Experimental Analysis of Performance Ratio of Solar Rooftop Photovoltaic System (SRTPV) for Various Roof Orientation and Tilt

Anita Kokate1,a), Mahesh Wagh2, b)
1,2 (Department of Technology, Shivaji University, Kolhapur, India)

a)anita29_kokate@rediffmail.com
b)waghmahesh2006@gmail.com

Abstract. It is observed that Solar Roof Top PV systems has to be installed under verity of roof having different orientations, tilts etc. under different geographical conditions, this variation is likely to affect the performance of the SRTPV system. One of the ideal condition to have maximum generation is that the radiation should strike perpendicular to the solar panels surface fixed on roof. It is necessary to evaluate Performance of the SRTPV system and a methodology is to be set for maximizing the generation under these varied condition. This research is concentrated on evaluating SRTPV system for different orientations and tilt, finds its effect on system performance and develop a methodology to optimize design conditions for different roofs for optimal best performance under field situations created by at laboratory by forming different roof orientations and tilts with sun locations. Performance ratio is considered as evaluation criteria for optimizing results. The experiments model is designed for varying roof orientations from 0 to 180 degree and tilt for each orientations 0 to 90 degree. The Sun varies from 0 to 180 degree. For the designing model “Taguchi Method” is used for controlling the measured parameters for evaluation. The analysis carried out show that the performance ratio for a given location should have an optim a roof and tilt to maximize generation and get optimal PR. This gives the guide lines how roof can be treated if roof does not have proper angle of orientations and tilt. If treatment is not done one losses money by value with less investment on returns. For treated roof the PR found is above 80% which can be well compared to estimated generations simulation software. Further a design methodology is developed for guidelines for designers under the situation.

Keywords: Roof slope/tilt, Orientation, Solar rooftop PV system (SRTPV), Performance ratio (PR), Taguchi Method, PV performance, effect of roof tilt on PR, effect of roof oration on PR

1. Introduction

The amount of solar energy incident on a solar panel in various time scales is a complex function of many factors including the local radiation, latitude, longitude, location of the earth with respect to the sun at the different time of year, the orientation and tilt of the roof exposed solar panel surface and the ground
reflection properties. The performance of a solar panel is highly influenced by its East-West orientation and its North-south angle of tilt. This is due to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the panel. The study is required to estimate maximize solar system performance and energy generation for different orientations of a solar panel with different tilt angles. There is no standard method for optimizing solar energy yield at present and solar contractors fix the solar panels directly on given roof resulting in less generation and return on investment does not match the commercial requirements.

As per literature studied it is observed that few researchers have studied the performance of SRTPV system at true south facing of the panel, very little work is reported with changing the facing of panels. This research work tries to analyze the effect of various roof tilt and roof orientation on SRTPV system on its performance.

2. Research work and methodology

The study was conducted in the Department of Technology’s Solar PV lab, Shivaji University Kolhapur having coordinates 16.7050oN and 74.2433oE. Design of Experimentation done by Taguchi method for minimizing climate and analytical parameters.

Data collection was done every 5 to 15 minutes. The tilt (slope) angles were varied between 0o-50o with intervals of 5o and 10o (zero indicating horizontal position). power outputs of the solar panel is measured to find performance ratio of the system.

Design of experimentation is done by Taguchi Optimization. The following steps are carried out in Taguchi optimization.
1. Selection of independent variables
2. Selection of the number of level settings for each independent variable
3. Selection of orthogonal array
4. Assigning the independent variables to each column
5. Conducting the experiments
6. Analyzing the data
7. Inference

- Experimentation:

| Experiment | Details |
|------------|---------|
| 1          | Roof tilt Analysis |
| 2          | Roof Orientation Analysis |
| 3          | Combination of Roof angle and Roof orientation |

