the active power of around 20 kW and reactive power of 5.5 kVar.

The simulation results show the modelling of the wind-solar hybrid system that is successfully implemented in a MATLAB Simulink simulator.

5 Scope for improvisation

It is successful to shift the land demand of the business to off-peak, period of (9-10 to 12-13) hours of the day.

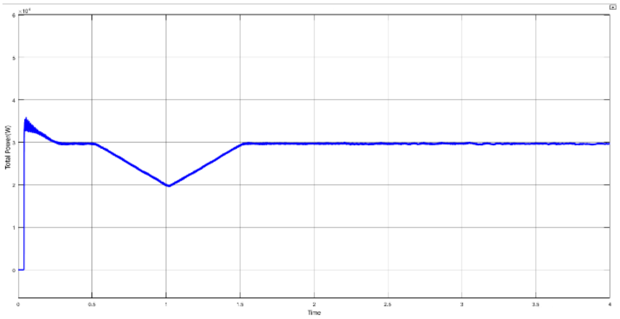

Figure 13: Total active power

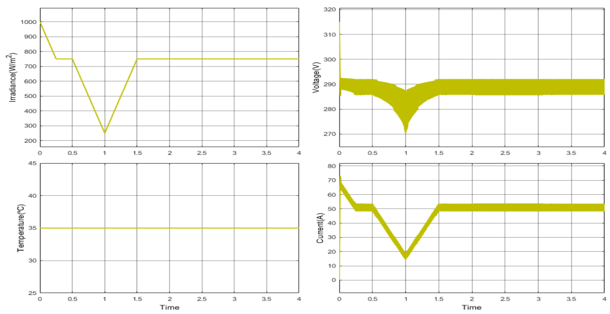

Figure 14: Irradiance, temperature, voltage and current in the case of solar PV system

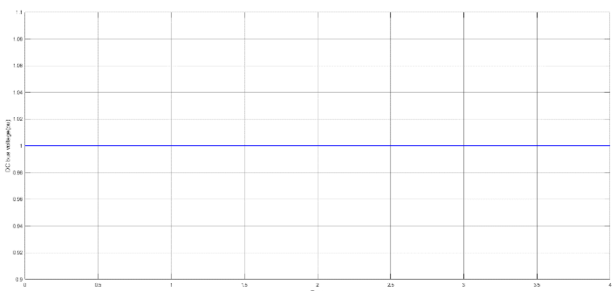

Figure 15: Voltage across Capacitor for solar PV converter

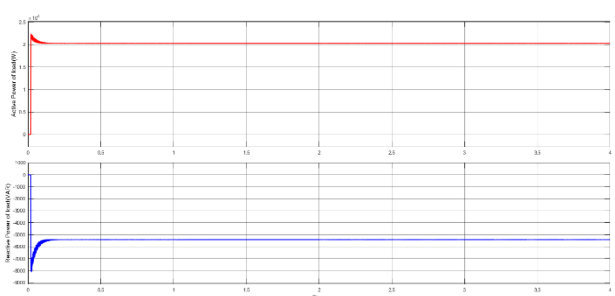

Figure 16: Active and reactive powers at load

However, there is still scope for smoothing the load curve. Energy demand increasing programs like establishment of small semi-automated cottage industries. These industries should only operate during off-peak period. A chart showing peak demand and off-peak period could be given to the operator so that purpose of the load curve smoothing could be effectively achieved.

Another scope is the use of the hybrid inverters as STATCOM (Static Synchronous Shunt Compensator). It could be used to meet the reactive power requirement of the village. Therefore, the STATCOM is one of the most promising methods to supply reactive power to support the voltage stability in this scope of system.

Based on the solar insolation chart of that area, the place has a good potential in solar. Hence, the reasonable and scientific subsidies and technical support could be provided to the villagers. Consequently, they could setup a small sized PV panel on rooftop; resulting in plenty of energy available for commercial usage which will transform the socio-economic standard of the villagers.

6 Conclusion

This paper describes the modelling of the wind-solar PV hybrid system using a MATLAB Simulink simulator and a case study of the hybrid system in a particular area in Nepal. The case study includes the recent data of wind-solar hybrid system. Moreover, it also explains the certain improvisation technique that can be applied to the site. Such a hybrid system when installing in rural areas not only contributes to the increasing reliability of the power system but also reduces the transmission line cost making it most economical alternatives for rural electrification. The opposite nature of wind and solar systems also reduces the component size fulfilling the actual demand of the area.

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