PERFORMANCE OF SOLAR PHOTOVOLTAIC PLANT INSTALLED IN IIT ROORKEE CAMPUS: A CASE STUDY

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ABSTRACT

The application of renewable energy in electrical power system is growing fast. Solar Photovoltaic energy and other renewable energy are being increasingly recognized as cost-effective generation sources for different area isolated power system. Solar energy is the most clean, abundant and inexhaustible of all the renewable energy resources till date. The power from the sun intercepted by the earth is about 4.2 X 10^{18} Watt-hours, which is many times larger than the present rate of all the energy consumption. Photovoltaic energy systems take place as the most dominant source among renewable energy technologies. PV grid connected systems offer a wide range of both technological and commercial challenges, more so in India, which has just started a major initiative in this direction under the auspices of Jawaharlal Nehru National Solar Mission. This paper presents the performance of solar photovoltaic (SPV) system installed in IIT Roorkee Campus in Uttarakhand state of India. The different technical parameters are used to carry out the performance analysis.

***Keywords*: *Performance Analysis, Solar Energy, Solar Photovoltaic, Solar Power Plant, Solar Radiation Data*.**

I. INTRODUCTION

The Solar Photovoltaic (PV) system installations in India have increased after the launch of Jawaharlal Nehru National Solar Mission (JNNSM) by the Ministry of New and Renewable Energy, Government of India. The main objective of the JNNSM is to achieve 20 GWp generations capacity using solar power systems by 2020 [1]. The contribution of Renewable energy sources in India's primary energy supply is about 30%. By conventional and renewable resources, the growth of electricity generation in India is increasing continuously. Renewable energy has increased the grid capacity by almost 4 times from year 2002 onwards. In April 2002, the installed capacity based on renewable energy was 3,497 MW (Mega Watt) which was 3% of the country‘s total installed capacity. It has become 40799 MW on 30 Nov. 2014, which is about 16% of the total installed capacity [2,3].

The energy from sun can be utilized directly or indirectly in the form of solar energy. Solar energy plays an important role to reduce the harmful gases for environment produced during the electricity generation. According to IEA report, SPV technology could stop 100 Giga tons of CO_2 emissions in the period of 2008-2050 [4]. Solar energy does not affect the cultivated land, reduces grid transmission lines propagation cost and increases the life style of people in distant areas [5]. Solar energy has three different technologies: solar photovoltaic and concentrating solar power for providing electricity, and solar cooling and heating. Based on IEA report, in 2050, around 11% of the global energy demand could be fulfilled by the solar energy [4,6].

II. SOLAR PHOTOVOLTAIC SYSTEM

Solar radiation is a general term for electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful form of energy, such as heat and electricity, using a variety of technologies [7]. However, the technical feasibility and economical operation of these technologies at a specific location depends on the variable solar resources. There are following types of solar radiation:

(i) Beam Radiation – Solar radiation received from the Sun without being scattered by the atmosphere and propagating along the line joining the receiving surface and the sun. It is also referred as direct radiation.

(ii) Diffuse Radiation – The solar radiation received from the Sun after its direction has been changed due to scattering by the atmosphere. It does not have a unique direction and also does not follow the fundamental principles of optics.

(ii) Total Solar Radiation – The sum of beam and diffused radiation on a surface. The most common measurements of solar radiation are total radiation on a horizontal surface often referred to as 'global radiation' on the surface.

It is direct conversion of sun light into electricity. Solar cell works on the photovoltaic effects. In order to get useful powers from the PV cells, which use basically semiconductor and semiconductor material as these materials having more capability of eliminating the electrons under sunshine. Following are the three conditions to get the output in form of electricity from semiconductor material: -

(i) Solar radiation in the form of Photon must be absorbed by the active part of material and Potential Energy of the photon should transfer the electron. Further with this extra energy particular electron must be dislodged from its bond.

