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DESIGN, PERFORMANCE EVALUATION AND COST ANALYSIS OF SOLAR PV-SYSTEM WITH DIESEL GENERATOR IN HYBRID POWER SYSTEM

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ABSTRACT

The Solar PV-Grid-Diesel Hybrid Power System can be used to overcome the inconvenience due to unavailability of power to a great extent. Integration of solar PV systems with the diesel plants is being disseminated worldwide to reduce diesel fuel consumption and to minimize atmospheric pollution and the proposed simulation has been done to assure that the solar PV- Diesel hybrid system is economically and technically feasible for rural places in India. Photovoltaic hybrid systems are used for improving reliability and energy services, reducing emissions and pollution, providing continuous power supply, increasing operational life, reducing cost and more efficient use of power. The objective of the present study is that the performance evaluation of the solar PV system, diesel generator in hybrid power system. The present work discusses design of the solar PV-grid-diesel hybrid power system and also explains the parameters that will affect the performance of the system. In this study, measurements are taken at the site for obtaining performance solar PV system and compared with diesel generator and also explained the predicting performance of the same PV system in other locations of India.

KEYWORDS: Photovoltaic (PV), Diesel Generator, Power, Performance, Radiation, Fill Factor

INTRODUCTION

A hybrid Power system is generally defined as an electrical generation and distribution system based on two or more energy sources such as solar photovoltaic, wind energy, diesel generator, grid power supply and battery energy storage. This system has number of advantages like reduction of overall system and maintenance cost, minimum need for energy storage, high degree of flexibility during system design and operation, optimum load can meet and efficiency of diesel engine can be increased. Solar Photovoltaic and diesel hybrid power system is best option for remote areas where the conventional grid power is not available due to various reasons. In this system solar photovoltaic or diesel generator which produces DC power is used to charge a large battery bank. The accumulated DC power from the battery is converted into AC mains voltage and frequency by an inverter and subsequently fed to the load. The main aim of the hybrid system is to provide 24 hours high quality AC power supply to remote areas, national parks, wild life research centers, farms, tourist facilities, telecommunication equipment and security services which are far away from main grids. The main objective of this paper is to design, evaluate the performance and demonstrate the operation of solar PV-Grid- Diesel hybrid power system which was installed in Center for Energy Technology, Osmania University, Hyderabad. In this work, performance parameters of the system like solar radiation, module efficiency, fill factor and maximum power developed by the system were also estimated based on current, voltage readings at ambient temperature in sunny and cloudy days. Projected performance of solar PV system for the entire year was found out compared to different locations in India based on mean sun shine hours.

EXPERIMENTAL SETUP

Solar PV- Grid-Diesel Hybrid Power System is the most efficient system which is the combination of solar PV, Diesel generator, Battery bank with power conditioning unit. In this Hybrid system, Solar PV modules or Grid power or Diesel generator is used to charge a large battery bank. This accumulated power from the battery bank is converted to A. C mains voltage and frequency by inverter and subsequently fed to the load. In this system, firstly the batteries are charged by the solar PV. If the solar energy is not available sufficiently, the batteries are charged with the grid power and if the grid power is also not available at that time the intelligent power conditioning unit present in the system will give an alarm sound that indicates to be started the diesel generator. The power from the diesel generator is used to charge the battery bank and passed to the load through the power conditioning unit (PCU). The PCU actually has a charge controller as well as an inverter as its main components. The schematic diagram of hybrid system is shown in figure 1.

