engineering proceedings

Proceeding Paper

# Design of On-Grid Photovoltaic System Considering Optimized Sizing of Photovoltaic Modules for Enhancing Output Energy †

**Muhammad Tamoor [1], Abdul Rauf Bhatti [1,*], Muhammad Farhan [1] and Sajjad Miran [2]**

1 Department of Electrical Engineering and Technology, Government College University Faisalabad, Faisalabad 38000, Pakistan; engr.muhammadtamoor@gmail.com (M.T.); mfarhan@gcuf.edu.pk (M.F.)
2 Department of Mechanical Engineering, University of Gujrat, Gujrat 50700, Pakistan; sajjad.miran@uog.edu.pk
* Correspondence: bhatti_abdulrauf@gcuf.edu.pk; Tel.: +92-333-6704386
† Presented at the 1st International Electronic Conference on Processes: Processes System Innovation, 17–31 May 2022; Available online: https://sciforum.net/event/ECP2022.

**Abstract:** Photovoltaic (PV) systems are utilized all over the world for clean energy production. Photovoltaic simulation software is used to predict the energy produced by photovoltaic array structures. Due to Pakistan's geographical location in the equatorial region, the prospect of harnessing photovoltaic energy is too high. In the context of this fact, this work conducted extensive research to optimize the photovoltaic energy output by using different PV module sizes. For fixed areas where photovoltaic modules are installed, the output energy would remain more or less the same for any size of PV module with insignificant differences in PV module efficiency or quality. Moreover, in this research, it is found that by using different PV module sizes (i.e., 340 watts to 540 watts) at a time, while keeping all other parameters and conditions constant, a large variation in the output energy of the system can be observed. This difference in output energy with the change of PV module sizes raises fundamental concerns about how to choose the right PV modules size to generate maximum output energy at any given location. This study intends to emphasize the fact that when designing an On-Grid photovoltaic system, relatively little consideration is given to selecting the appropriate type and size of PV modules, which can result in a significant energy loss of the system. In this research, different PV modules of various sizes and power ratings with nearly identical efficiencies were analyzed in two selected locations. HelioScope simulation software is used to simulate all PV systems having a PV modules power rating to analyze their monthly and annual energy generation and system losses. The simulation results show that the appropriate PV modules size must be determined in order to generate the maximum output energy from the proposed PV system.

**Keywords:** photovoltaic system; PV modules; helioScope; system losses; energy generation



**Citation:** Tamoor, M.; Bhatti, A.R.; Farhan, M.; Miran, S. Design of On-Grid Photovoltaic System Considering Optimized Sizing of Photovoltaic Modules for Enhancing Output Energy. *Eng. Proc.* **2022**, *19*, 2. https://doi.org/10.3390/ECP2022-12671

Academic Editor: Andrey Yaroslavtsev

Published: 30 May 2022



## 1. Introduction

With the increasing growth of the economy and urbanization, the problem of reducing consumption of traditional fuel and carbon emissions has received a lot of attention [1,2]. Solar power-generating technology is considered one of the most successful strategies for improving energy-related and environmental issues [3,4]. PV power plants [5,6] and rooftop PV systems [7,8] are the two main photovoltaic (PV) energy generation strategies. For photovoltaic power plants, proper site selection is a key factor to improve their performance [9].

Photovoltaic (PV) power generation is reliable and has the ability to reduce carbon dioxide ($CO_2$) emissions significantly [10]. Assuming the potential for grid parity and cost reduction in northern and southern Europe by 2020, photovoltaic (PV) is widely assumed to be one of the most important sources of energy generation in the future [11]. Pakistan is an energy-scarce country, with the majority of the people lacking access to essential energy services including electricity, liquefied petroleum gas and natural gas. In 2010 and 2011, per capita primary energy consumption was 5.85 megawatt hours and 5.75 megawatt hours respectively, compared to 37.40 megawatt hours and 34.60 megawatt hours in developed countries such as the United Kingdom [12]. Pakistan receives almost 15.5 × 1014 kilowatt hours of solar energy per year, with an average daily sunshine time of 8.0–10.0 h [13].