(ii) The charged particle having extra energy should be carried to the edge of the material so that it may be available to carry to the load. This particular condition can be provided to the material by creating an internal electric field in the material by developing pn junction through a process known as doping.

(iii) The charged particle available at the edges of a material should carry to the load through the external circuit.

III. SITE DETAILS

India lies in sunny regions of the world. Most parts of India receive 4–7 kWh (kilowatt-hour) of solar radiation per square meter per day with 250–300 sunny days in a year. The highest annual radiation energy is received in western Rajasthan while the north-eastern region of the country receives the lowest annual radiation [8].

Roorkee is located at 29.87°N 77.88°E. It has an average elevation of 268 meters (879 feet). Roorkee is 172 km north of the Indian capital New Delhi and located between the rivers Ganges and Yamuna, close to the foot hills of Himalayas.

Fig. 1 Location of Roorkee **Fig. 2 Uttarakhand Map**

Due to its location away from any major water body and its close proximity to the Himalayas, Roorkee has an extreme and erratic continental climate. Summers start in late March and go on until early July, with average temperatures around 28^{o}C (83^{o}F). The monsoon season starts in July and goes on up till October, with torrential rainfall, due to the blocking of the monsoon clouds by the Himalayas. The post monsoon season starts in October and goes on up till late November, with average temperatures sliding from 21^{o}C (70^{o}F) to 15^{o}C (58^{o}F). Winters start in December, with lows close to freezing and frequent cold waves due to the cold katabatic winds blowing from the Himalayas. The total annual rainfall is about 2600 mm (102 in).

Annual mean daily solar radiation in Roorkee is about 5.22 KWh/m^{2}/day, and there are about 250-300 clear sunny days in a year.

Availability of land: Installation of apparatus for solar energy generation requires land, which is both economically feasible and has ample amount of sunshine. IIT Roorkee has a vast amount of unused rooftop area. It can be used for the purpose, as it receives ample sunshine for most of its part. It's about 25200 sq. mts total rooftop area.

IV. PV SYSTEM PERFORMANCE EVALUATION

An accurate evaluation of photovoltaic (PV) system performance is important for the development of PV industry. The performance evaluation helps the component manufacturers to ensure the quality of their products and to identify future industry needs. There is a need for standard parameters on the basis of which the performance of a PV system can be evaluated. Thus, in order to evaluate the performance of a PV system, International Electro-technical commission (IEC) has developed standard performance parameters for photovoltaic system performance monitoring and analysis as per IEC standard 61724 [9].

These performance parameters are developed on the basis of following considerations:

(i) As the output of PV systems differs due to size, geographic location, season, design and technology so, it is difficult to compare various PV systems as such; the developed performance parameters should be able to provide a single base for comparing such PV systems.

(ii) The parameters should be capable of detecting the operational problems and various losses in the PV system.

(iii) The parameters should be able to validate the models developed for system performance estimation during the design phase.

V. PERFORMANCE EVALUATION METHODOLOGY

The performance of SPV plant is a function of climatic conditions, equipment used and system configuration [10]. The main parameters for evaluation of PV system performance as per IEC standards are as follows: -

5.1 Final Yield (Y_F)

At the standard test conditions (1000W/m^2 irradiance, 25^{0}C ambient temperature and air mass 1.5g) the total energy generated by the PV system for a defined period (E) divided by the rated output power ($P_{PV,\ Rated}$) of the installed PV system is called the Final yield (Y_F).

$Y_F = E / P_{PV,\ Rated}$ (1)

5.2 Reference Yield (Y_R)

The ratio of total in plane solar insolation (H_t) (kWh/m^2) to the reference irradiance (G) (1kW/m^2) is called the Reference yield. This parameter represents equal number of hours at the reference irradiance and is given as:

$Y_R = H_t/G$ (2)

5.3 Performance Ratio (PR)

The ratio of the final yield (Y_F) to the reference yield (Y_R) is known as Performance ratio. It is a dimensionless quantity and normalized performance parameter w.r.t incident solar radiation. It depicts about the overall effect of losses. This parameter is used to evaluate the long term changes in the performance. The decreasing year wise PR values are indicative of loss in the performance.

