Assessment of Optimum Installation and Power Injection Parameters for a Bifacial Rooftop System

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Received: 16.03.2021 Accepted:20.04.2021

Abstract- Bifacial Photovoltaics has gained significant traction in recent years due to a combination of superior radiation capture capabilities and reducing costs. This study builds on a prior 1.07 MW (DC) solar system analysis for Effat University Campus in Jeddah, Saudi Arabia, by adding a Bifacial system. The paper describes a modeling methodology focusing on critical parameters that affect bifacial gains, such as the solar system's tilt angle, surface albedo, and shading. The results have been summarized as sensitivities to changes in input variables such as the surface albedo with ceteris paribus assumption. This case study showed a change in surface albedo to increase the specific production from 1771 kWh/kW to 1829 kWh/kW suggesting an increase in bifacial gain of more than 3%.

Keywords Optimum installation; Power injection parameters; Bifacial rooftop system; "PowerWorld" Simulator; PVsyst software.

1. Introduction

There has been a massive rise in bifacial photovoltaic technology due to higher output yields than traditional photovoltaic technology [1]. Concerning photovoltaic modules, the solar industry has the difficulty of rapid innovation and evolving to advance energy conversion performance, increase its lifespan and overall performance, and minimize expenses. The difficulties pushed the industry to choose the right technologies, developing in the market. Polycrystalline and monocrystalline silicon technology are dominating the market currently. Other technologies have the potential for advancements, such as bifacial [2], PERC, double glass, HJT half-cell, GaAs that must be researched and examined. Currently, different kinds of technologies are chosen to generate more energy. The best choice for generating more energy absorption may be the bifacial solar panel. Monocrystalline silicon produced the first substrates of bifacial solar cells 40 years ago [3].

Multi-crystalline silicon bifacial photovoltaic cell is employed to enhance performance and decrease prices, particularly its monofacial equivalent [4]. Thin-film bifacial photovoltaic cells based on CIGS are used for optimum productivity [5]. A prominent target for bifacial dye-sensitized photovoltaic cells has been to pursue high energy transformation efficiency without compromising effectiveness or productivity concerning its cost [6 -9]. GaAs thin film [10-12] and CdTe [13-21] are increase attention as they provide a technically and economically convincing alternative concept. The weight of bifacial photovoltaic is considered too low, flexible, and semi-transparent. Bifacial photovoltaic performance evaluation is done by employing direct testing [22], modeling, and simulation [23] to look into the effect of thickness on bifacial photovoltaic cells accomplishment and efficiency. Light reflected on solar cells' rear surface is an efficient way of reducing solar electricity expenses, as more energy is generated per cell [24].

Bifacial photovoltaic energy production is highly reliant on a particular place or position and is significantly affected by how they are set up and assembled. The bifacial modules need to be mounted at a particular height over the earth's surface to achieve optimum power output. It is vital to assure no obstruction for the uninterrupted sun to shine on the photovoltaic panels underneath the module directly. Higher height is required for areas with low latitude. For places with higher latitudes, sunlight is more likely to reach the ground directly under the module. As a result, a lower module mounting height is needed. With the extended module mounting height, there is a saturation point to enrich power [25]. The cost of a silicon wafer is higher than the photovoltaic module's cost, which is approximately one-half [26].

Bifacial silicon wafer-based photovoltaic modules are desirable because of their cost-effective and higher energy yield than monofacial systems. Bifacial silicon wafer-based photovoltaic modules are desirable because of their cost-effective and higher energy yield properties compared to monofacial systems. Bifacial solar panels are made with dual tempered glass or transparent back sheets and can be formed from polycrystalline cells or monocrystalline cells. The Bifacial system is capable of utilizing both front solar irradiance and bounced light from the ground. Back reflectors are designed to increase the rear side module's cell energy by using front solar irradiance. Diffuse and semi-mirror type reflectors are also used to maximize the absorption and improve the bifacial solar cell's efficiency from the rear side by placing them at different angles and separation [27].

Bifacial cells absorb less infrared (IR) light due to the large open rear surface and thus function at lower temperatures and, consequently, higher electrical efficiency. It is vital to investigate the bifacial and mono-facial silicon solar cells' IR light absorption properties and the association with the cell's temperature behaviour [28]. The bifacial photovoltaic module provides an additional output because of its capacity to absorb reflected light from every direction upon the solar modules' reverse side. It is essential to determine the consequence of system installation parameters such as module elevation, title angle, albedo, pitch, soiling losses, shading, direct and diffused irradiation, temperature, and array size helps predict the system's power production precisely to quantify levelized energy cost (LCOE) [29]. There is a challenge for the industry to innovate and adapt the efficiency of energy transformation considerably, improving the lifespan of photovoltaic modules, and minimize the operation and maintenance costs of photovoltaic modules [30-34].

The photovoltaic system's technical and financial feasibility at Effat University in Saudi Arabia was conducted using a modeled system [35]. Prepared a comprehensive engineering design and power simulation summary, and the complete economic advantage of solar investments is estimated utilizing the examination of utility data. The financial model was prepared to analyse the return on investment and advantages. Sensitivity analysis was carried to learn about the fluctuations concerning target variables and input variables of the system. This study evaluated the impact of multiple solar system parameters on the bifacial gain and the overall production output. Given the proliferation of bi-facial modules, this paper builds on our previous work. The study explores the effect of multiple system-level input parameters and their significance in bifacial gain modeling. The complete simulation methodologies and technical assumptions, including the bifacial gain's contribution to the overall system performance, are studied in this paper. This paper also discusses the steps to model the power flow from the bifacial solar system source circuits until the injection point to the electric grid with the "PowerWorld" Simulator's help. This paper is segmented into five parts.