Energy security challenges have arisen as a result of increased energy demand in developing countries. On-grid Photovoltaic energy generation systems have proven to be the most cost-effective large-scale renewable energy source [14]. A PV system that is properly designed and sized eliminates extra costs from an oversized system and insufficient power delivery from an undersized system [15]. The performance of PV systems is influenced by a multitude of parameters, including the type of photovoltaic modules used, PV modules power rating, the sun irradiance potential and the geographic location of the system [16]. Photovoltaic power systems installed at the optimal inclination angle and row spacing generate maximum energy, avoid unnecessary costs and make optimal use of the available space [17].

In this research study, we analyzed the simulated photovoltaic output of different PV module sizes with identical efficiency in the same fixed area using the Helioscope simulation software, focusing on the fact that for a fixed area, the photovoltaic power generation depends largely on the optimal PV module size. With the variation of the PV module size having nearly identical efficiencies, there is a wide variation in power output. This research strongly recommended that the optimum PV module size for a certain location should be evaluated using available simulation tools to ensure maximum energy from the photovoltaic system.

## 2. Materials and Methods

In order to evaluate the optimal sizing of PV modules and PV energy potential at a proposed location, a number of experiments were carried out in this study. We analyzed photovoltaic modules of different sizes to obtain maximum power generation in the selected locations. There were four different ratings of PV modules analyzed for each location in the experiment. An azimuth angle of 180° and a tilt angle of 15° were used in all four scenarios. We used the HelioScope simulation tool developed by Folsom Labs for detailed modeling such as PV system analysis, annual power production and system losses. The study was conducted at the following locations:

- Location 1: Energy generation by PV system installed at the GC University Faisalaba
- Location 2: Energy generation by PV system installed at the University of Agriculture Faisalabad

The surface area of each location is 30,224.5 $ft^2$ for the GC University Faisalabad and 54,994.4 $ft^2$ for the Agriculture University Faisalabad. In this study, the Meteonorm program and database were utilized to measure solar energy resources. For PV energy output assessment irradiance data, sunlight hours, temperatures and precipitation are all important parameters to evaluate. Seasonally, the weather changes from a cold winter to a warm summer, with a high temperature of 46.0 °C.

### *2.1. Photovoltaic Modules*

The monocrystalline photovoltaic modules manufactured by Trina Solar were used in this study and their power rating varies from 340 watts to 540 watts. The specification of all PV modules is shown in Table 1.

**Table 1.** Specification of all Photovoltaic modules.

| Rated Maximum Power | 340 | 380 | 450 | 540 |
|---|---|---|---|---|
| $V_{MP}$ | 38.200 V | 40.300 V | 41.000 V | 31.200 V |
| $V_{OC}$ | 46.200 V | 48.800 V | 49.600 V | 37.500 V |
| $I_{MP}$ | 8.900 A | 9.430 A | 10.980 A | 17.330 A |
| $I_{SC}$ | 9.500 A | 9.940 A | 11.530 A | 18.410 A |

### 2.2. PV Inverter

For ease of evaluation, Ginlong Technologies (Solis-50K) solar inverters were used for each design and the specification of the inverter is shown in Table 2.

**Table 2.** Specification of PV Inverter.

| Parameters | Value |
|---|---|
| Manufacturer | Ginlong Technologies (Solis-50 K) |
| Maximum Power | 50.0 kW |
| Minimum Power | 250.0 W |
| Maximum Voltage | 1100 V |
| Maximum MPPT Voltage | 1000 V |
| Minimum MPPT Voltage | 200 V |
| Minimum Voltage | 200 V |
| AC Output | 380 Y/220 V |

## 3. Results

### 3.1. Energy Generation by PV System Installed at GC University Faisalabad

We conduct a simulation analysis and compare the output of PV systems installed in GC University Faisalabad to determine the most acceptable size of PV modules for this site. Table 3 shows the total PV installed capacity, annual energy generation, system performance ratio and load ratio for different PV modules rating.