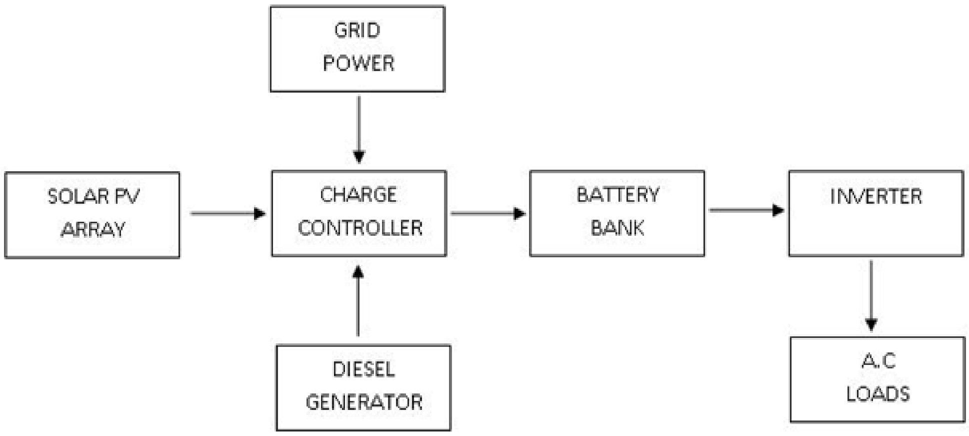

Figure 1: Block Diagram of Solar PV-Grid-Diesel Hybrid Power System

DESIGN OF A SOLAR PV-GRID-DIESEL HYBRID POWER SYSTEM

Design of the Hybrid Power System includes the sizing of the different components. Before sizing the system components, the following considerations are to be made. They are: All the loads are A. C Loads, System nominal voltage is taken as 48 VDC and considering the losses to be 25% which includes the losses of inverter, Battery efficiency losses and losses due to wiring, dust. The steps involved in the design of the Solar PV-Grid-Diesel Hybrid Power System are given below.

Estimation of A.C Loads Required

The AC and DC loads are estimated separately. They may vary from day-to-day and hence in such cases, weekly averaged load estimation are prepared. Care should be given on the load profile to see whether the load is constant or variable. If the load is variable, the full load is to be considered during design. If the load is same every day, size the array exactly to meet the load. The total estimation AC load used for this work is given Table 1.

Table 1

S. No	Appliance Load	Rating (Watts) (A)	Quantity (B)	Total Wattage (Watts) (A)X(B)=(C) Watts	Hours Used Per Day (D)	Daily Load (Wh/D) (C)X(D)= (E) Wh/D
1	Tube lights	50	10	500	4	2000
2	Fans	75	6	450	4	1800
3	Computers	175	6	1050	4	4200
4	Printers	100	2	200	2	400
5	Fax-Machine	100	1	100	2	200
6	Miscellaneous			200	2	400
Total Load (E) = 9000Wh/d						

The Total daily load required in watt-hour/day will get by multiplying total load of appliances with 1.25 to correct for the losses of inverter, battery and losses due to wiring and dust.

Total daily load required = (E) X 1.25 Wh/d

Estimation of PV Array Size or Array Sizing (Watts)

PV Array Size is defined as the ratio of Total daily load (Wh/d) and the sun light hours (h/d)

$$\text{PV Array Size (W)} = \frac{\text{Total Daily load (Wh/d)}}{\text{Sunlight hours (h/d)}}$$

$$\text{Total number of modules in an Array} = \frac{\text{PV Array Size (Watts)}}{\text{Peak power of selected module (Watts)}}$$

Number of Modules in series is defined as the ratio of nominal system voltage to nominal module votage.

$$\text{Number of Modules in series} = \frac{\text{Nominal system voltage}}{\text{Nominal module voltage}}$$

Estimation of Battery Capacity

$$\text{Battery Capacity } (A_h) = \frac{\text{Total daily load (Wh/d) X Days of storage}}{\text{Battery voltage } (V_{bat}) \text{ X Depth of discharge}}$$

Nominal voltage of battery (V_{bat}) is 48 VDC and Depth of discharge is 80%.

Number of days of battery storage or days of Autonomy = 3 days

$$\text{Number of batteries in series} = \frac{\text{Load Nominal voltage}}{\text{Battery Nominal voltage}}$$

Inverter Sizing

Inverter sizing is the important part of the system, so the following points are to be noted while sizing the inverter. The inverter should meet all continuous loads at a given time and meet surge demands also. To avoid unreasonably high surge demands, assume 2-3 times of load currents. The other features need to be considered during inverter selection include efficiency, output waveform, voltage or frequency regulation, etc. An inverter with a higher DC input voltage is preferred since this reduces the size of other components like wires, etc. While choosing a specific inverter, the inverter's output capacity must be matched to the size of the electrical loads.

Output Power (PV) = Output Power (Inverter) (Kilowatts)

PERFORMANCE OF THE PV SYSTEM

The performance of the Solar PV system was evaluated by calculating solar radiation using current-voltage (I-V) values under different loads at ambient temperature. Experiment was carried out by the following circuit. The performance of solar PV System was mainly based on module arrangement, radiation, cell temperature and load characteristics. The circuit diagram of solar PV system is shown in figure 2.