- Factors and its levels:

| Factors                      | Level 1  | Level 2  | Level 3  |
|------------------------------|----------|----------|----------|
| Roof Tilt (Degree)           | 0-20     | 20-40    | 40-50    |
| Roof orientation (Degree)    | 0-30     | 30-60    | 60-90    |
• Taguchi orthogonal array:

| Sr. No. | Slope (Degree) | Orientation (Degree) | Experiments |
|---------|----------------|----------------------|-------------|
| 1       | 0-20           | 0-30                 | E1          |
| 2       | 0-20           | 30-60                | E2          |
| 3       | 0-20           | 60-90                | E3          |
| 4       | 20-40          | 0-30                 | E4          |
| 5       | 20-40          | 30-60                | E5          |
| 6       | 20-40          | 60-90                | E6          |
| 7       | 40-50          | 0-30                 | E7          |
| 8       | 40-50          | 30-60                | E8          |
| 9       | 40-50          | 60-90                | E9          |

• Test Setup of Experimentation

Fig 1: Experimental test setup

Fig 2: Lab setup
Fig 3: Field Setup

I. EXPERIMENTATION ANALYSIS

1. Numerical and graphical analysis

Objective of this work is to establish a relationship between solar PV system input variation and its effect on output (Power). Therefore, following categorization for data collection is derived.

- Fix Orientation and tilt variation
- Fix tilt and orientation variation
- Tilt and orientation variation

The equations used for analysis as follows,

1. Inverter Efficiency:

\[ \eta(\text{Inverter}) = \frac{\text{AC Power}}{\text{DC input power}} \times 100 \]

2. System Efficiency:

\[ \eta(\text{System}) = \frac{\text{Power output}}{\text{Radiation} \times \text{Area of solar panel} \times \text{Efficiency of solar panel}} \times 100 \]

3. Performance Ratio:

\[ \text{PR} = \frac{\text{Power output}}{\text{Radiation} \times \text{Area of solar panel} \times \text{Efficiency of solar panel}} \times 100 \]

1. Lab test – Load – tilt variation
2. Lab test – Load – orientation variation
3. Field test – Load – Orientation variation

All experiments mainly analyzed on the basis of PR obtained.

- Lab Test:
  A. Lab Test for Fix orientation at Variable slop

It is observed that after 50 degrees tilt the results obtained are not reliable because inverter output (AC) shown more than the DC input as inverter also takes from the battery.
It is observed that with increasing tilt of the DC and AC output decreases up to 55%. But it is not linear because the incident solar energy which is a function of incident angle (Azimuth) and varies at large for the solar panel on the north side.

B. Lab Test for Variable orientation at fix slope
This experimentation was carried out at 10W AC load.

C. Outdoor/Field Test for variable Slope and Variable orientation.
This Test was carried out at 10W AC load.

The Graph of PR vs orientation indicates that the PR decreases with respect to orientation. As the orientation varies the incident angle on north and south varies and the incident angle is not optimum for generating the power. However, it is observed that PR varies linearly with orientation and the regression equation derived is

\[ Y = 84.00 - 0.619X \]
In this case, it indicates that for 20 Degrees tilt the maximum PR can be achieved is at 0-degree orientation. For any orientation other than this PR get reduce.

II. MODELING SOLAR ENERGY YIELD WITH RESPECT TO ROOF ORIENTATION AND TILT/SLOPE

The experimental tests are carried out by varying the orientation and the tilt of the roof and the results are analyzed to evaluate the performance of the system in terms of energy conversion ratio i.e. performance ratio (PR). The effect of orientation and the tilt on PR is modeled for guidelines for designers. The PR obtained with respect to the orientation and the tilt can analyzed for design guidelines.

\[ PR = \frac{\text{Power output}}{\text{Radiation} \times \text{Area of solar panel} \times \text{Efficiency of solar panel}} \times 100 \]

\[ PR \propto f(\text{Solar yield}) \]

\[ PR \propto f(\text{Irradiance}) \]

\[ \text{Irradiance} \propto f(\text{Orientation, Tilt, solar angles}) \]

The following table gives the PR \( \propto \) (yield) with respect to orientation and tilt of the roof which can give guidelines how PR affects so that one can decide to select proper final solar panel angle to maximize the yield.

