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Research paper

Estimation and Performance analysis of a 15kW Off-Grid Solar PV System

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Abstract

The primary and most universal measure of all kinds of work by nature is the energy. Coal, Natural gas, Oil and Nuclear energy are net energy yielders and primary sources of energy. The intent of this paper is to assess the performance of 15KW solar power plant installed in Priyadarshini Engineering College (PEC) campus, Vaniyambadi, Vellore District, Tamil Nadu. A 15 kW solar PV plant has been installed to supply electricity to the internet laboratory and library (lighting load). The results obtained from monitoring a 15 KW Solar Photovoltaic system installed on a library roofing of 10m height building. The system was monitored between (July-Sep2016) from 9.30AM to 4.30PM for three days in a week from Monday to Wednesday. The results can be used to provide manufacturers to develop their products and enhance the knowledge in the future in order to improve the design of the off-grid solar photovoltaic system, return of investment during these years. This work focuses on the performance of the solar photovoltaic plant (July-Sep2016) monthly average demand and annual performance parameters, Efficiency, fill factor,capacity Utilisation factor and the characteristics have been plotted in a graph. The graph is drawn between Generated power vs consumed power. The annual yield of the solar photovoltaic plant ranged from 6500-7000 Kwh and performance ratio of 78%. It has capacity Utilisation factor with 6.97%.

Keywords: *Capacity utilization factor,Off-grid connected, Performance Ratio,SPV System, Solar photovoltaic energy.*

1. Introduction

In the present scenario, there is a need for a continuous supply of energy in order to fulfill the load demand electrical energy can be stored in a battery for their utilization during cloudy days. Orgain remains will be the main fuel for thermal power and there is a fear that they will get exhausted in the next century. Alternative source is solar energy and this can be a major source of power demand. Suns energy can be utilized as photovoltaics. Its potential is 178 billion MW which is about 20,000 times the worlds demand. The main source of energy is the sun which releases the electromagnetic radiation to the earth's surface. When the energy is released from the sun it reflects back from the solar photovoltaic panel. Some of the energy is absorbed by the atmosphere. The intensity of solar radiation on reaching the earth's surface is about 1369 watts per square meter[1]. Solar energy a non-conventional type of energy resources which converts light energy to electrical energy by the solar array which consists of several numbers of solar panels with the solar cells, the total sum of light energy received from the sun to the earth. Sunlight is varying due to the cloud and climate condition and the energy is charged by using a battery and given to the load. An off-grid connected PV system consists of solar panels, MPPT, Battery, and 20 KVA online UPS. A 15KW off-grid SPV plant is used to assess the technical potential of solar energy[2] and load condition is briefly analyzed here[3]. A semi

conductor device that converts sunlight energy into electrical energy is solar cell.The cells are made up of semiconductors allows sunlight to be converted directly into electricity. These modules provide a safe, reliable, maintenance free and environmentally friendly source of power for a long time[4].

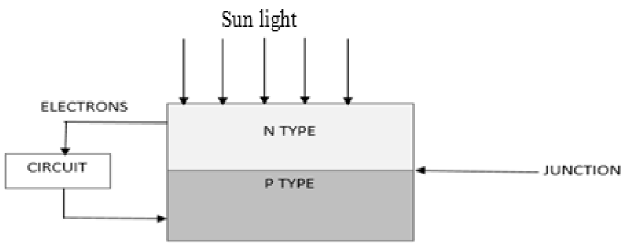

Fig. 1. Transection of Solar Cell

It is based on the principle of the photovoltaic effect. Whenever light strikes the surface of certain metal electrons are released. When sunlight falls on a solar cell it is converted into electrical energy[5].It consists of PN junction with a glass material on the surface of the top layer, the P-type consists of photons and N-type consists of electrons. When these photons and electrons collide it produces a sufficient amount of energy. Thus the cell produces the electric energy to the required load. This is shown in the above circuit diagram(Fig 1).

2. Proposed System

An off-grid connected SPV system consists of solar panels, MPPT, Battery and 20 KVA online UPS (fig 2). The system consists of polycrystalline photovoltaic modules and it is configured with a total power of 250 Watts, the 24V capacity to charge the 100AH deep storage battery bank. A 15 KW off grid SPV system is oriented towards the South with an inclination of 13^0 is the latitude of the area installed on the library with available space at 190.52 sq.mt in our college with battery backup. The solar power plant uses a solar panel from ACCESS SOLAR LIMITED and a 20 KVA Online UPS is installed to supply continuous power to the required load. MPPT charge controller receives the solar power and it is given to the battery. 20 Batteries are connected in series so that the overall voltage increases. The load is connected to internet laboratory and library (lighting loads). During the rainy season if the solar module energy is less than the energy required by the load, then the energy will be taken from EB Supply. The module mounting structure is seated on monolithic pedestals and designed to withstand wind velocity. This is being safeguard by lightning arrestor, earth kits and isolated switch avoids voltage surges.