**Table 3.** Performance comparison of photovoltaic system installed in GC University Faisalabad.

| PV Rating | Installed PV Capacity | Annual Energy Generation | Performance Ratio | kWh/kWp |
|---|---|---|---|---|
| 340 | 294.4 kW | 440.4 MWh | 81.2% | 1495.8 |
| 380 | 329.1 kW | 492.0 MWh | 81.2% | 1495.2 |
| 450 | 360.9 kW | 541.7 MWh | 81.5% | 1500.9 |
| 540 | 383.4 kW | 576.7 MWh | 81.7% | 1504.2 |

By comparison, we analyze that the photovoltaic energy generation system installed with 540.0-watt PV modules is more efficient installed at a fixed area in GC University Faisalabad. For this case, the simulation results show that the annual energy generation of the photovoltaic system is 576.7 MWh, and the performance ratio (PR) of the system is 81.7%. The comparison of monthly photovoltaic energy generation for different PV module ratings installed in GC University Faisalabad is shown in Figure 1.

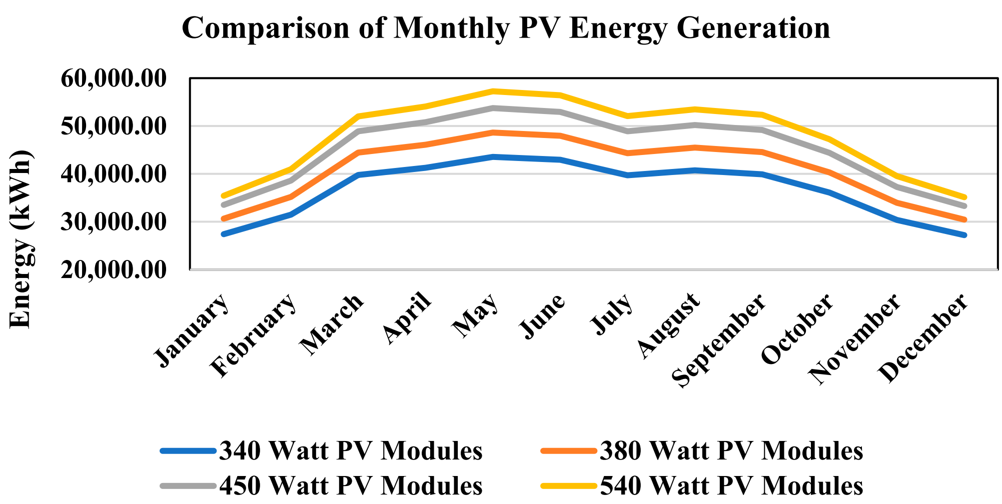


**Figure 1.** Comparison of monthly photovoltaic energy generation for different PV module ratings at GC University Faisalabad.

### *3.2. Energy Generation by PV System Installed at University of Agriculture Faisalabad*

We conduct a simulation analysis and compare the output of PV systems installed in the University of Agriculture Faisalabad to determine the most acceptable size of PV modules for this site. Table 4 shows the total PV installed capacity, annual energy generation, system performance ratio and load ratio for different PV module ratings.

**Table 4.** Performance comparison of photovoltaic system installed in the University of Agriculture Faisalabad.

| PV Rating | Installed PV Capacity | Annual Energy Generation | Performance Ratio | kWh/kWp |
|---|---|---|---|---|
| 340 | 658.2 kW | 944.5 MWh | 78.1% | 1434.9 |
| 380 | 735.7 kW | 1.056 GWh | 78.1% | 1435.6 |
| 450 | 782.1 kW | 1.125 GWh | 78.3% | 1438.0 |
| 540 | 789.5 kW | 1.131 GWh | 78.0% | 1433.2 |

By comparison, we analyze that the photovoltaic energy generation system installed with 450.0-watt PV modules are more efficient (having a high PR ratio and kWh/kWp) installed in a fixed area of the University of Agriculture Faisalabad. For this case, the simulation results show that the annual energy generation of the photovoltaic system is 1.125 GWh, and the performance ratio (PR) of the system is 78.3%. The comparison of monthly photovoltaic energy generation for different PV module ratings installed in the University of Agriculture Faisalabad is shown in Figure 2.

