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Beyond One-Sided Solar Unlocking Efficiency and Space with Bifacial Photovoltaic Systems

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Abstract: Bifacial photovoltaic systems (bPVs) have become increasingly popular in the past decade due to their ability to generate electricity from both sides of the module, resulting in improved efficiency through the utilization of scattered and reflected light. Typically, while bPVs tend to be more expensive than traditional monofacial photovoltaic panels, this is offset by their higher energy output on less land space. An economic analysis is conducted in this study to swap out a 2.4 MW single-sided solar panel system with bifacial ones on the rooftops of a university campus in Jordan. The additional space generated will be used to enhance the system's capability. The findings indicated that the new double-sided system could reduce the required area by over 27% if its capacity matched the current system. The findings indicated that expanding the area significantly augmented the current capacity by 47%. The return on investment (ROI) for the replacement procedure is 5.43% with a payback period of 8.2 years over a lifespan of 20 years.

Keywords: Photovoltaics, Bifacials, Return on investment, Payback period.

Introduction

Clean and sustainable energy sources are now one of the essential necessities in today's world. Renewable energy systems are classified as clean and viable sources (Sayed et.al., 2023). Normally, there are six sources of renewable energy: solar, wind, geothermal, hydropower, biomass, and hydrogen. Solar energy is the most prevalent option because of its dependability, affordability, and ease of use (Jordan et.al., 2020). Solar photovoltaics is a form of solar energy systems. These systems are in such high demand that their projected total capacity worldwide is expected to exceed 1.5 TW (Manasrah et.al., 2024). A standard solar photovoltaic module is comprised of two layers made of p-type and n-type silicon as well as other semiconductors. Sunlight energy enables electrons to move between these layers, generating current (Manasrah et.al., 2021). Despite the positivity surrounding solar photovoltaics, they require large amounts of land for installation, particularly with larger systems, leading to higher capital costs (Tawalbeh, et.al., 2021). There will be difficulties in expanding the current systems due to restrictions on space, particularly when they are mounted on rooftops.

Bi-facial solar panels (bPVs) are a potential solution to this issue. In contrast to traditional mono-facial modules, these modules are able to produce electricity from both sides by utilizing reflected and scattered sunlight (Jang & Lee, 2020; Manasrah et.al., 2023). Stated that bPVs can generate approximately 30% additional energy during certain times of the day compared to conventional mono-facial modules of similar size and capacity. Nonetheless, these solar photovoltaics are typically pricier than conventional mono-facial ones. Nevertheless, researchers have been studying the techno-economic characteristics of building-integrated PVs as substitutes for current solar PV farms and systems. For example, a study compared a traditional single-sided solar farm to a comparable double-sided one using a SWOT analysis. The results revealed that the bPV farm had a net present value that was more than 12% higher based on the assumptions provided (Kumbaroglu et.al., 2023).

This study involves conducting an economic analysis on substituting the modules in a 2.4 MW mono-facial system with bifacial ones. The existing system is situated on the rooftops of Al-Zaytoonah University of Jordan's buildings, which are in Amman, Jordan. The extra space created will be utilized to expand the capacity of the new system while using the existing rooftop areas. The goal of this research is to determine the expense of replacing, and to assess the payback and return on investment of the newly improved system using the equipment and labor costs in the local market. This research will offer an analysis on the economic viability of upgrading outdated photovoltaic systems with building-integrated photovoltaics (bPVs).

Background

Bifacial photovoltaics (bPVs) have been present in the worldwide market starting from the 1980s (Eguren, 2022). Numerous improvements and enhancements have been implemented since that time. Nonetheless, it wasn't until there was a notable decrease in the cost of silicon wafers that they began to attract attention (Kopecek & Libal, 2021). Subsequent to that, numerous studies have been carried out centering on the advantages of using bPVs as a substitute for traditional mono-facial solar panels. For instance, a particular study examined various characteristics of mono-facial and bifacial photovoltaic systems (Rodríguez-Gallegos et.al., 2018). The findings indicated that bifacial photovoltaic panels were a more economical choice than single-sided panels at latitudes higher than 40 degrees for installations with "any module orientation." Nonetheless, latitudes below 40 degrees experienced the opposite results due to low albedo values. In the same way, another research demonstrated that bPVs could lower the levelized cost of energy LCOE for solar photovoltaic systems at specific latitudes and module tilt angles (Patel et.al., 2019). Even in solar farms built on the ground.

