Performance Assessment of Solar PV Power Plant with Pvsyst Simulation Tool

Sumita[1], Nitin Goyal[2], Namita Soni[3], Monika Khurana[4], Monu Gupta[5], Madhukar Kumar[6]

[1,2,3,4,5,6]Mechanical Engineering Department, Swami Keshwanand Institute of Technology, Management and Gramothan, Jaipur 302017

--***--

Abstract - In India the energy generation trend has shifted rapidly towards renewable energy sources in recent years. Since the tropical climate condition of the country favors the capability of renewable energy sources and among them direct use of solar radiation and wind can be harnessed effectively to increase the energy capacity. Solar is the most secure, copious and non-polluting source of energy. Simple and direct conversion mechanism of photovoltaic system captures has emerged it as a global player in non-polluting sources of electricity generation.

The PV power plant located at Mechanical Engineering Department of SKIT, Jaipur is studied to evaluate the performance under the composite climate condition. The performance indices include the energy and economic parameters such as reference, array, final yield net present value, cost of energy and money payback period. The analysis involves a simulation tool PVsyst. The energy parameters found for the installed capacity also involve performance ratio, calculated throughout the year. The result shows the final yield for the plant as 4.5 kWh/kWp/day. The economic evaluation shows the money payback period as 4.3years.

*Key Words***:** Photovoltaic, economic evaluation, PVsyst, reference yield, temperature loss
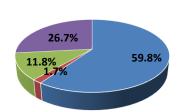
1.INTRODUCTION

In electricity generating system the renewable energy sources (RES) are playing in the mainstream. With the increase in economic growth, the demand for electricity has been increased and the world production of electricity has been recorded as 28433TWh for the year 2021. The contribution by combustible fuel was 61.8% and by hydropower 15.3%. The other renewable energy share was of nuclear 9.9%, wind 6.6%, solar 3.7%, and other 2.8% of total gross world electricity production [1]. The installed capacity of renewables increased to 3064GW by the end of the year 2021. Solar PV led the addition by accounting 55% of added capacity followed by wind 28% and hydro 11% [2]. The continuous decreasing cost of the PV system made it a global player in the energy sector.

1.1 India's Trend in RES

India's energy sector of electricity is primarily based on coal, which alone is not sufficient to fill the gap of growing demand and supply. On seeing the population of 1.4 billion people, India is a huge market for energy use. For meeting the demand of large number of people and maintaining the economic growth rate there is a strong need to shift from the conventional method of energy generation to the alternate source. In year 2021 countries' generation capacity has reached a total of 392GW with sharing 26% with the renewables as shown in Figure: 1. India's total capacity of renewables hit 104GW in December 2021 including 49.3GW of solar and 40GW of wind power. The government has planned to raise the share of renewable energy to 55 percent by the year 2030 [3]. In the direction of achieving the target of reducing CO_2 emission to 0.604kg/kWh by the year 2021-22 and to cope with the demand, renewable shares need to be increased. It was projected to reduce the 268 million tonnes of CO_2 emission by the end of year 2021-22 with the addition of Renewable energy resources [3].

India stands at 4th position in the world in deployment of solar and wind capacity installation. In last seven years, the installed solar capacity has increased to 49346MW in 2021 with the addition of 11882MW in 2021 which was 2630MW in 2014, it is increased by more than 15 times [4]. India's geographical location supports the development of different forms of renewable energy sources. The country is blessed with range of 2300 to 3200 sunshine hours.

Figure 1: Contribution of installed Capacity by different sources (MNRE, 2021)

The average radiation ranged between 4 to kWh/m^2/day, including 300 sunny days in a year [5]–[7]. Among the renewable sources, solar energy potential of 750GW has been reported by the national institute of solar energy.

2. SYSTEM DESCRIPTION

2.1 Grid-tied PV Power Plant

The grid-tied photovoltaic power plant became popular nowadays. In this system the generated electricity is utilized by either the connected load and excess of energy is transferred to the local grid or complete generation can be fed to the grid. The PV generation system is connected through a distribution board to the local grid, which records the transfer of energy. The other component includes the inverter for conversion of current according to the requirement of grid. In grid tied system the grid works as unlimited source of storage device as batteries in case of standalone system and supplies electricity when the PV system is unable to generate due to non-availability of sunshine or unfavorable weather condition. The facility to sell excess electricity back to the grid encourages the owner to earn money by feed in tariff or by saving in electricity bill. A general configuration of grid-tied PV power plant is as shown in Figure: 2.

Figure 2: Grid-tied photovoltaic power plant

2.2 Geographical Site Information

The studied solar PV plant is located in district Jaipur of Rajasthan and the geographical location of the plant is at latitude 26.90c N and longitude 75.80° E. The recorded yearly average of global horizontal irradiation for the plant location is 5.68kWh/m²/day and the average ambient temperature and wind velocity remain in a range of 25.1°C and 3 to 10 km/h respectively [8].