$PR = Y_F / Y_R$ (3)

5.4 PVUSA Rating

The PVUSA rating method is a regression method to study the PV system performance. This method uses the meteorological data of the site to calculate power at PVUSA Test Conditions (PTC), where PTC are defined as 1000W/m^2 plane-of-array irradiance, 20^{o}C ambient temperature, and 1m/s wind speed. According to PVUSA regression analysis, power is considered to be a function of irradiance, temperature and wind speed given as:

$P=E (A+B*E+C*Ta+ D*Ws)$ (4)

where, P=AC power in kW at the specific test condition, E=plane of array irradiance (W/m^2), Ta=ambient temperature (^{0}C), WS=wind speed (m/s), A–D = regression constants derived from operational data.

5.5 Capacity Factor (CF)

The capacity factor (CF) is defined as the ratio of actual annual energy output (E_{AC},a) of the PV system to the amount of energy the PV system would generate if it operates at full rated power ($P_{PV,\ rated}$) for 24h per day for year and is given as:

$CF=E_{AC,a} / P_{PV,rated} * 8760$ (5)

5.6 System Efficiency

The ratio of the energy generated ($E_{AC,D}$) to the incident irradiance (H_t) at the module area (A_a) given as:

$\eta_{sys,m} = E_{AC,D}/ (H_t * A_a)$ (6)

The Efficiency of the system: -

$\eta=P_{max}/ (H_t * A_a)$

where, P_{max}=Maximum Power generated i.e. multiple of maximum current (I_{max}), maximum voltage (V_{max}) & Fill Factor (FF), H_t = Incident irradiance, A_a =Module area, FF= ($V_{max} * I_{max}$) / ($I_{SC} * V_{OC}$).

These performance parameters provide the overall system performance w.r.t. energy production, solar resource, and overall effect of system losses.

VI. FACTORS AFFECTING THE PERFORMANCE OF PV MODULE

The performance of a PV module under actual outdoor conditions depends on several factors like type of PV technology used and the environmental conditions of the site where the module is deployed [11,12].

6.1 Type of PV technologies

A number of PV technologies available are mono-crystalline silicon, poly crystalline silicon, amorphous silicon and other thin film technologies like CdTe, CIS etc. Out of these, crystalline silicon PV technology is well established and shares about 85% of the world′s PV installations. However, upcoming PV cell technologies like triple junction under concentrated sun are expected to take up the larger share of the PV market in near future. Extensive research is going on to improve the efficiency of PV cells for the commercial use. The efficiency of the PV cell is one of the key parameters on which the performance of a PV module and system depends, which in turn is influenced by the temperature, solar irradiance, dust etc.

6.2 Effect of Ambient Temperature

The output power of a PV module depends on the temperature at which the solar cells operate. It is important to note that module temperature is always higher than the ambient temperature. The higher temperature of the module is due to the use of glass cover, which traps the infrared radiation. The increase in temperature results in the reduction of band gap of PV cells in the module. This leads to the increase in I_{SC} but decrease in V_{OC}. The decrease in V_{OC} is more prominent than the increase in I_{SC}. Therefore, over all power output and efficiency of the PV cells decreases with the increase in its operating temperature.

6.3 Effect of Solar Irradiation

The output power of the PV module strongly depends upon the solar irradiation falling on it. The power output of a module increases linearly with the increase in the incident solar radiation. With the increase in the incident solar radiation, more number of photons will be available to move the electrons from balance band to conduction band resulting into the production of more current.

6.4 Effect of Tilt Angle of PV Module

The performance of PV module depends on the amount of solar radiation received by a PV module which in turn depends on the orientation and tilt angle. The orientation of modules is generally south in northern hemisphere and north in southern hemisphere. The tilt angle is site dependent and has to be optimized to maximize the incident solar radiation on the surface of PV module. It is very helpful to have a solar site locator to determine the potential shading.