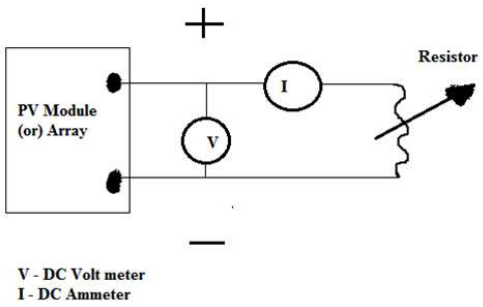

Figure 2: Circuit Diagram

Module Arrangement

Solar electrical systems required more than one module to be connected to one another. The slight difference in power from module to module reduced maximum power from each array. Hence care must be needed while installing modules. The module arrangements as pairs are shown in Table 2 for minimizing mismatch losses.

Table 2

Pair	Module Serial Number	Current (Amps)
1	5739 7663	5.900 5.883
2	5542 5486	6.087 6.135
3	5479 7681	5.867 5.844
4	7677 5572	6.074 6.052
5	5636 5566	5.921 6.025

Solar Radiation

The solar radiation is based on intensity of light which is hitting solar array exterior. The intensity of light was varied throughout a day, as well as day to day. Hence solar radiation calculations were based on sun, earth and seasons.

Cell Temperature

Cell temperature is a function of soar irradiation and ambient temperature. Hence performance of the system was varied with solar radiation as well as ambient temperature.

Load Characteristics

Solar PV Modules were produced DC output which was rated by standard test conditions. These conditions were created in industry, allowed for consistent comparisons of products and required to be changed for obtaining output under normal outside operating conditions.

RESULTS AND DISCUSSIONS

Performance of the PV System

It was found that there was a large difference in the power output of the PV array on the cloudy days because the clouds restrict the solar radiations coming on to the earth's surface. The other days which were giving better results because the readings were taken on a clear sunny days as shown in figure 3 and figure 4. From the measurements and calculations, it was found in figure 5 that the solar panels were getting above 70% of fill factor value for the individual pairs and for the total PV system. The efficiency values obtained were also varying from 15-18% except on cloudy days which are having low intensity of sunlight as given in figure 6. The efficiencies of PV module/array were theoretically calculated. And these values may vary from actual values.