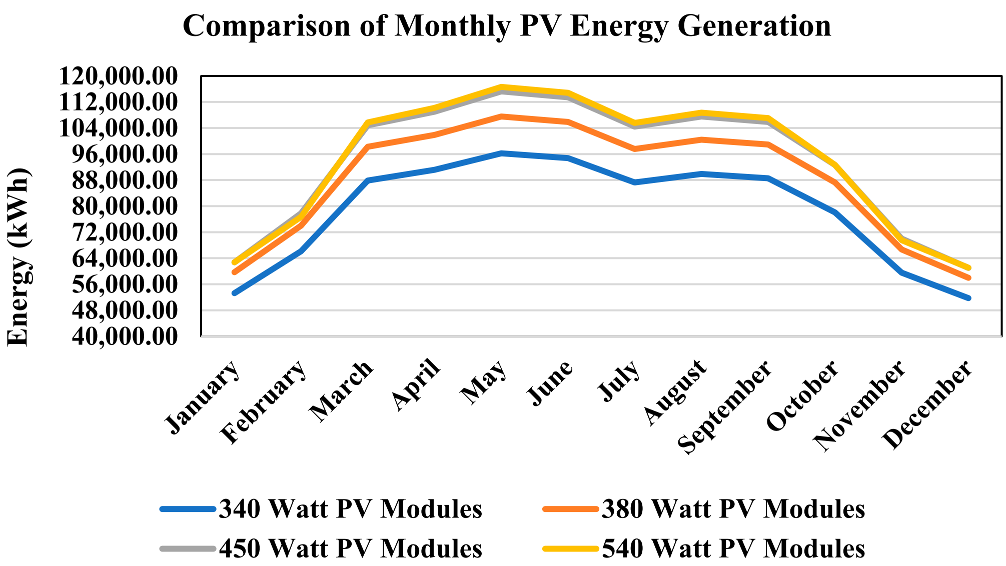


**Figure 2.** Comparison of monthly photovoltaic energy generation for different PV module ratings at the University of Agriculture Faisalabad.

## 4. Conclusions

This study intends to emphasize the fact that when designing an On-Grid photovoltaic system, relatively little consideration is given to selecting the appropriate type and size of PV modules, which can result in a significant energy loss of the system. In this research, different PV modules of various sizes and power ratings with nearly identical efficiencies were analyzed in two selected locations. HelioScope simulation software was used to simulate all PV systems having a PV modules power rating to analyze their monthly and annual energy generation and system losses. The simulation results show that the appropriate PV modules size must be determined in order to generate the maximum output energy from the proposed PV system. For GC University Faisalabad, the annual energy generation of the photovoltaic system is 576.7 MWh, and the performance ratio (PR) of the system is 81.7%. For the University of Agriculture Faisalabad, the annual energy generation of the photovoltaic system is 1.125 GWh, and the performance ratio (PR) of the system is 78.3%. This research strongly recommended that the optimum PV module size for a certain location should be evaluated using available simulation tools to ensure the maximum energy from the photovoltaic system.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ECP2022-12671/s1.