Table 4: Modelling of Project

| Slope/Tilt | Orientation | 0     | 10    | 20    | 30    | 40    | 50    |
|------------|-------------|-------|-------|-------|-------|-------|-------|
| 0          | 69.107      | 84.553| 97.995| 55.343| 30.098| 20.127|
| 10         | 66.059      | 81.871| 85.452| 52.464| 30.496| 16.677|
| 20         | 64.343      | 73.653| 83.128| 50.318| 27.050| 14.952|
| 30         | 61.373      | 61.918| 79.140| 21.253| 23.252| 13.118|
| 40         | 59.578      | 54.017| 78.45 | 22.304| 22.963| 11.977|
| 50         | 56.648      | 51.307| 80.412| 21.828| 22.517| 10.266|
| 60         | 56.648      | 44.391| 60.745| 21.860| 21.656| 9.050 |
| 70         | 55.170      | 45.538| 61.898| 35.494| 21.346| 7.353 |
| 80         | 54.202      | 33.885| 46.425| 21.105| 20.251| 6.787 |
| 90         | 51.298      | 30.029| 41.372| 16.106| 19.911| 5.090 |

Fig 8: Result of Lab Experiments  Fig 9: Result of Field experimentation
As results obtained in a lab test and field test, it is observed that the PR is almost comparable. Tabular Model of the project suggests that 10-30-degree tilt is favorable for installation of PV modules for location.

3. Conclusion

Solar Roof Top PV systems, it is necessary to evaluate Performance Ratio (PR) which is required to optimal at a given location. However, the roof orientation and roof slope/tilt affects the PR and hence output from SRTPV system. The PV simulation techniques Viz., PVsyst, Meteonorm, Helioscope, PV*SOL, GIS etc. do not give any standard solution for roofs at different ordinations and tilt. Literature Review do not conclude to suggest any method for further simulation and design criteria for various ordinations and combination w.r.t tilt. Under the circumstances the experimental analysis carried out helps to analyze the effect of orientation and tilt of the roof on the solar performance and generation (yield). This has direct effect of return on investment made in the solar project. The PR relation w.r.t orientation and tilt is not liner as parameters used in evaluating viz solar radiation and it’s angle of incident on solar panel surface is not liner.

The tabular optimization efforts shows that the PR is maximum while orientation w.r.t south (true south) at given location tends to 0 and slope tends to the latitude plus minus 2%. This methodology can be chosen for each location for optimizing PR.

References

[1]. Xiao Hang Wang, Wen Tong Chonga, Kok Hoe Wong, Lip Huat Saw, SaiHin Lai, Chin-Tsan Wang, Sin Chew Poh, “The Design, Simulation and Testing of V-shape Roof Guide Vane Integrated with an Eco-roof System”, Energy Procedia 105 (2017), 750 – 763.
[2]. Borja Cortés Sánchez, Michal Váry, Milan Perný, František Janiček, Vladimir Šály, Juraj Packa, “Prediction and production of small PV power plant” 978-1-5090-6406-9, IEEE (2017).
[3]. Renu Sharma, Sonali Goel,” Performance analysis of a 11.2kWproof top grid-connected PV system in Eastern India”, Energy Reports 3 (2017), 76–84
[4]. Haitham Samir, Northan Ahmed Ali, “Applying Building –Integrated Photovoltaics (BIPV) in Existing Buildings, Opportunities and constrains in Egypt”, Procedia environmental Science 37 (2017), 614 – 625.
[5]. Emrah Biyik, Mustafa Araz, Arif Hepbasli, Mehdi Shahrestani, Runming Yao, Li Shao, Emmanuel Essah, Armando C. Oliveira, Teodosio del Caño, Elena Rico, Juan Luis Lechón, Luisa Andrade, Adélio Mendes, Yusuf Baver Atli, “A key review of building integrated photovoltaic (BIPV) systems”, Engineering Science and Technology, an International Journal (2017).
[6]. Rajesh Kumar Prakhya, C. Krishna Reddy, “Comparison of Various Types of Rooftop Grid Connected Solar Plants: A Case Study”, International Journal of Electrical and Electronics Engineering Research (IJEEER), Vol. 7, Issue - 2 (2017), 11-22.
[7]. Rameen Abdel Hady. “Modeling and simulation of a micro grid-connected solar PV system”, Water Science 31 (2017), 1–10.
[8]. Daniela Mewes, Paulo Monsalve, Isabella Gustafsson, Belkiz Hasan, Jennifer Palén, Ryo Nakakido, Erika Capobianchi, Benjamin Österlund, “Evaluation Methods for Photovoltaic Installations on Existing Buildings at the KTH Campus in Stockholm, Sweden”, Energy Procedia 115 (2017), 409–422.
[9]. Renu Sharma, Sonali Goel, “Performance analysis of an 11.2 kWp rooftop grid-connected PV system in Eastern India”, Energy Reports 3 (2017), 76–84.