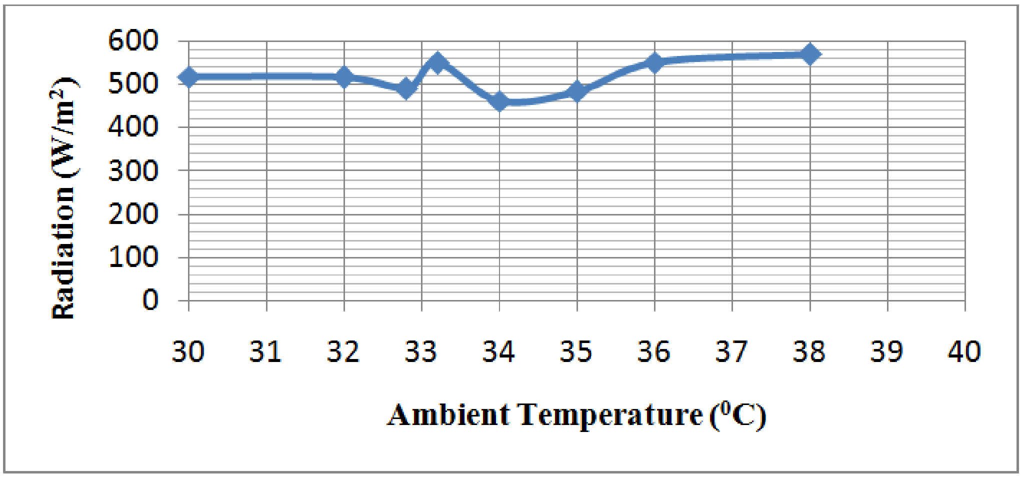

Figure 3: Effect of Ambient Temperature on Solar Radiation

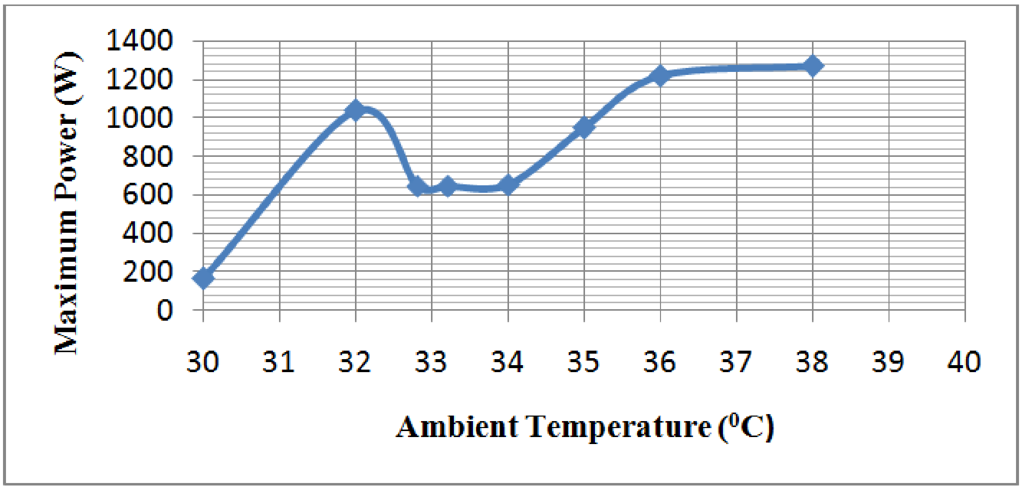

Figure 4: Effect of Ambient Temperature on Maximum Power Developed

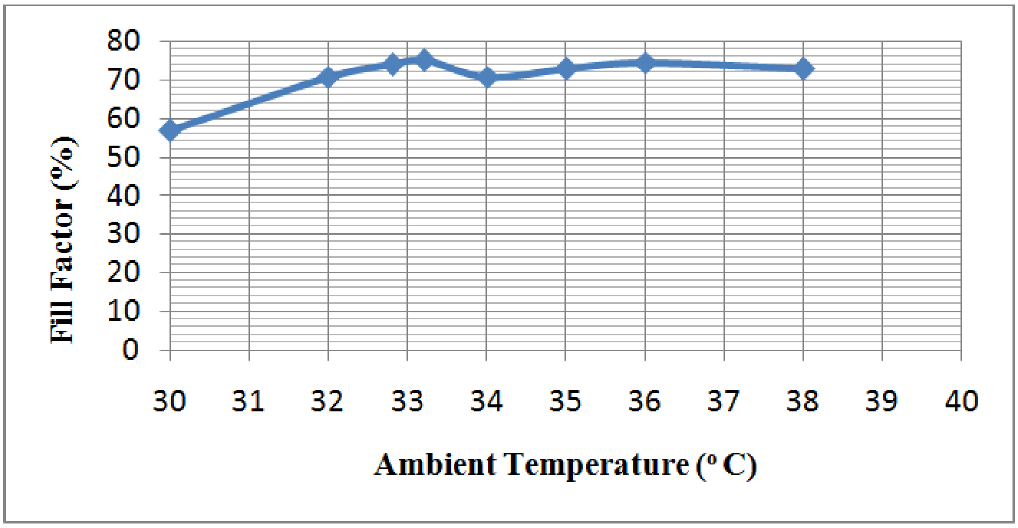

Figure 5: Effect of Ambient Temperature on Fill Factor

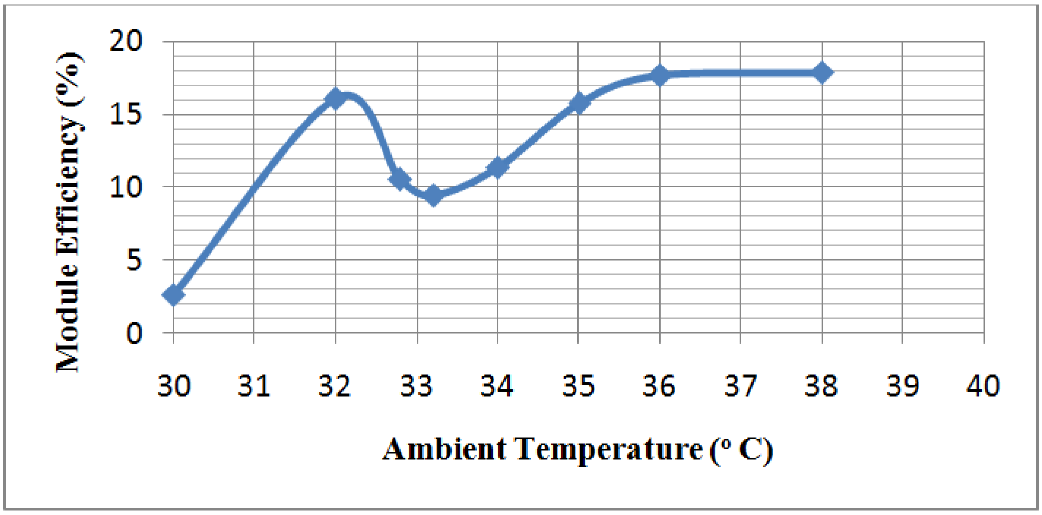

Figure 6: Effect of Ambient Temperature on Module Efficiency

Projected Performance of the PV System at Different Locations

The global solar radiation and power developed were calculated from different locations in India by taking data of mean sunshine hours throughout year shown in figures 7-10. It was observed that the monthly average solar radiation values for the months of July and August were low compared to the other months and the power output from the array was low for the months of very high radiation due to rise in cell temperature. The variation of radiation and power were not much higher for Hyderabad, but in case of other cities there were considerable variations. The radiation level was very low for the months of June to August. The ambient temperature was taken as 30^0C because most Indian cities are hot. The power output from panel/array varied with the combined effect of radiation and ambient temperature.