**Author Contributions:** Conceptualization, A.R.B., M.T. and S.M.; methodology, A.R.B., M.T. and M.F.; software, A.R.B., M.F. and M.T.; validation, A.R.B., M.T., M.F. and S.M.; formal analysis, A.R.B., M.T., M.F. and S.M.; investigation, A.R.B., M.T. and S.M.; resources, A.R.B. and S.M.; writing—original draft preparation, A.R.B. and M.T.; writing—review and editing, A.R.B., M.T., M.F. and S.M.; visualization, A.R.B., M.T., M.F. and S.M,.; supervision, A.R.B. and M.F.; project administration, A.R.B., M.T., M.F. and S.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Guo, Y.; Tian, J.; Chen, L. Managing energy infrastructure to decarbonize industrial parks in China. *Nat. Commun.* **2020**, *11*, 1–9. [CrossRef]
2. Armaroli, N.; Balzani, V. Towards an electricity-powered world. *Energy Environ. Sci.* **2011**, *4*, 3193–3222. [CrossRef]
3. Tamoor, M.; Abu Bakar Tahir, M.; Zaka, M.A.; Iqtidar, E. Photovoltaic distributed generation integrated electrical distribution system for development of sustainable energy using reliability assessment indices and levelized cost of electricity. *Environ. Prog. Sustain. Energy* **2022**, e13815. [CrossRef]
4. Yang, Y.; Campana, P.E.; Yan, J. Potential of unsubsidized distributed solar PV to replace coal-fired power plants, and profits classification in Chinese cities. *Renew. Sustain. Energy Rev.* **2020**, *131*, 109967. [CrossRef]
5. Chen, W.; Zhu, Y.; Li, Y.; Zhao, N.; Lv, Z. Research on Grid Parity Predictions of Centralized Photovoltaic Electricity. *Emerg. Mark. Financ. Trade* **2021**, *57*, 786–797. [CrossRef]
6. Martín-Martínez, S.; Cañas-Carretón, M.; Honrubia-Escribano, A.; Gómez-Lázaro, E.J.E.C. Performance evaluation of large solar photovoltaic power plants in Spain. *Energy Convers. Manag.* **2019**, *183*, 515–528. [CrossRef]
7. Zhao, X.; Xie, Y. The economic performance of industrial and commercial rooftop photovoltaic in China. *Energy* **2019**, *187*, 115961.
8. Fina, B.; Fleischhacker, A.; Auer, H.; Lettner, G. Economic assessment and business models of rooftop photovoltaic systems in multiapartment buildings: Case studies for Austria and Germany. *J. Renew. Energy* **2018**, *2018*, 9759680. [CrossRef]
9. Liu, J.; Xu, F.; Lin, S. Site selection of photovoltaic power plants in a value chain based on grey cumulative prospect theory for sustainability: A case study in Northwest China. *J. Clean. Prod.* **2017**, *148*, 386–397. [CrossRef]
10. Ayompe, L.M.; Duffy, A.; McCormack, S.J.; Conlon, M. Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. *Energy Convers. Manag.* **2011**, *52*, 816–825. [CrossRef]
11. Gielen, D.; Boshell, F.; Saygin, D.; Bazilian, M.D.; Wagner, N.; Gorini, R. The role of renewable energy in the global energy transformation. *Energy Strategy Rev.* **2019**, *24*, 38–50. [CrossRef]
12. Salam, R.A.; Amber, K.P.; Ratyal, N.I.; Alam, M.; Akram, N.; Muñoz, C.Q.G.; Márquez, F.P.G. An Overview on Energy and Development of Energy Integration in Major South Asian Countries: The Building Sector. *Energies* **2020**, *13*, 5776. [CrossRef]
13. Tamoor, M.; Tahir, M.S.; Sagir, M.; Tahir, M.B.; Iqbal, S.; Nawaz, T. Design of 3 kW integrated power generation system from solar and biogas. *Int. J. Hydrogen Energy* **2020**, *45*, 12711–12720. [CrossRef]
14. Kumar, B.S.; Sudhakar, K. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy Rep.* **2015**, *1*, 184–192. [CrossRef]
15. Quiles, E.; Roldán-Blay, C.; Escrivá-Escrivá, G.; Roldán-Porta, C. Accurate Sizing of Residential Stand-Alone Photovoltaic Systems Considering System Reliability. *Sustainability* **2020**, *12*, 1274. [CrossRef]
16. Tamoor, M.; Bhatti, A.R.; Farhan, M.; Miran, S.; Raza, F.; Zaka, M.A. Designing of a Hybrid Photovoltaic Structure for an Energy-Efficient Street Lightning System Using PVsyst Software. *Eng. Proc.* **2021**, *12*, 45. [CrossRef]
17. Tamoor, M.; Habib, S.; Bhatti, A.R.; Butt, A.D.; Awan, A.B.; Ahmed, E.M. Designing and Energy Estimation of Photovoltaic Energy Generation System and Prediction of Plant Performance with the Variation of Tilt Angle and Interrow Spacing. *Sustainability* **2022**, *14*, 627. [CrossRef]