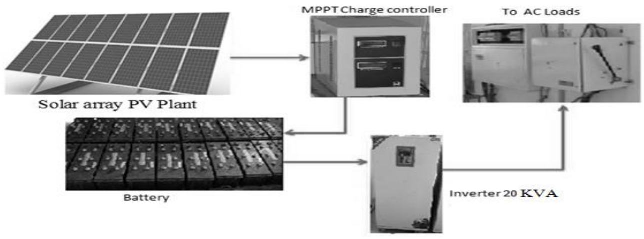

Fig.2. 15 KW off grid SPV Plant

2.1.1 Connections of a solar cell in Series and Parallel

A single cell can produce a very small amount of power generation. So we can use the bulk amount of cells for the power generation. The power generation mainly depends on the light incident on the solar panel. If the solar panel is increased then the current produced is also increased. (fig 3) shows that Photovoltaic modules are connected in series and parallel so that voltage and current are additive[6].

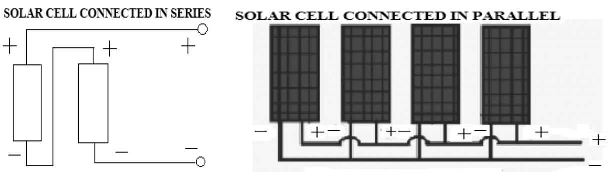

Fig.3. Solar cell in series & parallel connection

2.1.2 Solar PV Module Array

A solar Photovoltaic array is a combination of Photovoltaic modules which are in series and parallel connection [6]. In the SPV plant, 5 Panels are connected in series and 12 Panels are connected in parallel to increase the current in a PV system.The combinations of series and parallel connection of solar PV modules are called 'solar PV array' as shown below (fig 4).

The Solar cells are placed inside the glass material to protect from the environment. There is a single crystal of photovoltaic semiconductor material placed into the solar array. When light falls on the earth[6] bundles of photons produce a small amount of energy. These solar arrays are arranged in large numbers to produce a large amount of energy. The absorption of photons is mainly based on photons and the band gap energy present in the semiconductor material of a solar cell. This can be expressed in electron- volt (eV). Photons are produced mainly from the sunlight falling on the frontal of the solar panel to the solar cell in the semiconductor materials. A single PV cell can generate a very small amount of power of about 0.5V. The solar cell can generate the power at the minimum of 0.1 to 3 watts. Total 60nos of panels are connected in series and in parallel to generate power for a high power generation. We connect the solar cells in series by the positive terminal on one side of the terminal and negative terminal to the next side of the terminal for the power generation.

Fig.4. Solar PV Installation

2.1.3 MPPT

A device which is used to extract maximum power from a solar PV module at the operating conditions[6]. It is an electronic DC to DC converter that optimizes the match between the Solar array and battery bank or utility grid. Maximum Power Point Tracker shown in (fig 5). Normally MPPT gives the maximum output of about 94-97%[5].
When DC power is generated from the solar panel of variable DC voltage it converts to constant DC voltage. Thus it is known as a DC to DC converter. This MPPT is used for high output efficiency in the small components. This type of MPPT is used for Low capacity battery charging, Long distance wiring and also in low-temperature areas. To ensure a durable and safe installation junction boxes with cable glands of appropriate sizes for both incoming and outgoing of power flow are fitted.The size of cable shall be so selected that it keeps the voltage drop and losses to the minimum. These low conductor resistivity have the lower heating and thereby increase the life and saving in power consumption. It is mainly used to minimize the loss of about 99.97%.

Fig.5. MPPT

2.1.4 20 KVA Online UPS

Online UPS 20 KVA is used as an inverter is shown below (fig 6). It consists of a bidirectional inverter to supply continuous power to the load from the solar array to the battery bank. Thus PCU of 20KVA is chosen. The sine wave inverter generates a sinusoidal AC voltage with an exceptionally precise voltage and stabilized frequency. The inverter is protected against overload by a short circuit.Maximum V_{oc} = 440V.