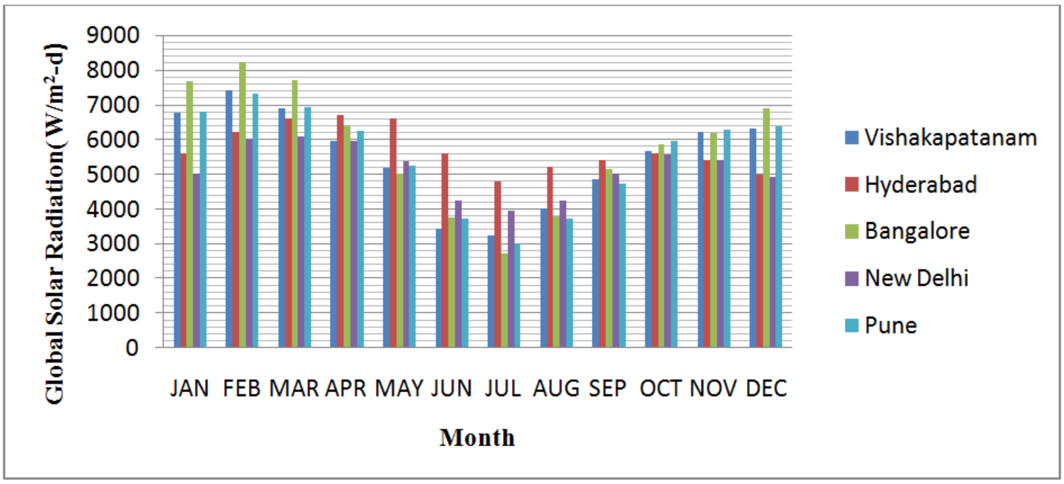

Figure 7: Radiation Level at Different Cities on Horizontal Surface

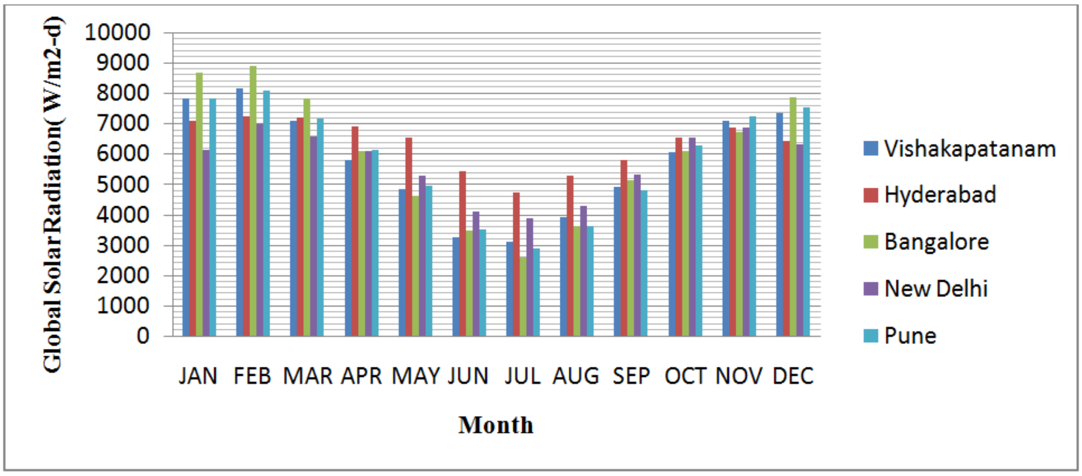

Figure 8: Radiation Level at Different Cities on Tilted Surface

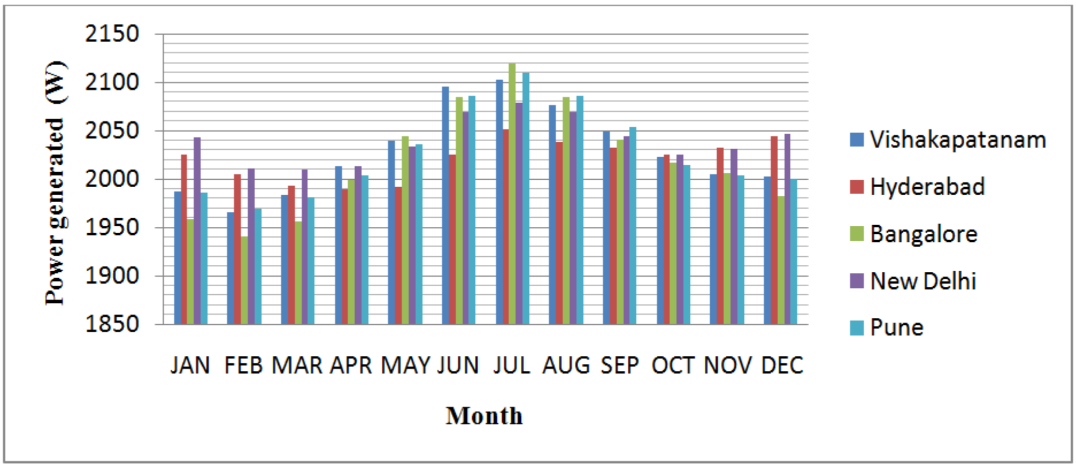

Figure 9: Power Generated Solar PV Array on Horizontal Surface

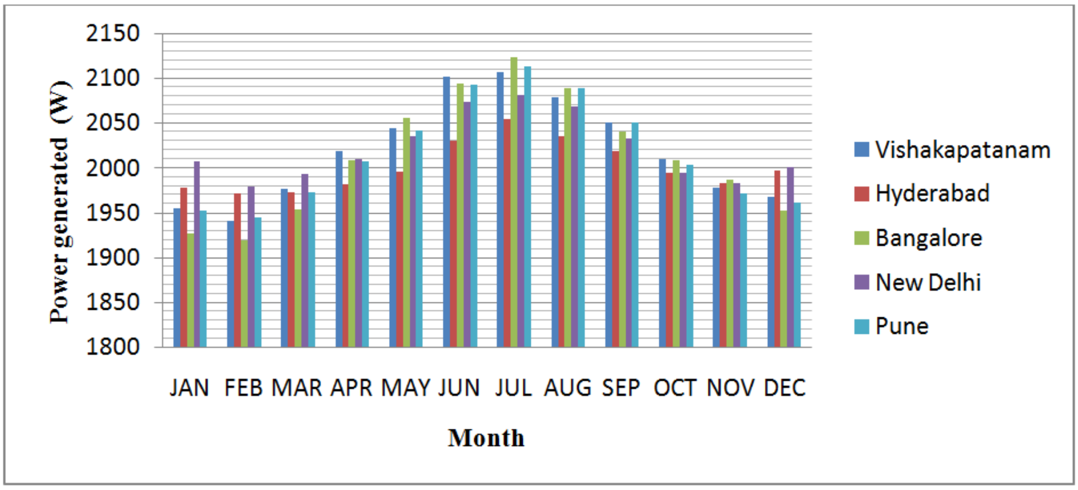

Figure 10: Power Generated Solar PV Array on Tilted Surface

Economics

The experiment was carried for the diesel generator at different loads and noted down the amount of fuel consumed as shown in figure 11. From the readings it was observed that the fuel consumed for most loads below 1000W is 0.5 lit/hr. The readings also shown that for a load of 2.1 KW, it is consuming 1 lit/hr. The solar PV system is designed to meet the loads upto 2 KW for 4 hours. If it is considered that the cost of diesel as Rs 60/- per liter, then Rs 240/- saved per a day by using solar PV system, the diesel fuel consumption was minimized, emissions were decreased, engine maintenance cost was also reduced and the life period of the generator increased. It is estimated that the amount of fuel required was 1335 liters for the utilization of power throughout year by taking 300 days as working. It is observed from calculations that solar PV system saved Rs.72000 /- per year when it is integrated with diesel plant.

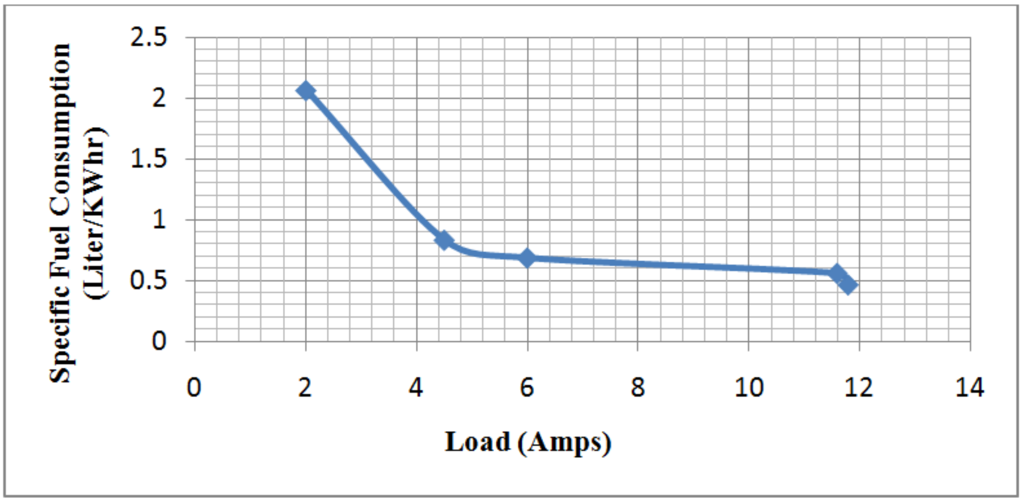

Figure 11: Specific Fuel Consumption by Diesel Engine AT Different Loads

CONCLUSIONS

