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Techno-economic Evaluation of Stand-alone Hybrid Renewable Energy System for Remote Village Using HOMER-pro Software

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ABSTRACT

The off-grid hybrid renewable energy generation system has lesser cost of energy with higher reliability when compared with solar Photovoltaic (PV) or wind energy system individually. The optimization design is worked out by reducing the Unit Cost Of Energy (UCOE) for different case studies and comparing the outcomes obtained by the use of HOMER-Pro (hybrid optimization model of electric renewable) software. The optimal cash flow analysis of hybrid energy system is based on the load patterns is discussed, solar irradiance (kW/m^2) of site at proper latitude and longitude, wind speed and price of diesel, which is collected from a remote village in Khurda District, Odisha in India. Moreover, the optimization and sensitivity results of the system are find out by varying the input parameters like solar radiation, wind speed etc.

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1. INTRODUCTION

Till today, about 36% of villages in India are un-accessed to grid electricity because of insufficient generation and difficulty in enhancement of transmission and distribution system. So, renewable energy sources (solar, wind, biomass and micro-hydro etc) are more suitable for remote/un-electrified village electrifications [1]. Standalone hybrid power generation systems are by now in running condition at several places of World, despite the fact that the solar energy or wind energy is unpredictable [2]. Single source of operation of these generating units are not proficient in requisites of cost, efficiency and trustworthiness. An effective alternate option is by uniting these dissimilar renewable resources to structure a Hybrid energy system [3]. Hybrid energy systems are free of greenhouse gasses, eco-friendly with little price and reduced erection time [4]. In order to get electrical energy from a hybrid system at a reasonable price, its plan ought to be optimized in terms of working principle and constituent part selection. Basing on algorithm of energy conception to optimize the solar photovoltaic (PV) module in a SPV-Wind hybrid system was discussed [5]. A simple mathematical model was implemented for component sizing and economic evaluation of an off-grid wind, solar PV hybrid system [6]. A linear programming procedure was developed for most favorable plan of a hybrid wind-solar PV power system for both off-grid or grid-connected applications [7]. A different aspect of SPV, wind, diesel and battery-based hybrid system including optimal sizing operation has been detailed discussed [8]. The different arithmetical models of a variety of designs and simulation models of the components that create these systems have been used. The difficulty in designing the models of the elements of the systems primarily depends on the type of applications [9]. A battery bank is also used in the system for short duration support to provide instant power [10]. The special energy storage/backup devices are integrated in the anticipated parallel hybrid system [11].

The facts of the system design, system unit-sizing, and the uniqueness of the most important system apparatus are also discussed in the paper. An overall power management approach is considered for the system to synchronize the power flows among the different energy sources. Simulation studies have been carried out to verify the system performance under different scenarios using practical load profile and real weather data.

2. SYSTEM CONFIGURATION

The proposed stand alone hybrid system is consists of PV modules, wind turbines (AC), diesel generator, inverter, batteries which is shown in Figure 1. The photovoltaic generator and wind energy generator will supply power at day time and the excess power generated by solar modules and wind turbine will be stored by battery bank. The wind turbine is operated with an induction generator with variable speed. The diesel engine is acting in parallel to provide electrical energy to meet the load demand. The AC primary loads are typically residential loads. The water pumps, rice mills are transient type of loads connected to the system.

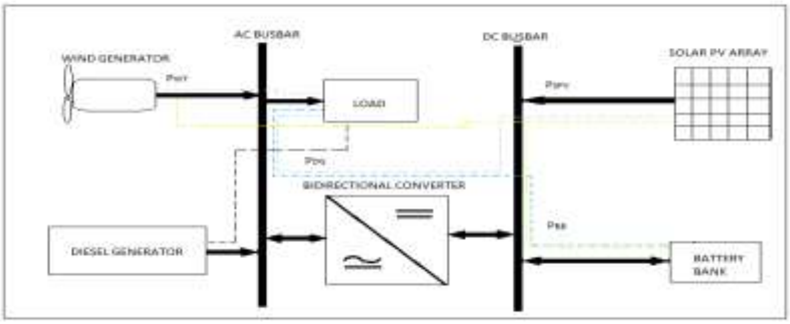


Figure 1. Model configuration of proposed hybrid renewable power system

3. METHODOLOGY

A rural village Gangapada (latitude $20^0 12'$ N and longitude $85^0 40'$E) in Odisha, is chosen for this research because the grid supply is available for few hours per day. Then by collecting important data like hourly load demand, the total electricity demand per year is calculated. The energy potential of renewable energy resources in that village, such as solar, wind or biomass by measuring of each resource based on their parameters is calculated. The most appropriate combination of renewable energy resources to be proposed as a renewable hybrid energy system. The model of the hybrid renewable energy with all the components involved is prepared. After finishing the model, the computer simulation of the system is done by HOMER-Pro software. The output resulted by the simulation is to be analysed and finally there is justification of the hybrid system.

3.1. Designing and unit sizing

For unit sizing the renewable energy resources used in hybrid system, the power obtained from the photovoltaic module and wind generator during every hour is calculated as in equation (1):

$$P_{res}=N_{spv}.\ P_{spv} + N_{wt}.P_{wt} \quad (1)$$

Where, P_{res} is the power generated from the renewable sources at particular interval of time, N_{spv} and N_{wt} are the number of photovoltaic modules and wind turbine generators respectively, P_{spv} and P_{wt} are the power generated from PV modules and wind turbine generators respectively.

The unit sizing is done by fixing some PV modules and wind turbines as both PV modules and wind turbines are used as energy sources. The storing devices (battery Bank) and the backup diesel generator are to be sized according to load requirement. The battery bank is chosen with the capability of storing maximum energy from the renewable energy sources when there is peak periodof supply.The sizing of battery bank capacity depends on the daily energy consumption (KWh/day).

$$Battery\ Capacity = \frac{Daily\ energy\ demand}{Battery\ efficiency}\ X\ \frac{Days\ of\ Autonomy}{Depth\ of\ discharge}[\text{Wh}] \quad (2)$$

When there is no energy from renewable resources or battery bank, the diesel generator is sized basing upon load demand to meet peak load demand and is capable of supplying power for 24 hour.

$$P_{dg(p)}=P_{Load(p)} \quad (3)$$

Where, $P_{dg(p)}$ is peak load power of diesel generator and $P_{Load(p)}$ is the peak load demand of system.

The main constraints of the hybrid system are periodically accessibility of renewable energy resources, balancing of the load demand-supply, optimum working restrictions of the individual components. The most advantageous operating policy and yearly LCC (life cycle costs) of this design is calculated by the help of HOMER-Pro. The minimum price, less utilization of DG set and service consistency is preferred as the best possible combination.

4. COMPONENTS OF HYBRID POWER SYSTEM

In this paper, the system consists of wind turbine generator, solar PV generator, and diesel generator and battery bank. The diesel gen-set must be able to supply the power when renewable energy source with battery bank power lesser than the load demand.