[10]. Teerasak Somsak, Lutturit Thongporn, “Techno evaluation on a grid connected 9.8 kWp PV rooftop at various orientation in Thailand”, IEEE (2016).

[11]. V. Deepika, Dr. K. Vijayabaskar Reddy, N. Ramchander, “Effect of Seasonal Variations on 100 kWp Solar PV Power Plant Installed at BVRIT” IJAREEIE, Vol. 5, Special Issue 8, (2016), 69-75.

[12]. M. Shravanth Vasisht, J. Srinivasan, Sheela K. Ramasesha, “Performance of solar photovoltaic installations: Effect of seasonal variations”, Solar Energy 131 (2016), 39-46.

[13]. Akash Kumar Shukla, K. Sudhakar, Prashant Baredar, “Design, simulation and economic analysis of standalone roof top solar PV system in India”, Solar Energy 136 (2016), 437-449.

[14]. Rhythm Singh, Rangan Banerjee, “Impact of Solar Panel Orientation on Large Scale Rooftop Solar Photovoltaic Scenario for Mumbai”, Energy Procedia 90 (2016), 401 – 411.

[15]. Ritu Sharma, Atma Ram Gupta, “Seasonal Loading Impact on Performance of Solar DG for Loss Reduction Based On Capacity Factor”, Procedia Technology 25 (2016), 751 – 758.

[16]. Akash Kumar Shukla, K. Sudhakar, Prashant Baredar, “Simulation and performance analysis of 110 kWp grid-connected photovoltaic system for residential building in India: A comparative analysis of various PV technology”, Energy Reports 2 (2016), 82–88.

[17]. Luis Ramirez Camargo, Roland Zink, Wolfgang Dorner, Gernot Stoeglehner, “Spatio-temporal modeling of roof-top photovoltaic panels for improved technical potential assessment and electricity peak load offsetting at the municipal scale”, Computers, Environment and Urban Systems 52 (2015), 58–69.

[18]. Muhammad Luqman, Sajid Rashid Ahmad, Saniullah Khan, Usman Ahmad, Ahmad Raza, Farkhanda Akmal, “Estimation of Solar Energy Potential from Rooftop of Punjab Government Servants Cooperative Housing Society Lahore Using GIS”, Smart Grid and Renewable Energy (2015), 128-139.

[19]. Habtamu B. Madessa, “Performance analysis of roof-mounted photovoltaic systems – The case of a Norwegian residential building”, Energy Procedia 83 (2015), 474 – 483.

[20]. Susana de Leon, Hugo Calleja, Jesus Mina, “Reliability of photovoltaic systems using seasonal mission profiles and the FIDES methodology”. Microelectronics Reliability, (2015)

[21]. M. Koussa, M. Haddadi, A. Sae, A. Malek, S. Hadji, “Sun tracker systems effects on flat plate photovoltaic PV systems performance for different sky states: A case of an arid and hot climate”, Energy Procedia 18 (2012), 839 – 850.

[22]. Amnaj Chimtavee, Nipon Ketjuya, Kobba Sriprapha and Sarayoth Vaivudh, “Evaluation of PV Generator Performance and Energy Supplied Fraction of the 120 kWp PV Micro Grid System in Thailand”, Energy Procedia 9 (2011), 117 – 127

[23]. Energy Audit and Project Management, BEE book, 12-25

[24]. Introduction – Ministry of New and Renewable Energy, Retrieved from http://mnre.gov.in/mission-and-vision-2/mission-and-vision

[25]. Chapter-2- Introduction to Taguchi Method from http://www.ecs.umass.edu/mie/labs/mda/fea/sankar/chap2.html