Distance from object to array= Object Height * Spacing Factor

6.5 Other Factors

In addition, there are several factors like dust accumulation, humidity and air velocity, which affect the performance of PV module.

VII. DATA COLLECTION AND ANALYSIS

In order to estimate the solar radiation, data were collected from the different sources.

7.1 Insolation Data

The average insolation data for Roorkee is presented in the table below. Since the peak power output of solar modules is delivered at STC of 1000 W/m^2 insolation, the actual power output depends upon the insolation at the place [13].

Table 1: Insolation Data of Roorkee

Month	Insolation ($kWh/m^2/day$)
1	3.16
2	4.43
3	5.86
4	6.83
5	7.37
6	6.47
7	5.63
8	5.38
9	5.29
10	5.13
11	3.83
12	3.21
Yearly average	5.22

The average insolation value is 217.5 W/m^2 for evaluating power output of modules.

7.2 Solar Devices

In Solar PV systems, there are various devices, which are connected in order to generate the required energy. These devices should have some common and standard parameters so as to allow the parameters to be interconnected to each other. In this works, some of devices and its parameters used are as follows:

(i) Modules

PV system is long life plants in which those modules are used which have higher efficiencies in order to obtain the desired power outputs. In these works, the modules from Tata Power solar system Ltd. manufacturer have been using with preference ranges.

Electrical rating under STC (1000W/m^2, A.M. 1.5, Cell temperature= 25^OC) [14].

Table 2: Module Details

Manufacturer	Tata Power solar system Ltd.
Model	TS230MBT
Pm (W)	230
Vm (V)	29.1
Im (A)	7.9
V_{OC} (V)	36.7
I_{SC} (A)	8.4

(ii) Inverters

IIT Roorkee is connected to grid having 3 phase system. Therefore, Inverter of three phases with the following parameters from Delta 30 kW, 20 kW, 15 kW and 11 kW series are recommended. However, the systems are flexible to use any type of inverter regardless of /independent of the efficiency and compatibility with the system.

7.3 Number of Modules, Peak Power Output and Module Area

Table 3: Number of Modules, Peak Power Output and Module Area

S.No	Site (Department)	No. of PV Modules	Peak Power Output (kWp)	Module Area (m^2)
1	AHEC	184	42.32	306.7
2	Archite. & Plan.	289	66.00	481.8
3	Biotech	261	60.26	436.8
4	Civil	870	200.0	1450.1
5	Chemistry	267	61.00	445.1
6	Chemical	518	119.0	863.5
7	DOMS	174	40.03	290.1
8	Earthquake	289	66.00	481.8
9	Earth Science	218	50.05	363.4
10	ICC	140	32.20	233.4
11	WRDM	188	43.24	313.4
12	E&C	496	114.0	826.8
13	Electrical	741	170.0	1235.3
14	HS	154	35.42	256.7
15	Hydrology	115	26.00	191.7
16	Maths & Physics	261	60.26	436.8
17	Metallurgy	692	159.06	1153.6
18	MCA Block	066	15.18	110.0
19	IIC	096	22.08	160.0
20	Mechanical	436	100.0	726.8
21	Library	184	42.32	306.7
22	LH-1, -2	131	30.28	218.4
23	New LH	368	84.00	613.5
24	Mandi Cell	267	61.00	445.1
25	Industrial	210	48.30	350.1
26	OP Jain Audi	092	21.16	153.4
27	RS Wing	201	46.23	335.1
Total		**7910**	**1816**	**13186**

7.4 Calculation and Analysis

The Performance indices of solar photovoltaic system installed in IIT Roorkee campus for six months i.e.