4.1. Wind turbine generator

The output power (P_{wt}) of the wind turbine is as follows in (4)

$$P_{wt}=1/2.\ \rho_{air}\ .C_p(\beta,\ \lambda).\ A_{wt}\ V^3_{wind} \quad (4)$$

Where:

ρ_{air}; the air density in kilogram per cubic meter
C_p; the power coefficient of wind turbine depends on design
β; pitch angle
λ; tip speed ratio,
A_{wt}; the area swept by the rotor blades in square meter,
V_{wind}; the wind velocity in meters per second,
ω; rotor speed of wind turbine

The output power is kept constant when wind speed is higher than the rated wind velocity even though the wind turbine has the potential to produce more power. This is done through the pitch angle control to protect the electrical system and to prevent over speeding of the rotor. Figure 2 shows variation of wind power with wind speed (MATLAB).

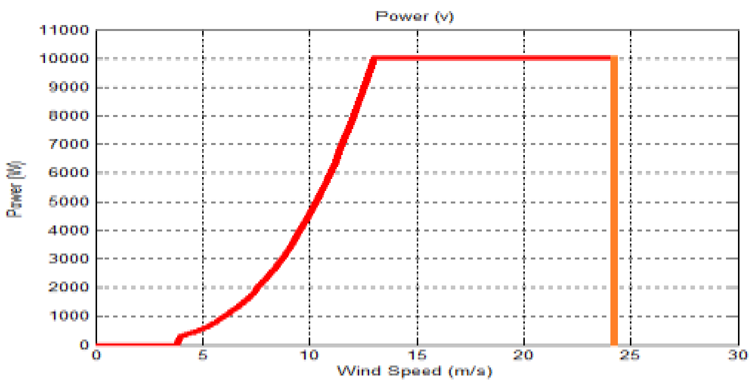


Figure 2. Variation of wind power with wind speed (MATLAB)

4.2. Solar PV generator

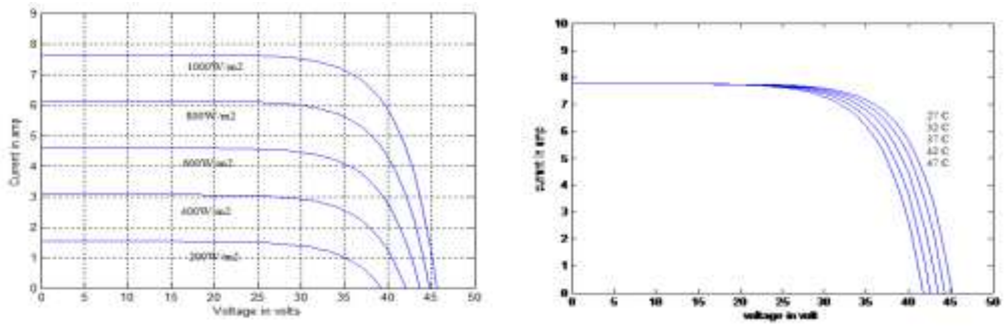
When solar radiation is incident upon the silicon cell, the electrical energy is generated. The output power of solar PV array P_{spv}:

$$P_{spv}=n_s.\ n_p.\ V_{oc}.\ I_{sc}.\ FF \tag{5}$$

Where, n_s and n_p are the number of series and parallel solar cells, V_{oc} is the open circuit voltage of solar module; I_{sc} is the short circuit current of PV module and *FF* is the fill factor.

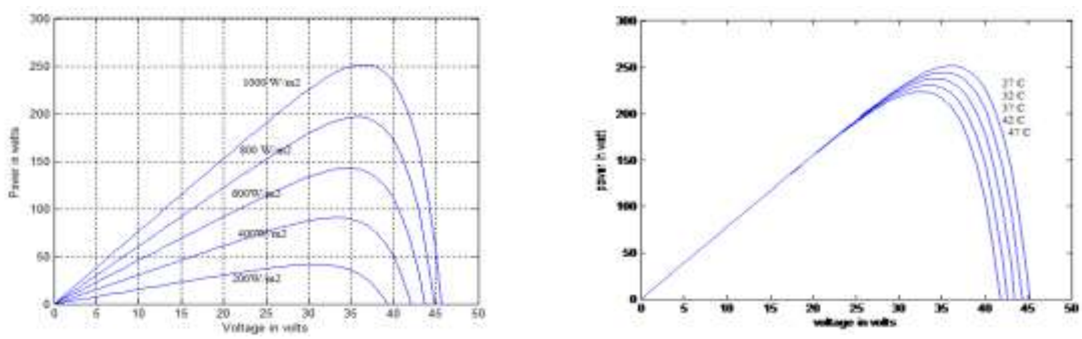
The characteristic curves (MATLAB) of the PV module used in this study under different irradiances (200W/m^2, 400W/m^2, 600W/m^2, 800W/m^2 and 1000W/m^2) at constant temperature 27^{0}C are shown in Figure 3(a), 4(a) and 5(a). It is noted from the figures that the higher the irradiance, the larger are the short-circuit current (I_{sc}) and the open-circuit voltage (V_{oc}). As a result, the larger is the output PV power.

The temperature plays an important role in the PV performance because the four parameters (I_{ph}, I_0, *Rs* and α) are all functions of temperature. The effect of the temperature on the PV model performance is illustrated in Figure 3(b), 4(b) and 5(b). It is noted from the figures that the lower the temperature, the higher is the maximum power and the larger the open circuit voltage.



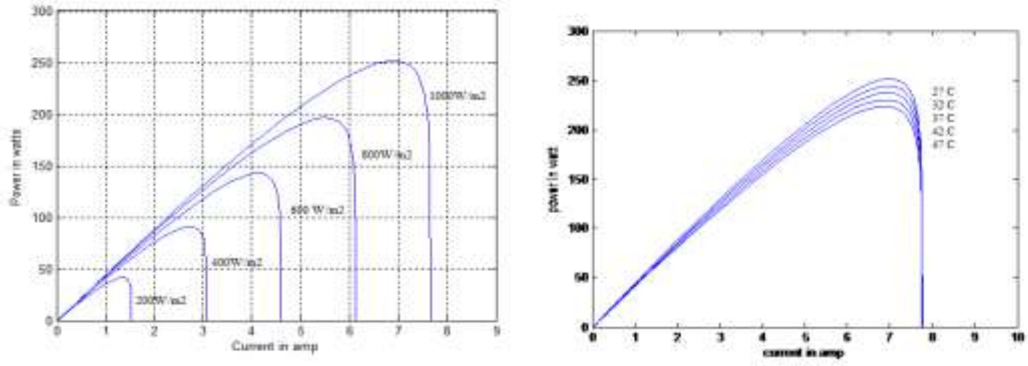
(a) (b)

Figure 3. (a) I-V characteristics curve at different solar radiation (b) and at different temperatures



(a) (b)

Figure 4. (a) P-V characteristics curve at different solar radiation (b) and at different temperatures



(a) (b)

Figure 5. (a) P-I characteristics curve at different solar radiation (b) and at different temperatures

4.3. Diesel generator

The utilization of DG set is universal in various types of hybrid power system to ensure continuity of power supply. It is a combination of diesel engine and synchronous generator to produce electrical power to meet the load demand. The synchronous generator operates at constant speed of diesel engine to provide required output voltage at 50 Hz frequency.These type of DG sets mostly operate at efficiency of 30% for nominal load. The diesel generator fuel consumption depends upon the output power. About 25% of the fuel at rated full power is still consumed by generator even if no power is generate from it and also gives huge amount of pollutant gases. But to reduce the pollutant gas emissions, the diesel generator should run for short duration of time.