The fill factor for most of the experimental cases was exceeded 70%, so it can be concluded that the solar PV modules used for this project were worked satisfactorily. The efficiency was also found to be good. The actual efficiency may vary because the values for radiation were theoretically calculated and there may be a slight reduction in the value of efficiency. From the measurements obtained for diesel power generator, it was observed that the fuel consumption was saved by using the solar PV system. The fuel cost and maintenance cost were minimized. From this, it can be concluded that the solar PV system is better to integrate with the diesel power plant to provide a power supply for 24 hours.

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APPENDICES

Specifications of components which were used in the system are given Table 3.

Table 3

PV Array	
Make	M/S Titan
Module range	160 – 225 W
Number of modules	10 – 12
Accuracy	$\pm$ 4%
Number of cells in a module	72
Efficiency	> 15 %
Inverter	
Make	Powertronics, Bombay
Single phase	
Rated output (continuous)	3000 W
Surge capacity	6000 W for 1 second
Rated input voltage	48 V
Rated output voltage	240 VAC
Frequency	50 Hz
Efficiency	90%
Wave form	True sine wave
Charge Controller	
Input Voltage	48 VDC
Maximium current	50 Amps
Battery	
Make	HBL, Hyderabad
Battery capacity	900 Ah @ 48 VDC
Nominal single battery voltage	2 VDC
Number of batteries	24
Battery type	Deep discharge low maintenance lead acid batteries
Diesel Generator	
Single phase	
Maximum output power	4.5 – 5 KVA
Rated output voltage	230 – 240 V
Frequency	50 Hz