

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

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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 photovoltaic energy output by using different PV modules sizes. For fixed areas where photovoltaic modules are installed, the output energy would remain more or less the same for any size of PV modules with insignificant differences in PV modules efficiency or quality. Moreover, in this research, it is found that by using different PV module sizes (i.e. 340 watt to 540 watt) 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 modules 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 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 PV modules power rating to analyze their monthly, 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

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1. Introduction

With the increasing growth of the economy and urbanization, the problem of reducing consumption of traditional fuel and carbon emissions has gotten 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 (CO₂) 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-hour and 5.75 megawatt-hour respectively, compared to 37.40 megawatt-hour and 34.60 megawatt-hour in developed countries such as the United Kingdom [12]. Pakistan receives almost 15.5×10^{14} kilowatt-hour of solar energy per year, with an average daily sunshine time of 8.0–10.0 hours [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 have 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 optimum PV module size for a certain location should be evaluated using available simulation tools to ensure maximum energy from 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 selected locations. There were four different rating of PV modules are analysed for each location in the experiment. An azimuth angle of 180° and a tilt angle of 15° were used in all four scenarios. We use 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 following locations:

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

The surface area of each location is $30,224.5 \text{ ft}^2$ for GC University Faisalabad and $54,994.4 \text{ ft}^2$ for Agriculture University Faisalabad. In this study, the Meteororm programme 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 change from a cold winter to a warm summer, with a high temperature of 46.0°C .

2.1. Photovoltaic Modules

The monocrystalline photovoltaic module manufactured by Trina Solar are used in this study and their power rating vary from (340 watt to 540 watt). The specification of all PV modules are shown in table 1.

Table 1. Specification of all Photovoltaic module.

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

2.2. PV Inverter

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

Table 2. Specification of PV Inverter.

Parameters	Value
Manufacturer	Ginlong Technologies (Solis-50K)
Maximum Power	50.0 kW
Minimum Power	250.0 W
Maximum Voltage	1,100V
Maximum MPPT Voltage	1,000V
Minimum MPPT Voltage	200V
Minimum Voltage	200V
AC Output	380Y/220V

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 analyse that the photovoltaic energy generation system installed with 540.0 watt PV modules are more efficient installed at 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 modules rating installed in GC University Faisalabad are shown in figure 1.

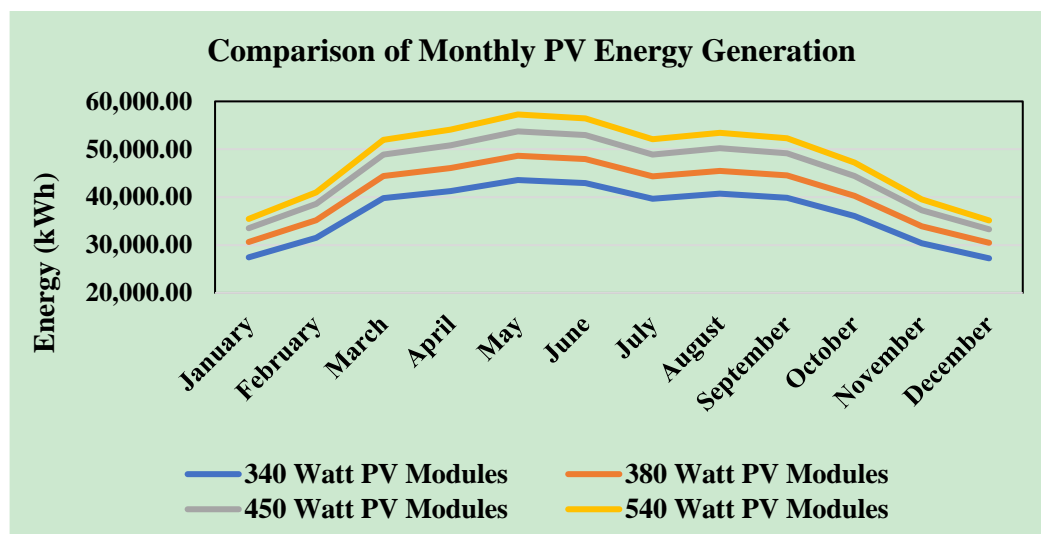


Figure 1. Comparison of monthly photovoltaic energy generation for different PV modules rating at GC University Faisalabad.

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 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 modules rating.