4.4. Battery bank

4.4.1. State of charge of battery

At any time the status of battery is related to the previous state of charge, the energy production and consumption of the system during the period from (t-1) to t. When the total output of the wind turbine and solar PV exceeds the load demand, then the battery starts charging [11]-[12].

$$C_{batt}(t)=C_{batt}(t-1).(1-\sigma)+[E_{WT}(t)+E_{SPV}(t)-\frac{E_L(t)}{\eta_{inv}}]\eta_{batt} \quad (6)$$

On the other hand when the load demand exceeds the available generated energy, the battery is in discharging state [13]-[14].

$$C_{batt}(t)=C_{batt}(t-1)).(1-\sigma)-[\frac{EL(t)}{\eta inv}-\{E_{WT}(t)+E_{SPV}(t)\}] \quad (7)$$

Where $C_{batt}(t)$ and $C_{batt}(t-1)$ are battery bank capacity (wh), η_{batt} is battery bank efficiency, σ is self discharging rate, $E_{WT}(t)$,$E_{SPV}(t)$ and $E_L(t)$ are the energy generated by wind generator PV generator and load demand respectively. η_{inv} is the inverter efficiency.
At any hour, the storage capacity is subject to the following constraints;

$$C_{batt(min)} \leq C_{batt}(t)) \leq C_{batt(max)} \quad (8)$$

Where $C_{batt(max)}$ and $C_{batt(min)}$ are the maximum and minimum allowable storage capacity.
Using for $C_{batt(max)}$ the storage nominal capacity $C_{batt(n)}$, then

$$C_{batt(min)}=DOD.\ C_{batt(n)} \quad (9)$$

Where, DOD (%) represents the maximum permissible depth of battery discharge.

5. OPTIMAL OPERATING PROCESSES

Optimal control strategy of hybrid renewable power generation system is to come across the most reasonably priced investigation for dissimilar combinations of renewable generators with diesel generator and battery backup, gratifying load balance, resource accessibility and apparatus constraints. The dispatch policy is such that the battery charges, if the renewable energy is bigger than the load demand and discharges, if load exceeds the output of renewable energy. Diesel generator is used as part of the structure to act in response to the urgent situation where renewable production and stored energy are not adequate to meet the load demand. The renewable energy source constraints are such that they should be used as much as possible. The optimal operation approach for a solar PV-Wind combination so as to minimize the annual operating cost (C_{op}) computed based on the operating cost for the interval (t) in a day. Operational costs are calculated on the basis of component characteristics, size and efficiency.

6. RENEWABLE ENERGY SOURCES

6.1. Solar radiation

From the data provided by National Renewable Energy Lab database, the average solar radiation for the selected un-electrified area (latitude $20^0$12' N and longitude $85^0$40'E) is estimated to be 4.84 kWh/m2/day and average clearness index is 0.522. This is explained in Figure 6. It can be noticed that more solar irradiance can be expected from the month of February to June and October while less solar irradiance is to be expected from July to September and December. This correlates to the load requirements as discussed earlier.

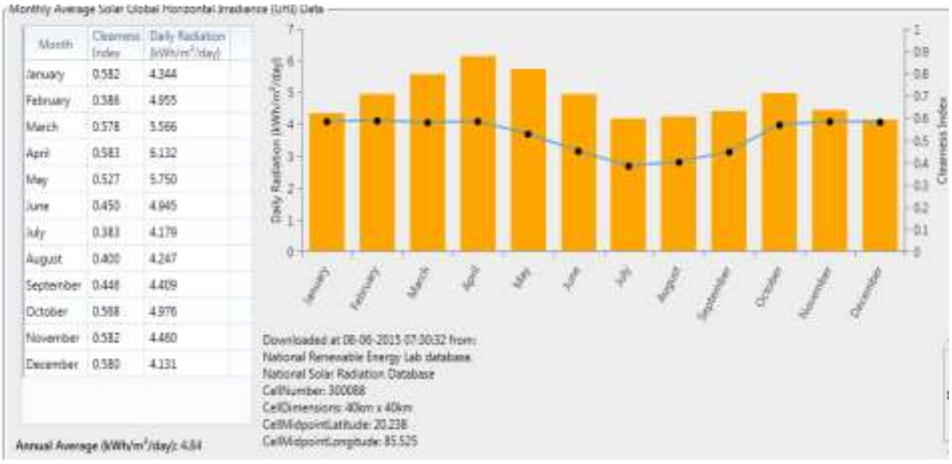


Figure 6. Monthly average solar radiation and clearness index (HOMER-Pro)

6.2. Wind resources

The hourly wind speed data of the region (latitude $20^0$12' N and longitude $85^0$40'E), is measured at the height of 15m by Anemometer. Annually wind speed distribution profile of the selected site is shown in Figure 7. According to wind speed data, the regional average wind speed is about 3.93m/s. Moreover, it is clear that the highest and lowest wind speed values occur in April and January respectively.

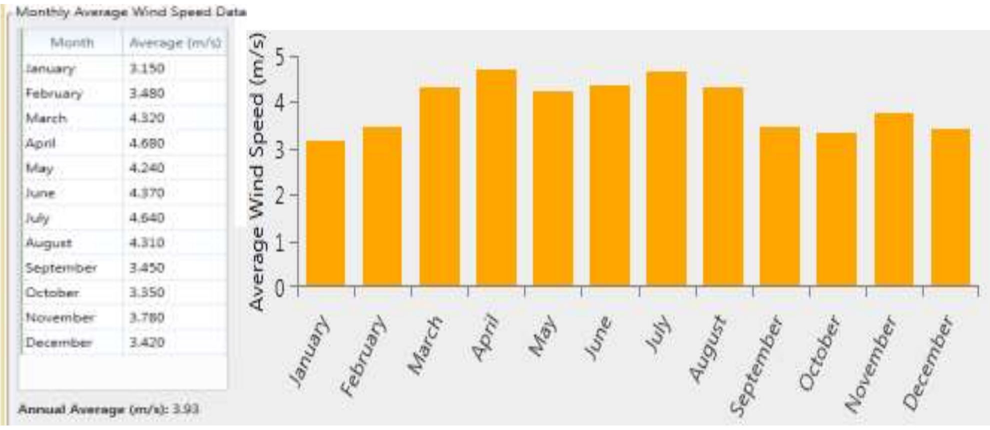
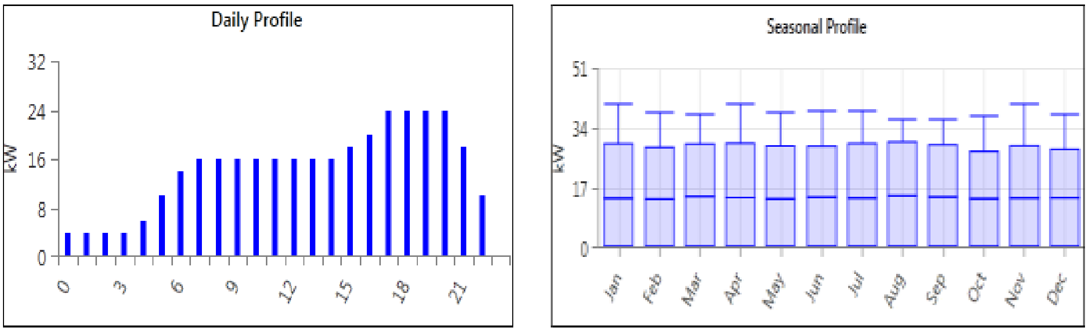


Figure 7. Monthly average wind speed of site (HOMER-Pro)

6.3. Load demand

There are various types of domestic loads such as fan, CFL, fluorescent lamps; colour TV, FM radio sets, electric iron etc are used in residential system in rural villages. The electrical load consumption of the un-electrified village for 24 hour is calculated. The hourly basis electricity consumption (340kWh/day) and monthly average load (25.09kW peak) is shown in Figure 8 (a) and (b).