Fig.6. Inverter

2.1.5 Batteries

It is an electric energy storage medium. Batteries are the backbone for the inverters because without the energy storage a solar PV system will not be able to deliver the power to the load during the absence of sunlight (Nighttime). The basic purpose of the battery is for charging and discharging the power. The Battery consists of two terminals of the positive terminal and negative terminal.The overall voltage increases when batteries are connected together in series,but currently remains the same, when connected in parallel the overall current increases but the voltage remains the same [6]
A solar photovoltaic panel is connected to the battery by a positive terminal in the cathode and negative terminal in the anode in

the series. The power generated from the solar PV module to the battery is called charging. During charging the power generated from electrical energy is converted into chemical energy is shown (fig 7). The process of consumption of power from the battery is called discharging. During discharge chemical energy is converted into electrical energy which is supplied to the load. The battery repeatedly by charging and discharging is called as a rechargeable battery (secondary battery) and battery which allows a single time recharge is called non-rechargeable battery (primary battery). The required operating temperature of the battery is 25°c
Battery capacity can be measured as
Battery Capacity(c) = Charge stored in the battery (current) at the given period of time
(c) = Current (A) *hour (H).

Fig.7. Battery

2.1.6 Earthing and Lightning arrester

The SPV power plant shall be provided with lightning and over-voltage protection. This protection shall be to reduce the overvoltage to a tolerable value before it reaches the Photovoltaic or other subsystem components. Metal oxide varistors shall be provided inside the array junction box. Electrical safety is considered the most important aspect. Precautions should be taken so that the person carrying or handling the module does not get shocked and avoid shorting the terminal of the battery to prevent from damage.

3. Performance Analysis

The Performance of off-grid connected solar PV plant is categorized into four stages
1. Unit Generation and consumption per day
2.Unit Generation and consumption for three days (per week)
3.Unit generation and consumption per month
4.Unit generation and consumption per three months

The performance analysis of an SPV system is indigent upon many factors such as season, cloudiness, performance ratio and capacity utilization factor. Power generation of the SPV system is around 553 units per month and saves Rs. 4147.5 of electricity bills to our college.

3.1.1 Data Monitoring

Data monitoring helps in monitoring the generation and consumption of power utilization from 09.30 Am to 04.30 pm for 3 days a week (from Monday to Wednesday) and for three months.
For 15 KW solar modules the panels are connected as six structures, each structure carrying 10 panels. The output voltage from one structure is 240 volts. The specifications of the solar panel and battery are shown below

3.1.2 Panel Specification

Total No of modules = 60
Maximum Power =250 WP
Open Circuit Voltage =44V
Short Circuit Current =7.636 A
The voltage at maximum power = 36.7 V
Current at maximum power =6.818 V
Maximum system Voltage =1000 VDC
Maximum reverse current = 8 A
Normal Operating Temperature =47°c ± 2°c
Temperature coefficient power =0.00157% / °c

3.1.3 Battery Specification

Backup hours =1.6hr
Battery Voltage= 240V
Total Ah =100 Ah

3.1.4 Load Specification

Load Connected = 14KW

Connection Given To Library (Lighting Load)

Light 40 *60 = 2.4 KW
Fan 12*75= 1 KW

Computer (Internet Laboratory)

40 System for Internet lab = 40*(250) =10KW
For 15KW solar module:
Open Circuit voltage rating of 20 KVA inverter = 240V
Panel voltage (V_{oc}) = 44 V
Short Circuit Voltage = 7.636 V
P = V * I
250 = V * 7.636
V = 32.739 V
For one Panel:
P = V * I
P = 32.739 * 7.636 = 249.995
For 60 Number of solar panel
P = 250 * 60 = 15 KW
For 15 KW Solar Module:
Inverter Voltage Rating = 240 V
Open Circuit voltage (Voc) = 44 V.
Voltage Rating of panel/Voltage of panel=240/44=5.4
Number of Panels connected in Series = 5
Panel Voltage = 32.739 V
Total Panels in series = 5 * 32.739 V
Total Voltage = 163.695 V
Total Power (P) = 250 * 60 = 15KW
I=15000/163.695=91.633A
Short Circuit Voltage =7.636 A
Number of panels connected in parallel = 12
The efficiency for the solar PV module can be calculated as max power delivered by the panel (output) to the max power produced by the panel (input).

$$\text{Efficiency of a solar cell} = \frac{Voc*Isc*FF}{Pin*A} = P_m/P_{in}*A$$

Efficiency=Pm/Pin*A=250/1000*1.632
η = Efficiency in Percent ,P_{max}= Output power in watts
A = Solar cell area in m^2,P_{in}= 1000 Watts per square meter
η= 15.3 %.