Researching efficiency comparisons between monofacials and newer bPVs has also been a popular theme in literature. A recent research conducted in Poland by Olczak and colleagues (2021) compared the two types in terms of power gain and reduction of CO2 emissions. The research demonstrated that bifacial photovoltaic systems generated about 10% to 28% higher electrical power compared to mono-facial systems. Additionally, the research revealed that the reduction in CO2 emissions is 16% greater in bifacial photovoltaic systems compared to monofacial systems. A different experiment carried out in Fiji yielded comparable findings regarding economic impact and reduced CO2 emissions (Prasad & Prasad, 2023). The research found that bPVs are a better choice than mono-facials on smaller land sizes. The research conducted in this study examines if it is possible to replace the modules of a functioning 2.4 MW traditional single-sided system with new bifacial modules. The new units will offer additional room for the growth of the existing system situated on the roofs of Al-Zaytoonah University of Jordan. The research will allow for the exploration of various upgrade options for comparable systems in the Middle East area.

Location

Figure 1. The campus of ZUJ, located in Amman, Jordan.

Table 1. Estimated current PV capacities for each building.

Building	Estimated PV capacity [KW]	Approximate utilized area [m^2]
School of Pharmacy	150	1,400
Schools of Business	340	3,300
Library	260	2,500
Schools of Engineering and Architecture	300	2,800
Schools of Science and Nursing	320	3,000
School of Literature	190	1,800
Deanship of Scientific Research	60	560
Deanship of Student Affairs	60	600
Main Cafeteria	55	550
Center of Consultations and Services	25	240
Sports Center	230	2,200
Workshops and Warehouse building	170	1,700
University’s Nursery	50	450
University’s mosque	40	400
Bus parking lot	180	1,700
Total	**2,430**	**23,200**

ZUJ is situated in the southern part of Amman, Jordan. The campus covers about 300,000 square meters, as depicted in Figure 1. Since 2011, major campus buildings have had a 2.4 MW mono-facial photovoltaic system installed on their rooftops. At the moment, there are 14 structures equipped with rooftop solar panels, along with the bus parking lot roofs. Table 1 illustrates the current distribution of photovoltaics on buildings, including the size of their rooftop areas based on Google Earth phootage and measurements.

Slight variances in PV capacity can be observed among buildings with comparable rooftop sizes. This results from variations in the kinds and formations of the modules as the system underwent installations at various times, along with numerous replacements and upgrades. The PV capacities were estimated based on location sitings, utilized areas, and inverter capacities. The typical power output of the modules in place is approximately 305 W per module, with an average efficiency of 16% and measurements of 1690 x 990 mm. All modules face south with a tilt angle of approximately 23 degrees over different installation heights.

Methodology

To assess the necessary space for installation of the new bPV modules, a specific type of bPV will be utilized for this analysis. Table 2 displays the features of the updated bPV module in use. The selected bPV module has an average power output of 385 W, and can achieve a power gain of up to 30% when installed at heights ranging from 1.2 to 1.5 meters. The new module has a slightly bigger surface area, requiring more rooftop space. Nevertheless, increased capacity and power increase will compensate for the discrepancy.

Table 2. Electrical and physical characteristics of the bi-facial module.

Open circuit voltage [V]	49.58
Short circuit current [Amp]	9.87
Maximum power voltage [V]	40.88
Maximum power current [Amp]	9.42
Maximum power - Pmax [W]	385
Module efficiency [%]	19.8
Dimensions [mm]	1968 x 990 x 40

Labor, exchanging, and setup expenses will be determined by the typical prices found in the local Jordanian market. Normally, quotes and proposals are bundled together, so breaking down costs will be estimated based on the total price. Local market quotes and offers will be used to conduct an economic assessment, in order to estimate the levelized cost of energy (LCOE), payback period, and return on investment (ROI). This evaluation will take into account expenses and revenues associated with dismantling old modules and building taller steel structures where necessary. The revised system is linked to the grid but does not include battery pack choices. Based on that, the average cost of bPV solar energy is around $700 per KW. This includes the costs of the modules, tall structures and inverters. However, to calculate the levelized cost of energy LCOE, Equation 1 can be used (Emblemsvåg, 2021).

$$LCOE = \{\frac{Capital\ Cost * Recovery\ factor + fixed\ O\&M}{8760 * Capacity\ factor}\} + \{fuel\ cost * heatrate\} + \{variable\ O\&M\}$$

In this system, heat rate and fuel costs do not apply because there is no heat storage or solar-thermal subsystems. The analysis relied on a 20-year operational timeframe, a 20% capacity factor common for solar PV systems (i.e., the ratio of the annual energy the system produces as opposed to full capacity), and set costs of $25 per KW fixed and $0.2 per KW variable. The campus was classified as non-residential so electricity rates were set at $0.18 per KWh. Moreover, the return on the investment and payback period are calculated using the follwing equations (Benli & Gurturk, 2021).

$$ROI = \frac{Gain\ from\ investment - Cost\ of\ investment}{Cost\ of\ investment}$$

$$Payback\ period = \frac{Initial\ investment}{Cash\ flow\ per\ year}$$

Results and Discussion

With a cost of $700 per KW, a 2.4 MW bPV system would have an estimated price of approximately $1,700,00.00, equivalent to the capacity of the previous mono-facial system. Nevertheless, the new system requires only $6.5m^2$ for each 1KW while the current system needs $9m^2$ according to Table 1. This results in a decrease in size of over 27% by utilizing the bPV capacity and dimensions listed in Table 2. We can determine the capacities of the subsystems for every building on campus, as demonstrated in Table 3. The findings indicated that a 3573 KW (equal to 3.57 MW) setup could potentially be placed on the same allotted space, allowing for approximately 47% more capacity than the existing system.