(a) (b)

Figure 8. Daily and Seasonal load profile of selected site (HOMER-Pro)

7. COMPONENT DETAILS

Basing upon the availability and potential of renewable energies in the study area, a hybrid power generating system is modelled consists of wind turbines, solar PV system, Diesel generator and battery storage system as backup. The details of various parameters of PV module, wind turbine, DG set, battery, converter etc in the proposed hybrid scheme have been collected from different resources which are given in Table 2 (a, b, c, d, and e).

Table 2 (a). The Specifications of Wind Turbine

Descriptions	Specifications
Rotor diameter	2.62 m
Blades	3
Start up wind speed	3.93 m/s
Rated power	10 kW
Generated voltage	24 V
Lifetime	20 years

Table 2 (b). The Specifications of Solar PV Module

Descriptions	Specifications
Material	Monocrystalline-si
Rated power	250 W
Nominal Load Voltage	24 V
Voltage at maximum power point	35 V
Short Circuit current	7.75 A
Current at maximum power point	7.14 A
Nominal Efficiency	13 %
Life time	25 years

Table 2 (c). The Specifications of Battery Bank

Descriptions	Specifications
Nominal Voltage	12 V
Nominal capacity	83 Ah
Round trip efficiency	80 %
Minimum state of charge	40 %
Energy capacity of each battery	1 kWh
Life expectancy	20 years

Table 2 (d). The Specifications of Converter

Descriptions	Specifications
Nominal power	20 kW
Maximum input voltage	450 V
Maximum input current	50 A
Peak efficiency	94 %
Output voltage	480 V
Lifetime	20 years

Table 2 (e). The Specifications of Diesel Generator

Descriptions	Specifications
Rated power	10 kW
Rated voltage	400/230 V
Load current	62.5A
Rated power	10 kW
Fuel cost	0.95 $/L
Lifetime	15000hrs

8. HOMER SIMULATION OF HYBRID POWER SYSTEM

The selection and sizing of components of the hybrid energy system have been done, using HOMER-Pro software. Input information is provided to HOMER like yearly load demand, average solar radiation, wind speed data and detailed costs. HOMER-Pro is an optimization model which does thousands of simulations and gives best possible design for the system. The choice of the site has been made based on the fact that the wind and solar power throughout the year is sufficient for setting up a hybrid power generation in Figure 9.

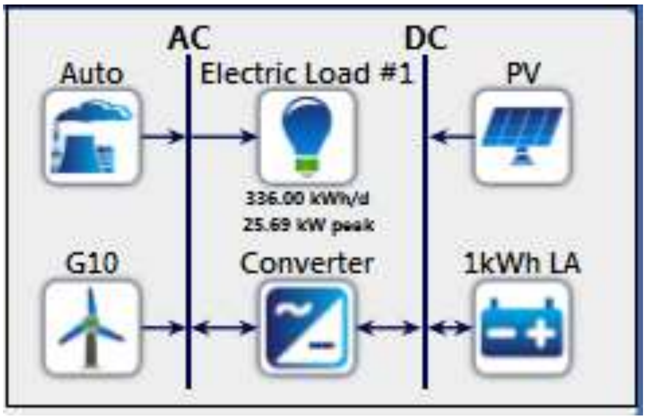


Figure 9. Proposed Hybrid system by HOMER-Pro software

9. RESULT AND DISCUSSION

9.1 Sensitivity results

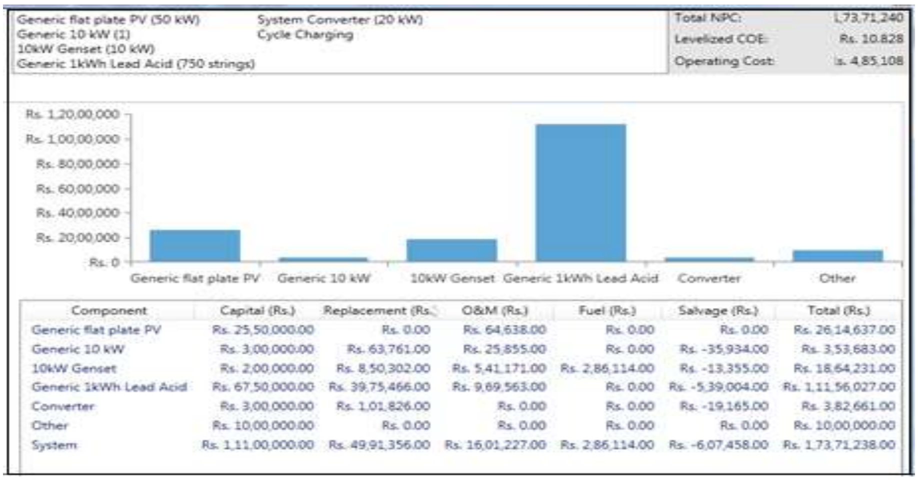
The sensitivity variables such as solar insolation, temperature, wind speed and diesel cost are selected for this study. The search space may be lengthened by putting a range of options to select best possible configuration. HOMER-Pro simulates each and every one of designs in their respective search space for every sensitivity values. An hourly time series simulation for every possible system type and configuration is done for one year duration. A feasible structure is defined as a solution or hybrid system configuration that is capable of meeting the load. HOMER-Pro discards all infeasible configurations and positions the practicable designs in accordance with ever-increasing net present cost (NPC). It moreover permits so many parameters to be displayed against the sensitivity variables intended for selecting the best possible structure.

Taking into consideration current diesel price (0.95$/L), a PV- wind-diesel-battery based hybrid system is appropriate for stand-alone loads. Total net present cost (NPC), Capital cost and cost of energy (COE) for such a system is (Rs 1, 62, 46,870) $270,781, (Rs 1, 11, 00, 000) $1, 85,000 and (Rs 12.10) 0.201$/kW h, respectively. For the site with minimum wind penetration, PV- DG set- Battery bank structure is more preferable. However, the capital cost and NPC are lower for such a system; the COE is much higher ($0.376/kW h). Related overheads of hybrid energy systems are augmented too. One significant assessment is that, a photovoltaic based structure comes into the picture only when wind resource is very inadequate, solar energy density is very high and cost of diesel is elevated. Diesel price and battery bank cost multiplier are taken as the sensitivity parameters.