2.3 Plant Layout

The solar photovoltaic power plant (SPVPP) located at Swami Keshvanand Institute of Technology, Management and Gramothan (SKIT) Jaipur. The plant was built under the scheme of National Solar Mission (NSM) and commissioned in the year 2015 [9]. With the installation of SPVPP of total capacity of 900kWp (400kWp rooftop and 500kWp captive), SKIT, Jaipur became the first net zero energy campus of Rajasthan. The SPVPP generates 14 lakh units of electricity in a year and save environmental burden of 1150 Tonnes of carbon dioxide. The green campus of the institute promotes saving of around 34000 trees in a year by consumption of clean energy produced by photovoltaic power plant[10].

The SPVPP installed at the Vishwakarma block has been selected for study and the block is installed with capacity of 62kWp at the roof.

2.4 Specification of Module and Inverter

The modules are arranged in an array of 20*10 and total installed modules are 200 in number. The type of PV modules used are poly-Si modules of each 310W capacity. The inverter used is of grid connected type that also works as a data logger system for the PV power plant.

The specification of module and inverter installed at plant site is given in Table: 2 and 3 respectively.

Table 1: Specification of module

Parameters	Values
Module type	JC310M-24
Maximum Power	310W
Open Circuit Voltage	45.0V
Short circuit Current	8.80A
MPP Voltage	37.0V
MPP Current	8.38A
Efficiency	15.9%
Weight	27kg
Dimension(L*W*H)	1956*992*40mm

Table 2: Specification of Inverter

Parameters	Values
Type	SG50KTLM
Make	Sungrow
Min. MPP Voltage	300V
Max. MPP voltage	950V
Max. input voltage	1000V
Rated output power	50000W
Rated output voltage	3phase, 400V
Max. output current	80A
Efficiency	98%

3. PV POWER PLANT PERFORMANCE INDICES

Performance indices are the parameters used to compare and analyze the particular selection. These indices are different for different photovoltaic system according to the configuration in which it is involved. The performance of PV power plant is readily compared by the actual energy generation with reference to the standard and maximum power conditions. Such performance indicators for grid connected SPVPP are reference yield, system yield, array yield, various losses occurred at different junction of power transmission process and the performance ratio etc. [11].

Reference Yield: It is defined as the energy output from the PV array as it is operating at its nominal efficiency. It is calculated as the total in-plane radiation to the solar radiation at standard condition i.e., 1000W/m². Numerically it represents the sunshine hours for a day if calculated in terms of kWh/m²/day [12], and given as:

$$Yr = \frac{total\text{-}in\text{-}plane\ radiation\ (Ht)}{reference\ radiation\ (Go)}$$

Array Yield: It defines the DC energy output from the PV array at nominal power rating, and given as:

$$Ya = \frac{DC\ energy\ output\ (Earray)}{nominal\ power\ rating\ (Po)}$$

The nominal power rating defines the output generation at standard test condition (1000W/m², AM1.5 and 25ºC).

Final Yield: it is defined as the ratio of final output of PV plant i.e. AC at the inverter output that is fed to the grid to the nominal power rating.

$$Yf = \frac{AC\ energy\ output\ (Egrid)}{nominal\ power\ rating\ (Po)}$$

Performance Ratio: It is the ratio of final yield to the reference yield.

$$PR = \frac{Yf}{Yr}$$

Losses: The actual output generation from the photovoltaic module vary from the standard condition due to various losses occurred at different stages of power generation system.

Array Capture Loss: It is defined as the difference of reference yield and array yield. The array does not produce the reference yield due to the variation in temperature, dust accumulation, shading effect and mismatch in power tracking [7], [13]–[15], and computed as:

$$Lc = Yr - Ya$$

System Loss: It is the difference of final yield to the array yield and occurred in system due to the properties of electrical components used in grid integration [7], [13]–[15].

$$Ls = Yf - Ya$$

The financial analysis involves the capital cost involved in installing the complete photovoltaic power plant including labour cost. The economic evaluation calculates the net present value, money payback period and levelized cost of electricity.

Net Present Value: As long the life of a solar system is, it will generate more energy and as will be the expenses and profits, so accounting all expenditure and profit to its present value is known as net present value, and it is calculated as:

$$Net\ present\ value = \sum_{t=1}^{n} \frac{Rt}{(1+i)^t}$$

Where R_t=Net flow of income for the year (t)
i = Discount rate that could be earned in alternative investments
n = lifetime of the system

Money payback period (MBPP): It is defined as the duration in which the investment made in installing photovoltaic power plant will be recovered.

$$MPBP = \frac{NPV}{annual\ saving}$$

Annual saving is calculated from the annual generation multiplied by electricity tariff. Here the tariff considered for evaluation is ₹10 per kWh [16].