Table 4. Performance comparison of photovoltaic system installed in 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 analyse that the photovoltaic energy generation system installed with 450.0 watt PV modules are more efficient (having high PR ratio and kWh/kWp) installed at fixed area in 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 modules rating installed in University of Agriculture Faisalabad are shown in figure 2.

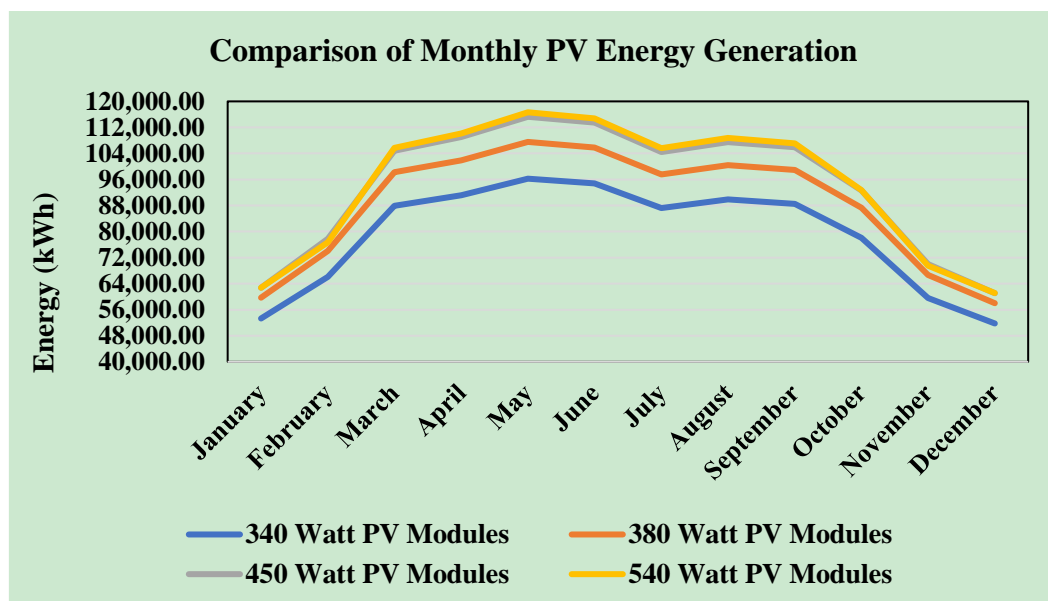


Figure 2. Comparison of monthly photovoltaic energy generation for different PV modules rating at University of Agriculture Faisalabad.

4. Conclusion

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 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 PV modules power rating to analyze their monthly, 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 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 optimum PV module size for a certain location should be evaluated using available simulation tools to ensure maximum energy from photovoltaic system.

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References

- Guo, Y.; Tian, J.; Chen, L. Managing energy infrastructure to decarbonize industrial parks in China. *Nature communications* **2020**, *11*(1), 1-9.
- Armaroli, N.; Balzani, V. Towards an electricity-powered world. *Energy & Environmental Science* **2011**, *4*(9), 3193-3222.
- Yan, J.; Yang, Y.; Elia Campana, P.; He, J. City-level analysis of subsidy-free solar photovoltaic electricity price, profits and grid parity in China. *Nature Energy* **2019**, *4*(8), 709-717.
- 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. *Renewable and Sustainable Energy Reviews* **2020**, *131*, 109967.

5. Chen, W.; Zhu, Y.; Li, Y.; Zhao, N.; Lv, Z. Research on Grid Parity Predictions of Centralized Photovoltaic Electricity. *Emerging Markets Finance and Trade* **2021**, *57*(3), 786-797.
6. Martín-Martínez, S.; Cañas-Carretón, M.; Honrubia-Escribano, A.; Gómez-Lázaro, E.J.E.C. (2019). Performance evaluation of large solar photovoltaic power plants in Spain. *Energy conversion and management* **2019**, *183*, 515-528.
7. Xin-gang, Z.; Yi-min, X. 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. *Journal of Renewable Energy* **2018**, 1–16
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. *Journal of Cleaner Production* **2017**, *148*, 386-397.
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 conversion and management* **2011**, *52*(2), 816-825.
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 Reviews* **2019**, *24*, 38-50.
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.
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. *International Journal of Hydrogen Energy* **2020**, *45*(23), 12711-12720.
14. Kumar, B.S.; Sudhakar, K. Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy reports* **2015**, *1*, 184-192.
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.
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. *Engineering Proceedings* **2021**, *12*, 45.
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.