9.2 Optimization results

In HOMER-Pro, the optimization results could be categorized for a particular set of sensitivity parameters, considering the diesel price fixed at 0.95$/L, (wind speed 3.93 m/s and solar irradiation 4.84 kW h/m2/d). At present, a PV- wind-diesel generator-battery system is the most suitable. Considerable reduction in carbon emission, and dependency on fossil fuel could be achieved by replacing the diesel with blending of biodiesel in system.

Figure 10, gives a complete abstract of the net present values of different costs involved in the project throughout its lifetime of 20 years. After 05 years battery replacement occurs. But the diesel generator replacement does not occur within 20 years lifetime of the project, because the hours of operation of the generator during a year is about 1240 and therefore the total operating hours of the generator during the project lifetime is 24800 which is less than the lifetime operating hours of the generator (25000 hrs). Figure 11 shows cash flow of hybrid system through out life time.



Component	Capital (Rs.)	Replacement (Rs.	O&M (Rs.)	Fuel (Rs.)	Salvage (Rs.)	Total (Rs.)
Generic flat plate PV	Rs. 25,50,000.00	Rs. 0.00	Rs. 64,638.00	Rs. 0.00	Rs. 0.00	Rs. 26,14,637.00
Generic 10 kW	Rs. 3,00,000.00	Rs. 63,761.00	Rs. 25,855.00	Rs. 0.00	Rs. -35,934.00	Rs. 3,53,683.00
10kW Genset	Rs. 2,00,000.00	Rs. 8,50,302.00	Rs. 5,41,171.00	Rs. 2,86,114.00	Rs. -13,355.00	Rs. 18,64,231.00
Generic 1kWh Lead Acid	Rs. 67,50,000.00	Rs. 39,75,466.00	Rs. 9,69,563.00	Rs. 0.00	Rs. -5,39,004.00	Rs. 1,11,56,027.00
Converter	Rs. 3,00,000.00	Rs. 1,01,826.00	Rs. 0.00	Rs. 0.00	Rs. -19,165.00	Rs. 3,82,661.00
Other	Rs. 10,00,000.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 0.00	Rs. 10,00,000.00
System	Rs. 1,11,00,000.00	Rs. 49,91,356.00	Rs. 16,01,227.00	Rs. 2,86,114.00	Rs. -6,07,458.00	Rs. 1,73,71,238.00

Figure 10. Cost Summary of Hybrid system by HOMER-Pro software

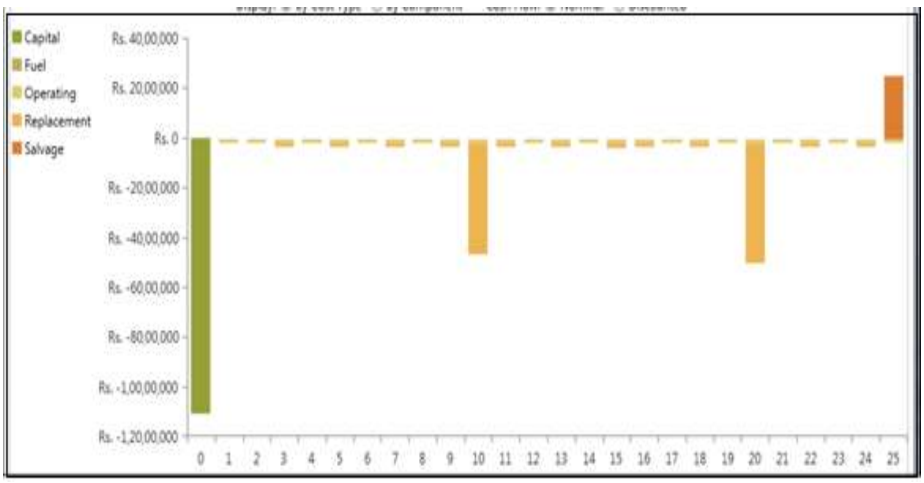


Figure 11. Cash flow of Hybrid system through out life time

9.3. Performance analysis

Monthly average electric power production from each of the system components in the hybrid system is shown in Figure 12. Here we can see that the largest percentage of the power is generated by the solar PV. Especially the generated power from the solar PV is considerably higher during the months from March to May and October. On the other hand the average power generated from the solar PV is relatively small during the period of June to August. Therefore, the diesel generator has to produce much more energy during June to August than the other month. As can be seen in the figure, energy generation from the renewable systems is considerably high during March to May. But still there is a contribution from the diesel generator. That implies that the diesel generator is still required to supply the peak demand during this period.

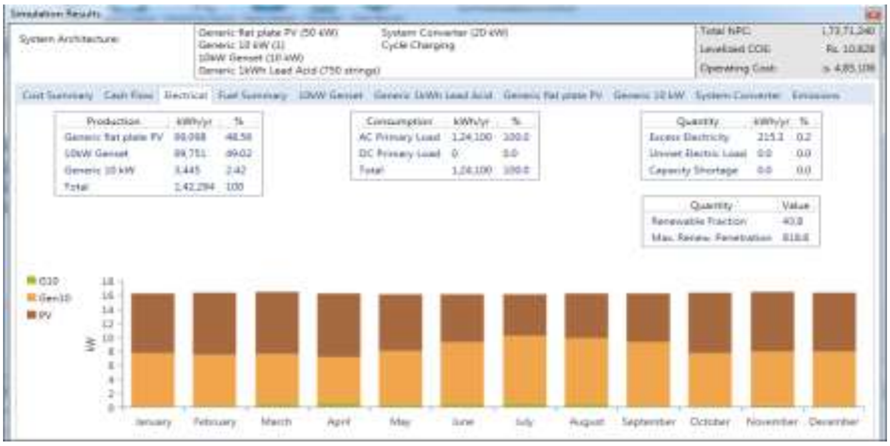


Figure 12. Monthly average electrical energy production from different elements of hybrid system

Figure 12 demonstrates the yearlyl energy production statistics from different apparatus and additional related performance analysis of the hybrid system. The wind turbines generate the lowest percentage of 2% of the total annual energy generation while solar PV and the diesel generator generate each 49 % of the total. Therefore the renewable fraction of the system is 44% and 0.2 % of the total annual energy generation is excess energy, according to simulation. The There is no capacity shortage of thos design. The generator dispatching strategy used here is the load following criteria; therefore the generator must be operated such that it produces only the required amount of power to cover the shortage capacity that cannot be supplied from the renewable systems or battery bank to meet the load. The capacity factors of PV-system, wind generator and diesel generator are 15.8%, 3.93% and 77.5% respectively. Figure 13 shows fuel consumption summary of Hybrid system by HOMER-Pro software. Figure 14 shows generator power output of Hybrid system by HOMER-Pro software.