$$FF = \frac{Im*Vm}{Isc*Voc}$$

FF = Fill Factor,V_{oc} = open circuit voltage,
I_{sc} =short circuit current,P_{in} =input power,
$P_{m=}$output power,A =Area of Panel.
The Fill Factor can be Measured as
FF=Pm/Voc*Isc=250/44*7.636=74.4%

3.1.5 Capacity utilization Factor

-Capacity utilization factor is defined as the ratio between the actual energy generated by the solar photovoltaic plant to the maximum gross energy possible in the period under running condition. The monthly CUF was calculated.
Monthly Solar CUF=Monthly Solar energy produced in Kwh
Rated monthly Solar energy production in Kwh.
The highest yield of the period in August 2016 was627.9.
Monthly Solar CUF=627.9/15*24*25=6.97%

3.1.6 Performance Ratio

Performance ratio (also quality factor) is the measure of the performance of a solar photovoltaic system.

$$\text{Performance ratio} = \frac{\text{Energy Measured(Kwh)}}{\text{Irradiance(Kwh /m}^2\text{) x Active area of PV Module(m}^2\text{) PV Efficiency}}$$

An anticipated nominal yield output is 80Kwh. The actual yield per day after the proper load is 60 Kwh. The performance rato is result 78%.

$$\text{Performance ratio} = \frac{\text{Actual reading of plant in Kwh}}{\text{Calculated, nominal plant in Kwh (Target Value)}}$$

$$PR = \frac{55Kwh}{70Kwh} \times 100 = 78\%$$

4. Result & Discussion

The Solar modules absorb the solar radiation and converted to useful power. The data is collected manually at 09.30 am 01.15 pm and 04.30 pm in the month of 4th July 2016. The solar radiation is maximum at the panel at Peak time (01.15 pm) and power generation and consumption are very high at this time as shown in (tab 1) below. A graphical plot showing the variation of energy with respect to time giving the daily results is shown in the bar graph (fig 8).

Table 1. Unit Generation and consumption per day [4th July 2016]

S.No	Time	Unit Generation	Unit Consumption
1	09.30 AM	13.9	12.5
2	01.15 PM	18.3	17
3	04.30 PM	14	12.8

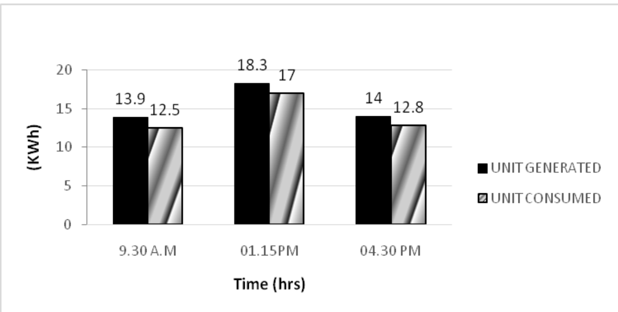

Fig.8. Unit Generation and Consumption Per Day

The weekly data is taken for three days (Monday to Wednesday) at different times of the day to obtain the weekly results on various days. Higher Power generation and consumption on 6th July indicates the maximum power demand of the day and is tabulated (tab 2). From the daily bar graph is shown above weekly results drawn for unit Generation and Consumption for three days is represented in bar graphs (fig 9)

Table 2. Unit Generation and consumption for three days (per week) [4thJuly-6thJuly-2016]

S.No	Day	Unit Generation	Unit Consumption
1	Monday	45.2	42
2	Tuesday	43.7	41.2
3	Wednesday	48.4	45.3

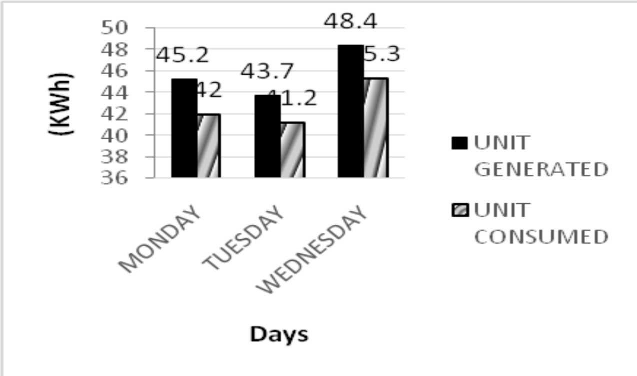

Fig.9. Unit Generation and Consumption for three days a week

The monthly results can be obtained from the weekly bar graph of that month. The average value of power generation, Generation and Consumption over a month at different times of the day, week are plotted on the graph and is represented in bar graphs (Fig 10 11,12) for various months (July, August, and September).