Levelized Energy Cost: It is defined as the cost of energy generated by the PV power plant over the net present cost of plant.

$$LEC = \frac{\sum_{t=1}^{n} \frac{(It + Mt)}{(1+i)^t}}{\sum_{t=1}^{n} \frac{(Et)}{(1+i)^t}}$$

I_t = represents investment and expenses for the year (t)
M_t = represents operation and maintenance cost for the year (t)
E_t = represents electricity produced

Return on investment (ROI): It is the ratio of net benefit obtained from the generation of electricity from the photovoltaic power plant to the initial investment made. A negative ROI indicates that the system is not profitable.

$$ROI = \frac{Net\ benefit\ over\ lifetime}{Total\ investment}$$

4. PVSYST SIMULATION:

PVsyst is a simulation tool developed by the University of Geneva to analyze the performance of a photovoltaic system equipped with different configurations. the simulation tool allows to estimate the performance of PV system accurately based on the input parameter. PVsyst is designed with set of parameters for different configuration and can be selected for photovoltaic system such as grid connected, standalone and pumping.

In the present study the project is selected as grid connected system and the field data collected from the plant site for the simulation analysis. The climate information of the site location is selected from the map. The parameters related to the geometry of plane of array entered to the system as tilt and azimuth angle as 26º and 0º with fixed tilted plane condition. In the system information, the module and inverter has been selected from the inbuilt database as Renesola and Sungrow made respectively. The program suggests the configuration of array according to the plant size, module and inverter capacity, system layout and default losses applicable for the PV power plant.

5. RESULT & DISCUSSION

5.1 Energy output

The energy generation from the photovoltaic power plant is estimated at array and inverter output. Monthly variation of global inclined irradiation (GIncI) and the array output (Earray) is presented in Figure: 4. Total yearly GIncI at the plant location is 1.95 MWh/m². The energy generated by PV array at module

efficiency of 15.9% is obtained as 102MWh. The monthly average of energy output and global inclined irradiation is 8.53MWh and 6.3MWh respectively.
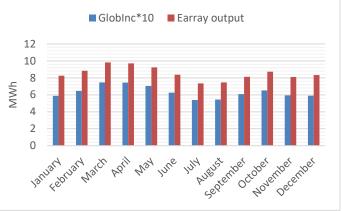

Figure 3: Global inclined radiation and Array output of SPVPP

The maximum and minimum array output is obtained as 9.8MWh and 7.3MWh for the month of March and July respectively. The maximum and minimum global inclined irradiation for the plant location is obtained as 192kW/m2 and 138kW/m2 for the month of March and July respectively.

5.2 Normalised Array Production

The normalised array production represents the energy generation from the installed power plant as per kWp capacity that is used to compare the similar power plants. The reference, array and final yield is presented in Figure: 5. Array yield is represented as sum of final yield and system loss (Ls) and reference yield is addition of array yield and capture loss (Lc). The maximum and minimum reference yield is obtained as 6.4 and 4.5 kWh/m²/day for April and July month respectively. The maximum and minimum array yield is obtained as 5.2 and 3.8 kWh/kWp/day for the month of April and July respectively.

The maximum and minimum final yield 5.14 and 3.77 kWh/kWp/day for the month of April and July respectively.

The yearly average of reference, array and final yield are obtained as 5.36kWh/m²/day, 4.53and 4.46 kWh/kWp/day respectively.

The total array capture loss occurred in a year is 0.83kWh/m²/day due to variation in operating condition. The system losses calculated for a year is found as 0.06kWh/kWp/day shown in Figure.5.
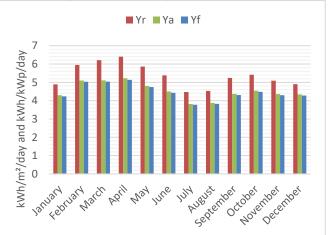

Figure 4: Reference, Array and Final yield

5.3 Losses and Performance Ratio

The temperature affects the performance of photovoltaic power plant significantly and power loss occurred due to temperature is presented in Figure: 6. Maximum power loss has been observed in month of April and May as 1.35MWh. The minimum power loss has been seen in month of January 0.45MWh.
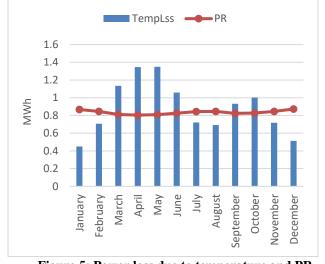

Figure 5: Power loss due to temperature and PR

The performance ratio varies in range of 0.8 to 0.86 and yearly average is obtained as 0.83 shown in Figure: 5.