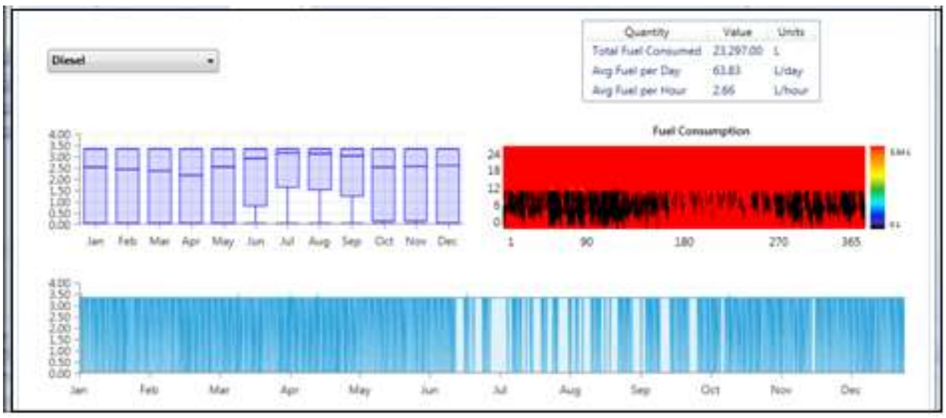


Figure 13. Fuel consumption summary of Hybrid system by HOMER-Pro software

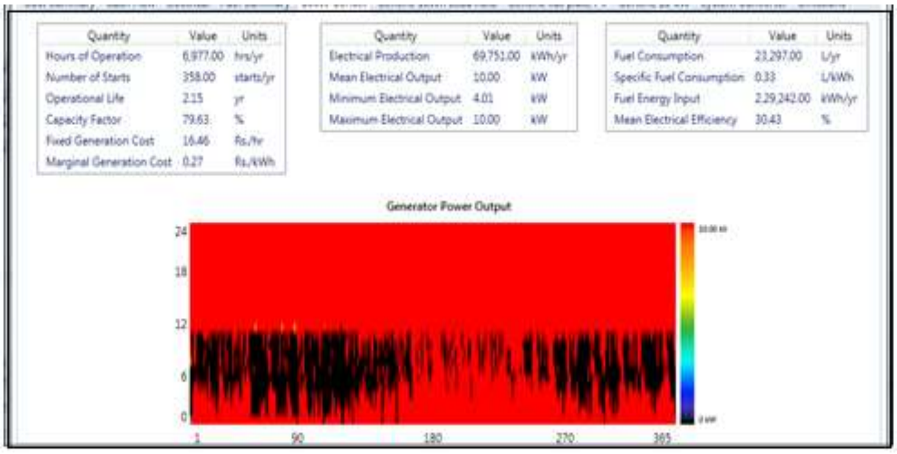


Figure 14. Generator power output of Hybrid system by HOMER-Pro software

The ecological advantage should be the important criteria, while preparing the renewable hybrid power generation system, for the reason that several developing nations tries to mitigate the global warming effect by reducing green house gas emissions. Although there is no financial charging plan for polluting gas emissions in India but so many guiding principles applied in this perspective so far. So, the GHG emission costs should be taken into consideration while, analyzing the hybrid generation system. Here major apprehension towards Carbon Dioxide (CO2) which is produced from burning diesel in generator as shown in Table 3. The charges of carbon dioxide per ton are different from nation to nations. The current prices of CO2 per ton are varying from country to country. By considering the financial condition of India, it is assumed a value of $10 per ton of carbon dioxide for this analysis. Figure 15 shows lead acid battery details of Hybrid system by HOMER-Pro software.

Table 3. Emission details of Diesel Generator by HOMER-Pro Software

Emissions	Value	Unit
Carbon Dioxide	61,349	Kg/Yr
Carbon Monoxide	151.43	Kg/Yr
Unburned Hydrocarbons	16.77	Kg/Yr
Particulate Matter	11.42	Kg/Yr
Sulphur Dioxide	123.20	Kg/Yr
Nitrogen Oxides	1351.20	Kg/Yr

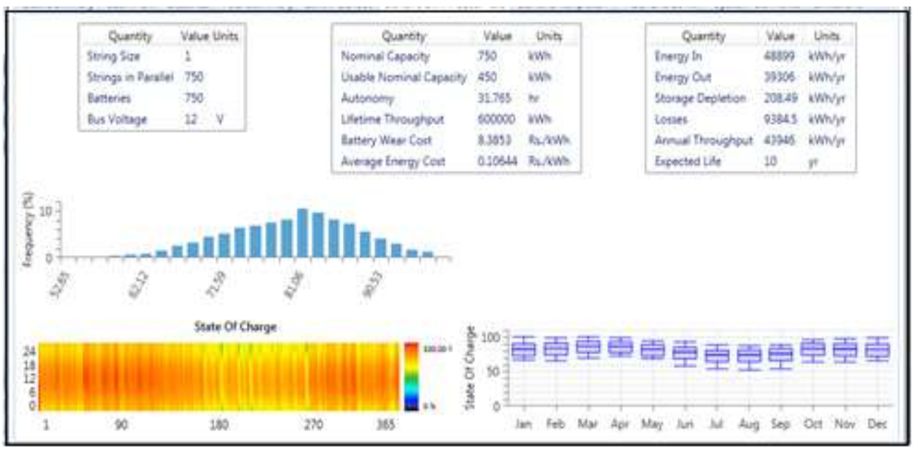


Figure 15. Lead acid battery details of Hybrid system by HOMER-Pro software

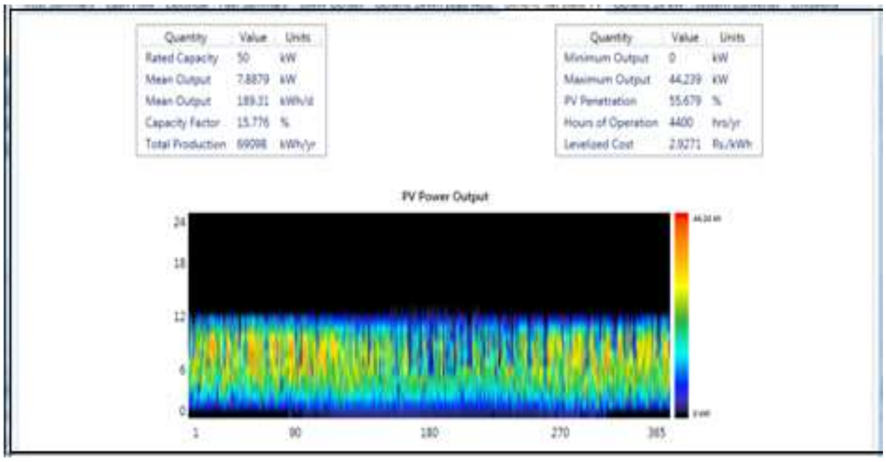


Figure 16. PV power output of Hybrid system by HOMER-Pro software

Figure 16 shows PV power output of Hybrid system by HOMER-Pro software. Figure 17 shows wind turbine power output of hybrid system by HOMER-Pro software. Figure 18 shows converter output of hybrid system by HOMER-Pro software. Figure 19 shows daily output of different components of Hybrid system by HOMER-Pro software (January &April).