(i) Final Yield, $Y_F = E / P_{PV, Rated}$

where, E= total energy generated by the PV system, for six months in IITR i.e. 1227419 kWh

P= the rated output power of the installed PV system i.e. 1816 kW

Then, Y_F = 1227419 (kWh)/1816 (kW) = 675.89 (h/d)

(ii) Reference yield, $Y_R = H_t/G$

where, H_t = total in plane solar insolation in (kWh/m^2) i.e. 6.16 kWh/m^2/day (Average)

G = the reference irradiance i.e. 1kW/m^2

Then, Y_R = (6.16*183)/1 = 1127.59 (h/d) (for 6 months)

(iii) Performance Ratio, PR = Y_F / Y_R

Then, PR= (675.89/ 1127.59) = 0.5994

Hence, The Performance Ratio of IITR Campus for six months is 59.94%.

(iv) Capacity Factor, CF=$E_{AC,a} / (P_{PV,rated}$ * 8760)

But we can measure the CF for six months (i.e. 183 days).

Then, CF= 1227419/ (1816*4392) = 0.1539

Hence, The Capacity Factor of IITR Campus for six months is 15.39%.

(v) System efficiency, $\eta_{sys,m} = E_{AC} / (H_t * A_a)$

where, E_{AC}= total energy generated by the PV system, for six months in IITR i.e. 1227419 kWh

H_t= total in plane solar insolation in (kWh/m^2) i.e. 6.16 kWh/m^2/day=1127.59 kWh/m^2

A_a= Module area in (m^2) i.e. 13186 m^2. Then, $\eta_{sys,m}$= 1227419/ (1127.59*13186) = 0.0826

Hence, The System efficiency of IITR Campus in the month of April is 8.26%.

7.5 Economical Analysis

The cost analysis is based upon the following factors:

(i) Cost of the system (in rupees) = Rs. 14.14 crore

(ii) First 5 year O&M cost = Rs. 13.75 lacs

(iii) O&M cost 6 to 25 year = Rs. 3.49 to 15.55 lacs per year

According to the Actual cost and O&M cost, the Unit generation cost is as follows: -

Unit generation cost = Rs. 8.5 per unit (without subsidy)

= Rs. 0.85 per unit (with subsidy)

Electricity Generation= 30.8 lacs units annual and The CO_2 Reduction = 2464 ton p.a.

According to the given data of Cost, O&M and Electricity Generation, the energy saving is shown: -

Table 4: Economical Analysis

Capital Cost of the system (Rs.)	14.14 crore or 14,14,00,000
Subsidy (Rs.)	12.72 crore or 12,72,60,000
Actual Capital Cost (Rs.)	1.41 crore or 1,41,40,000
Saving per annum (Rs.)	26.18 lacs or 26,18,000
Payback Period (Year)	5.4 years or 5 years 4 months

Note: - Capital subsidy of 90% of the benchmark cost would be available for special category states, viz. NE, Sikkim, J&K, Himachal Pradesh and Uttarakhand.

VIII. CONCLUSIONS

Detailed investigation on Performance Evaluation of Solar Photovoltaic system Installed in IIT Roorkee Campus leads to following conclusion: The solar radiation data from National Aeronautics and Space Administration (NASA) and NREL are collected and found that the minimum sunshine hour for the site is 3.16 for the month of January 2014. Collected data of energy generation, solar radiation were analyzed and Performance indices is Performance ratio, Capacity Factor & efficiency were found to be 59.94%, 15.39%, 8.26% respectively. During the analysis, Shading effect, inclination angle etc. were assumed to be fixed as no arrangement is made/provided (in the installed system) to vary these parameters. Through detailed analysis of the data, it has been found that the system is viable, efficient and cost effective. As a result, due to JNNSM subsidies, the financial viability of the project is extremely good. The Payback period of the PV system installed in IIT Roorkee Campus is 5.4 Years. The CO_2 Reduction 2464 ton p.a. shows the solar PV system installed in IIT Roorkee Campus is Eco-friendly and good for Environment.

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