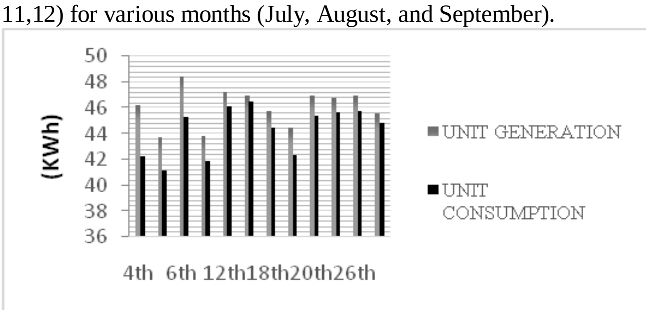

Fig.10. Unit Generation and Consumption for the month of July-16

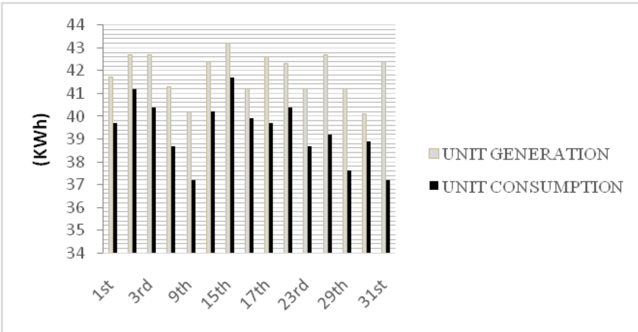

Fig.11. Unit Generation and Consumption for the month of Aug-16

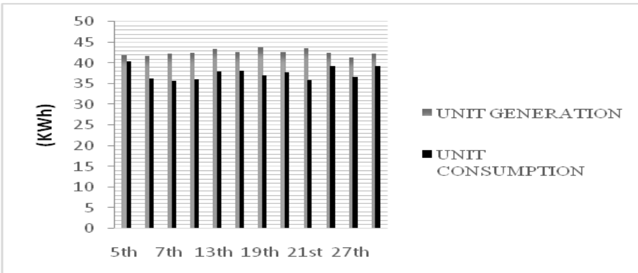

Fig.12. Unit Generation and Consumption for the month of Sep-16.

The different fractions of the total load at various times of the day as per the requirement the power generation and consumption varies continuously with time..The monthly results are shown in the table (tab 3) and observe the variation of power during different instants of the day. August month gives 627.9 units generated and consumed 590.7 units. The graph below shows three months results of unit generation and consumption is represented in bar graphs (Fig 13).

Table 3. Unit generation and consumption for three months [July-Sep 2016]

S.No	Month	Unit Generation	Unit Consumption
1	July	553	531.9
2	August	627.9	590.7
3	September	510.5	450.8

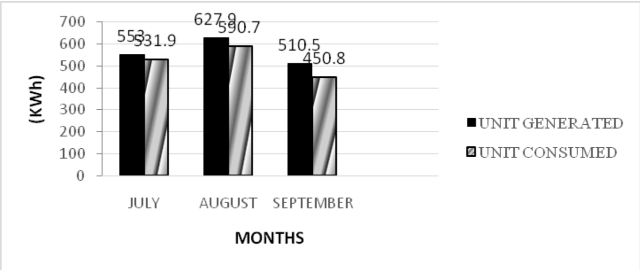

Fig.13. Unit Generation and Consumption for three months

5. Conclusions

In this study, the performance ratio of a 15kw Solar photovoltaic plant is studied and the daily, monthly yields during the period are analyzed. The monthly yield of the plant varied between 553 kWh in July, 627.9 in August and 510.5 in September while their annual total energy generated (Approx) is 6500 Kwh. Performance evaluation of 15KW Solar Photovoltaic system is carried out and the variation of the 12 days in a month yield during the period is analyzed. The capacity utilization factor of the solar photovoltaic system is 6.97%. Average performance ratio of the SPV system is around 78%. Typically the performance ratio of the PV power plant varies between 70% to 80%. In future, there is scope to calculate the performance ratio and CUF of 15 KW off-grid SPV system for six days and yearly data will be obtained from 9.00AM to 4.30PM and also savings of SPV plant may be analysed.Comparison results from this study with simulation results in different locations will improve the plant performance.

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