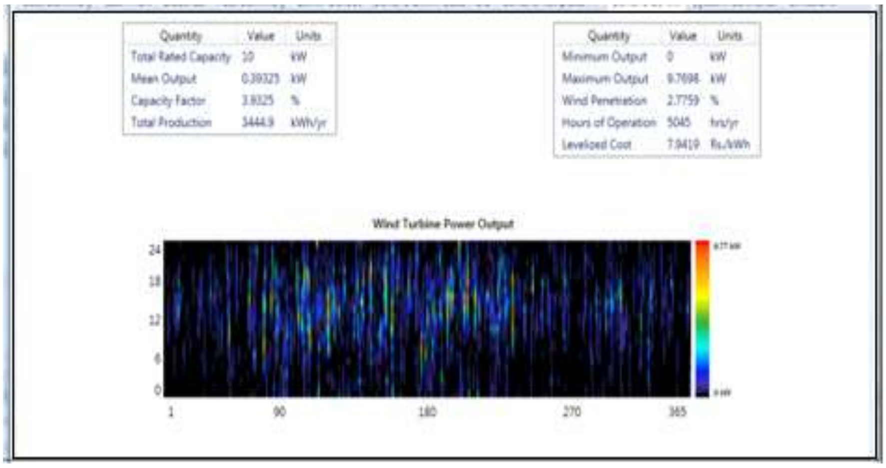


Figure 17. Wind turbine power output of hybrid system by HOMER-Pro software

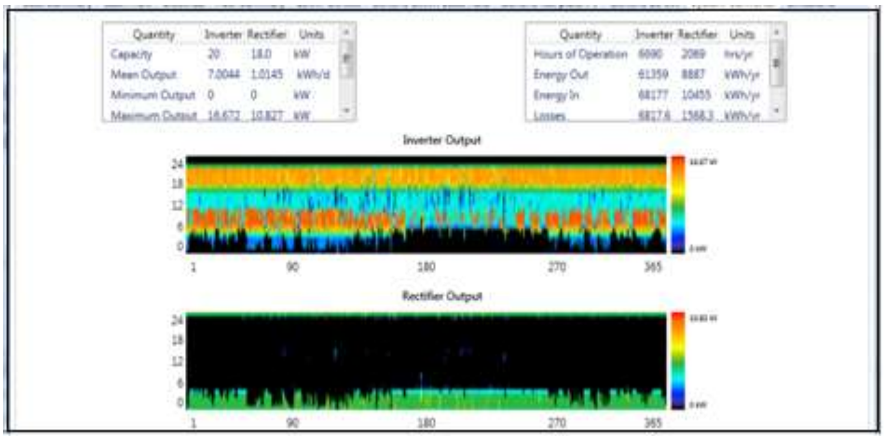
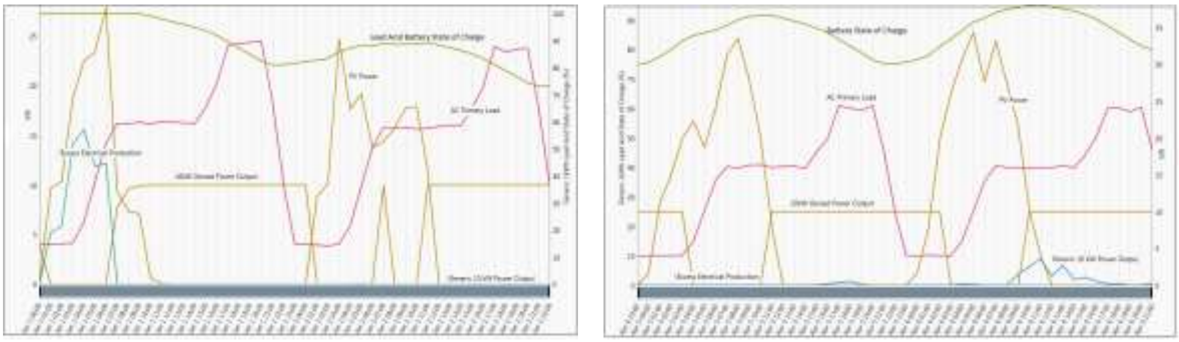


Figure 18. Converter output of hybrid system by HOMER-Pro software



(a) (b)

Figure 19. Daily output of different components of Hybrid system by HOMER-Pro software (January &April)

Figure 20 shows daily output of different components of Hybrid system by HOMER-Pro software (May). Figure 21 shows daily output of different components of Hybrid system by HOMER-Pro software (July &October).

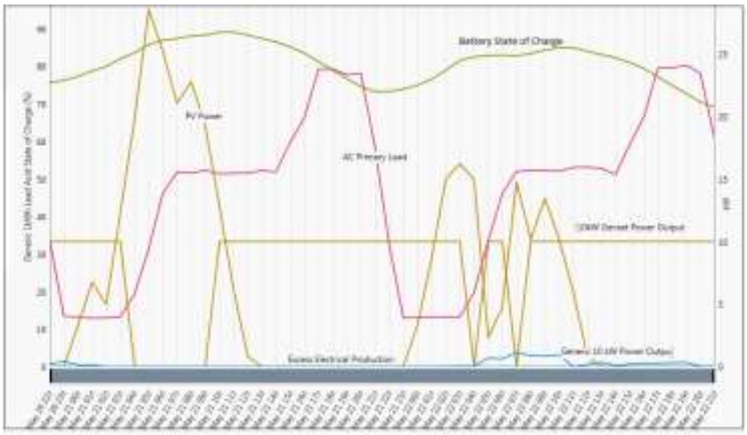


Figure 20. Daily output of different components of Hybrid system by HOMER-Pro software (May)

The performance analysis of five months is discussed in above and below figures. In each figure, the assessments of two days are given. It is observed that the peak load demand and the output of each generator are not matching. So, the diesel generator runs for long duration. Due to low potential of wind speed, the outcome of wind generator is very low compared to PV system. The state of charge of lead acid battery is above 70% always.

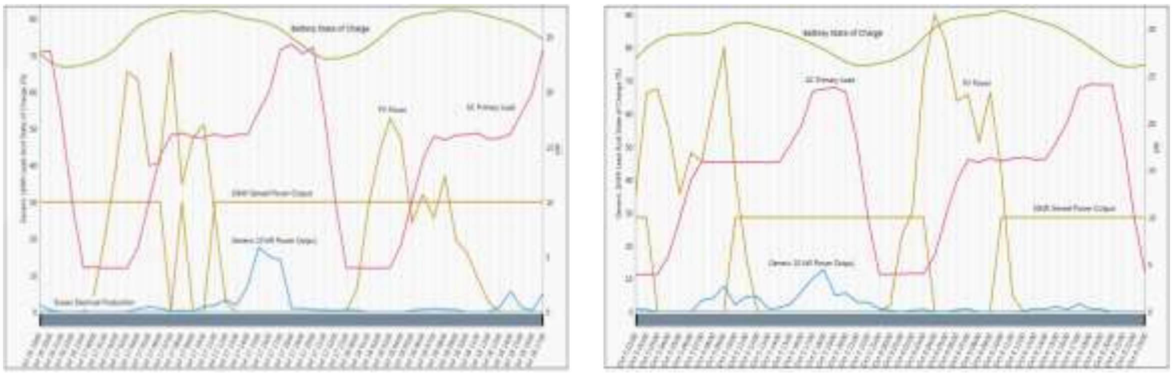
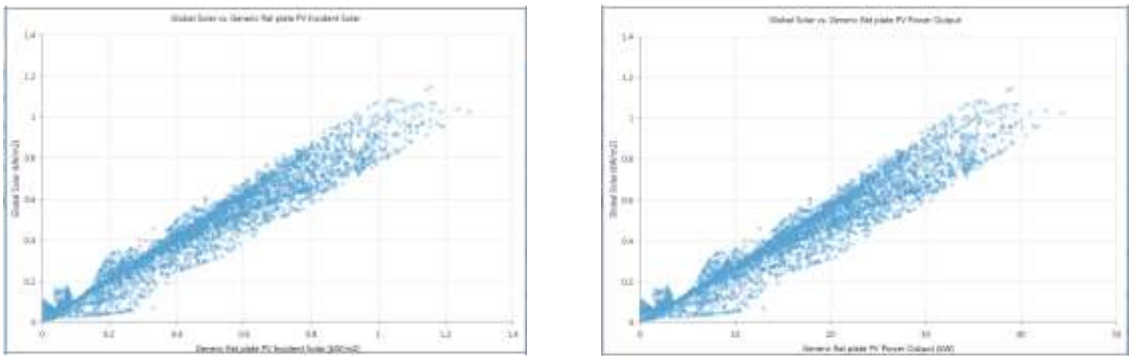