5.4 Economic Evaluation

The simulation result for the economic evaluation of studied grid-tied SPVPP considered the installation cost of power plant as ₹54/kWp [17]. All economic parameters are considered for the lifetime of PV of 25 years. The maintenance and operation cost for the plant is considered as 1% of initial investment and evaluated with the discount rate of 8%. The electricity tariff considered as ₹10 for per kWh of energy consumption form the local grid. The economic evaluation shows the net present value of the plant as ₹9355489. The net income flow from the electricity generation is shown in Figure: 7.
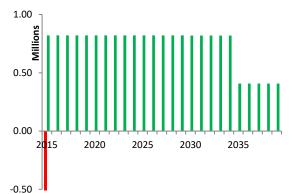

Figure 6: Net income flow diagram

The money payback period shows the duration in which investment made in PV power plant will be recovered and obtained as 4.3 years.

The levelized cost of energy calculated by the simulation shows the price of generated electricity as ₹0.91/kWh. The return on investment is calculated as 274% from the electricity generation by PV power plant.

6. CONCLUSION

The SPVPP located at Mechanical engineering department, SKIT, Jaipur is analyzed with simulation software PVsyst. The results are concluded as follows:

- The annual electricity injected to the local grid is 102MWh/year with specific production of 1628kWh/kWp/year.
- The average value of the performance ratio (PR) is obtained as 83%.
- Power loss due to temperature, climate condition, and due to system properties has obtained as 885kWh/month 0.83kWh/m²/day and 0.06 kWh/kWp/day.
- The money payback period calculated for the investment made is 4.3 years.
- The carbon emission saved over life is 1980 tonns.

The simulation results concluded that installed PV power plant system is generating high energy output per installed capacity and sustain the clean energy environment. Further, the user-friendly simulation program PVsyst can be used to analyze different photovoltaic configuration and technologies to further improve the performance.

References

[1]   IEA, "ELECTRICITY INFORMATION: OVERVIEW," 2022.

[2]   REN.2022., "Renewables 2022 Global Status Report," 2022.

[3]   MNRE, "Annual Report 2021-22," 2022.

[4]   Central Electricity Authority, "national electricity planning," 2022.

[5]   A. Sharma, "A comprehensive study of solar power in India and World," *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1767–1776, 2011.

[6]   F. Ansari, R. Kumar, S. Luthra, S. L. Shimmi, and S. Chatterji, "Analysis of barriers to implement solar power installations in India using interpretive structural modeling technique," *Renew. Sustain. Energy Rev.*, vol. 27, pp. 163–174, 2013.

[7]   V. Sharma and S. S. Chandel, "Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India," *Energy*, vol. 55, pp. 476–485, 2013.

[8]   synergy enviro Engineers, "Average Global Horizontal Irradiance," 2020. [Online]. Available: synergyenviron.com.

[9]   A. K. Nayak and D. Singh, "Performance Evaluation of 400 kW Grid Connected Rooftop Solar Photovoltaic Power Plant Installed at SKIT , Jaipur," *Ski. Res. J.*, vol. 9, no. 1, 2019.

[10]   SKIT, "Infrastructure." [Online]. Available: https://www.skit.ac.in/infrastructure.html.

[11]   S. K. Yadav and U. Bajpai, "Performance evaluation of a rooftop solar photovoltaic power plant in Northern India," *Energy Sustain. Dev.*, vol. 43, pp. 130–138, 2018.

[12]   N. M. Kumar, M. R. Kumar, P. R. Rejoice, and M. Mathew, "Performance analysis of 100 kWp grid connected Si-poly photovoltaic system using PVsyst simulation tool," *Energy Procedia*, vol. 117, pp. 180–189, 2017.

[13]   B. S. Kumar and K. Sudhakar, "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India," *Energy Reports*, vol. 1, pp. 184–192, 2015.

[14]   IEC, "Photovoltaic System Performance Monitoring-Guidelines for Measurement Data Exchange and Analysis," 1998.

[15]   C. M. Ayompe LM, Duffy A, Mc Cormack SJ, "Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland," *Energy Convers. Manag.*, pp. 1601-1606., 2011.

[16]   J. Discom, "Tariff Order," 2020. [Online]. Available: https://energy.rajasthan.gov.in/content/dam/raj/energy/jaipurdiscom/PDF2020/February2020/JPR1026.pdf.

[17]   MNRE, "STANDARD, SPECIFICATION & BENCHMARK COST," 2019. [Online]. Available: https://mnre.gov.in/img/documents/uploads/2a4e2c9c7c6a47b098255d07fd752264.pdf.