Table 3. Estimated new bPVs capacities for same building areas.

Building	Estimated bPV capacity [KW]	Approximate utilized area [m^2]
School of Pharmacy	215.6	1,400
Schools of Business	508.2	3,300
Library	385.0	2,500
Schools of Engineering and Architecture	431.2	2,800
Schools of Science and Nursing	462.0	3,000
School of Literature	277.2	1,800
Deanship of Scientific Research	86.24	560
Deanship of Student Affairs	92.40	600
Main Cafeteria	84.70	550
Center of Consultations and Services	36.96	240
Sports Center	338.8	2,200
Workshops and Warehouse building	261.8	1,700
University’s Nursery	69.30	450
University’s mosque	61.60	400
Bus parking lot	261.8	1,700
Total	**3,573**	**23,200**

According to the prices in the local market, a 3.57 MW bifacial photovoltaic system is priced at $2,500,960.00. The new system will encompass the total space currently used by the existing system on campus. The price encompasses the expenses of elevating the steel structures as necessary and the earnings from selling the previous mono-facial system as scrap. Additionally, the ROI can be determined using the equation that was previously mentioned. Figure 2 displays profits and expenses for investments throughout a 20-year period, representing the system's lifespan. The new system has an annualized ROI of 5.43%.

The payback period was determined using the previously mentioned equation. In this estimate, a reduction of 5% in cash flow was taken into account, along with a 10% discount rate, over a span of 20 years. Figure 3 depicts the payback period for the recent bPV system at 8.2 years and an annual cash flow return rate of 8.36%.

Furthermore, the levelized cost of energy, LCOE, for the new modules was calculated between $0.04~$0.06 per KWh compared to the utility rate at $0.18 per KWh.

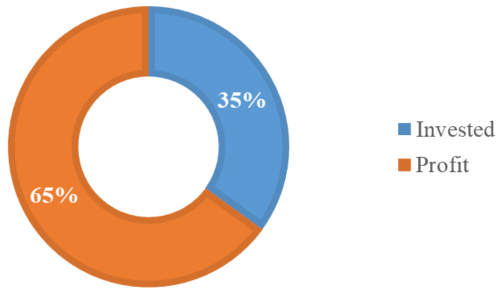

Figure 2. Profits and expenses of the investment over 20 years.

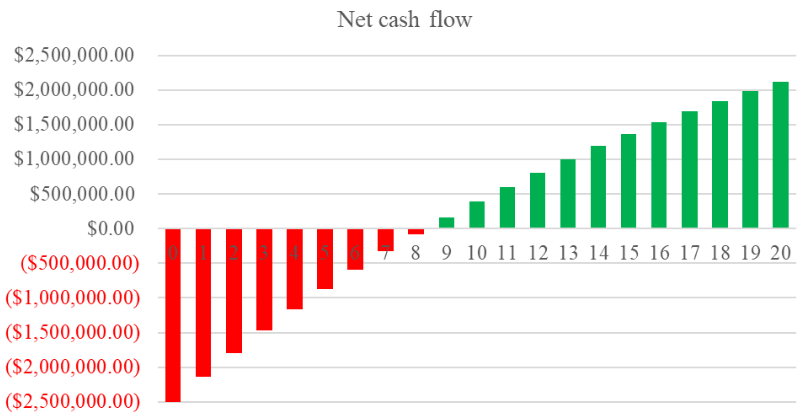

Figure 3. Net cashflow and payback period of the investment.

Conclusion

An economic analysis was carried out in this research to assess the viability of installing new bifacial modules instead of traditional mono-facial modules in a 2.4MW system. The installation took place on the rooftops of the buildings situated on a university campus. This theoretically will conserve space for future system expansions. Replacing a 2.4MW system would cost $1,700,000.00. Using the new bPV modules would mean assigning 6.5m^2 per kilowatt instead of the current 9m^2, resulting in a 27% reduction in space utilization. Nonetheless, it is possible to install a 3.57MW bPV system that will use up all available space and result in a 47% boost in electrical capacity compared to the current system. According to the findings, the recently proposed 3.57MW system would have a price tag of $2,500,960.00. The new bPV system is projected to generate a yearly ROI of 5.43% throughout its 20-year lifespan. The system had a payback period of 8.2 years, annual cash flow return rate of 8.36%, and LCOE ranging from $0.04 to $0.06 per KWh.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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