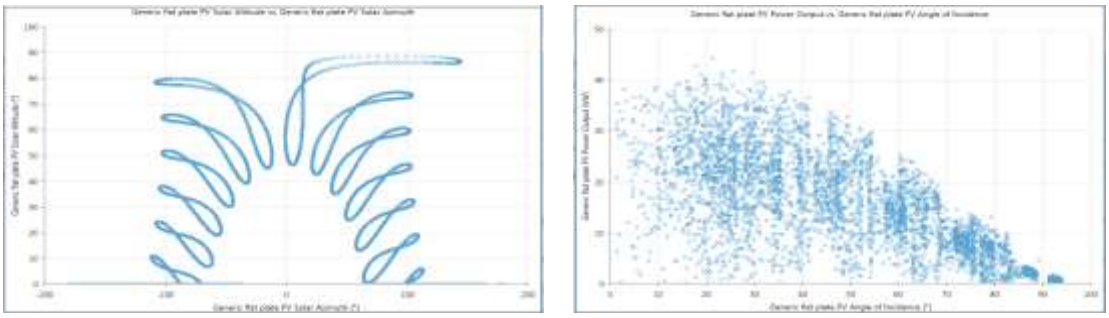
Figure 21. Daily output of different components of Hybrid system by HOMER-Pro software (July &October)



(a) (b)

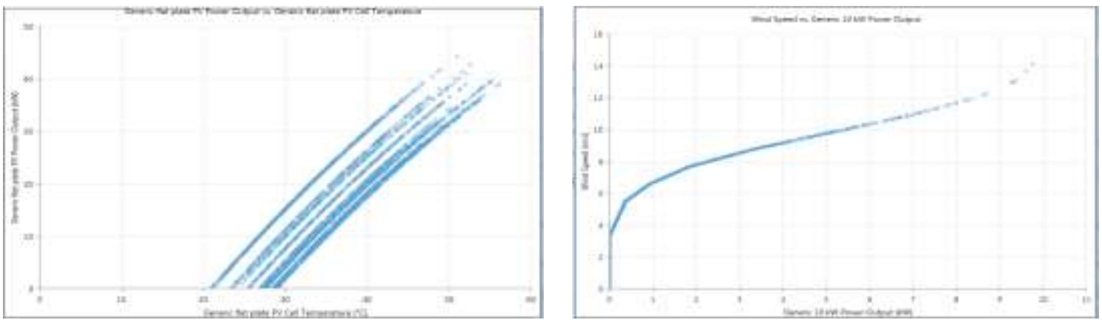
Figure 22. (a) Relation between Global solar and Incident solar (b) and Variation of PV power output with Global solar radiation

The solar radiation incident from sun is 1367W/m2. Due to several losses occurred in atmosphere, approximately 1000W/m2 solar insolation reaches on earth which is clearly observed from Figure 22(a). The output power released from the solar cell fully depends on the solar radiations that can be seen in Figure 22(b). The photovoltaic output is inversely proportional to solar angle of incidence. It is observed from the Figure 23(b) that larger the angle of incidence, lower is the PV cell output. Figure 23(a) also establishes the relation between solar altitude and solar azimuth. Figure 24(a) demonstrates how the output power of solr cell affected by cell temperature. The performance of PV cell is satisfactory at ambient temperature. The wind speed is the key factor of output power of wind turbine, which is observed from the characteristic curve in Figure 24(b).



(a) (b)

Figure 23. (a) Relation between Altitude and Azimuth of solar PV (b) and Variation of solar PV power with Angle of incidence of solar insolation

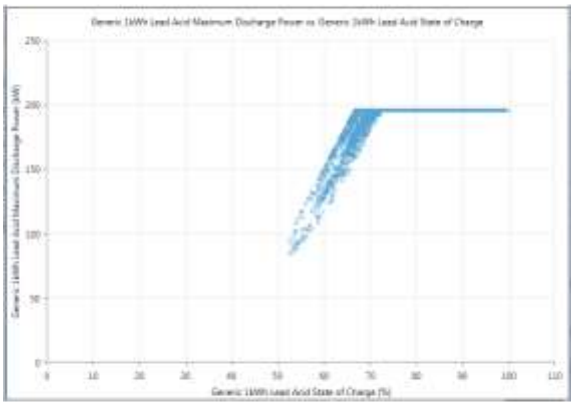


(a) (b)

Figure 24. (a) Variation of PV output power with cell temperature (b) and Wind power versus wind speed

The state of charge of lead acid battery depends on the charging capacity of battery. The minimum state of charge is 40% and also the battery can not discharge below that. Care should be given to battery for 100% charging always for better performances, than can be find out from the Figures 25 (a) and (b).

(a)



(b)

Figure 25. (a) Lead acid battery state of charge versus battery charge power (b) and discharge power

10. CONCLUSIONS

Now days, hybrid renewable energy system generating lesser amount of GHG emissions are cost effective in nature, compared to traditional fossil fuel based off-grid or grid tied generating system. On the other hand, there is still requirement of the research and development towards the renewable energy technology to improve its quality and reliability meant for extensive utilize of such generating systems. A variety of energy sources (solar, wind and diesel generator) and storage devices (battery bank) were chosen for this analysis. The optimization tool developed by NREL, HOMER-Pro is utilized to select the best possible hybrid combination and their applications. Following conclusions could be abstracted based on this analysis:

(a) Solar resources in Odisha having outstanding prospective compared to wind energy and exploitation of wind resources might not be cost effective in most cases.
(b) At present, a PV-wind-diesel-battery system is the most suitable solution for stand-alone applications. Cost of energy for such a system in Gangapada village (delivering 340 kW h/d, peak 25 kW), is around 0.201$/kW h.
(c) A PV–Battery system would be a more attractive for 100% renewable fraction. In such a case capital cost, net present cost and cost of energy would be around $3,98,529, $2,86,166, and $0.299/kW h, respectively.
(d) Larger hybrid systems would be costcompetitive for remote communities, instead of using single stand-alone units, and the economies of scale might bring down the cost of energy towards the present utility electricity price.

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