This paper incorporates the introduction of bifacial technology and the importance of accurate bifacial gain modeling. It also evaluates the system parameters responsible for accurate system designing. Furthermore, it provides simulation methodologies and assumptions to design photovoltaic systems at Effat University in Saudi Arabia. Moreover, it involves creating the power flow model and loss calculations along with future works and conclusions.

2. Impact of system input parameters

In this section, simulations were performed to analyze and correlate the impact on power generation and installation parameters, including albedo, module elevation, title angle, pitch, soiling losses, shading, direct and diffused irradiation, temperature, and array size.

2.1. Tilt angle

Adjusting the angle connecting the horizontal plane and the solar panel to optimize the seasonal or yearly collection of energy is called a tilt angle. (see Fig. 1). The maximum tilt angle varies for bifacial photovoltaic modules and depends primarily on parameters such as elevation, albedo, geographical location, and time of year. Optimally adjust the tilt angle of a bifacial system as it enhances the rear-side albedo light collection and improves system performance. Fig. 1 shows the tilt angle and the rear-side irradiation collection.

Considering Effat University campus in Saudi Arabia (Latitude-21.4790, Longitude-39.2123), a simulation was performed to evaluate the energy yield at various tilt angles. Fig. 2 shows that the highest output is at 15° tilt with a specific production of 1769 kWh/kWp. The previous study on the Effat University campus in Saudi Arabia considered 12° tilt for the monofacial system, which resulted in a specific production of 1,709.6 kWh/kWp. Most tilt modules consider the shading effect induced by adjacent rows and nearby objects, as shading decreases system performance and may be responsible for hotspot formation[36].

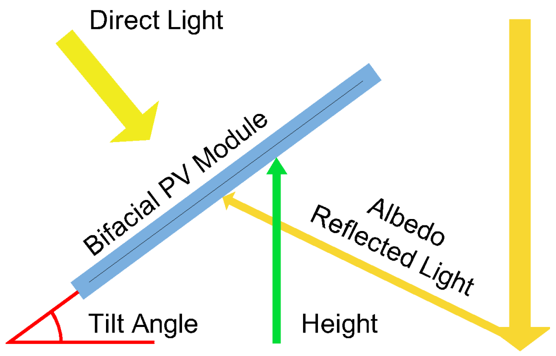

Fig. 1. Tilt angle and Rear-side Irradiation Collection

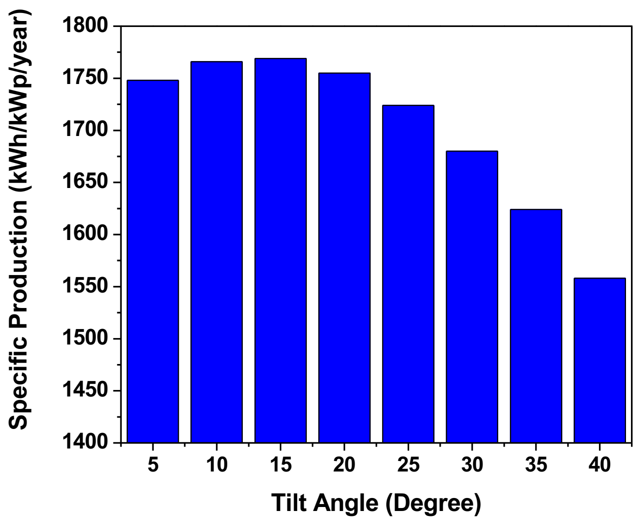

Fig. 2. Production versus optimal tilt analysis at 0.6 m elevation

2.2. Module elevation

The following important factor is the module's height, which influences energy production shown in Fig. 3. According to Albuquerque's research for three different bifacial arrangements, there was a significant reduction in backside irradiance capture due to self-shading when the bifacial modules are placed much closed to the surface [37]. The elevation (module height) is described as the range separating the ground surface and the bottom of the module's lowermost section [38]. Our simulation observes a general trend of increasing specific production from 1762 kWh/kWp at 0.2m to 1770 kWh/kWp at 0.6m and then tapering off after reaching the height of 0.6m. The simulation data suggests that a rise in elevation above a certain level does not incrementally add to production as self-shading effects diminish, as shown in Fig. 4. These results align with new bifacial-based racking technologies such as the OPSUN bifacial rooftop racking system.

The average elevation for flat roof photovoltaic racking is in the range of 0.4-0.6 m (Sunrail Bifacial Racking Datasheet) and customized according to the system requirements.

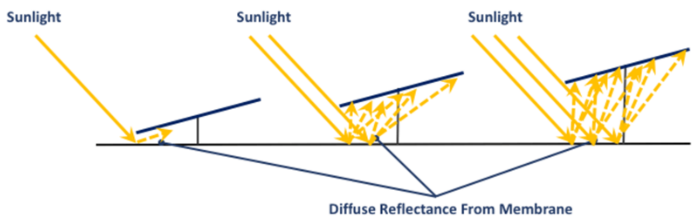

Fig. 3. Impact of Elevation on Rear-side Irradiation

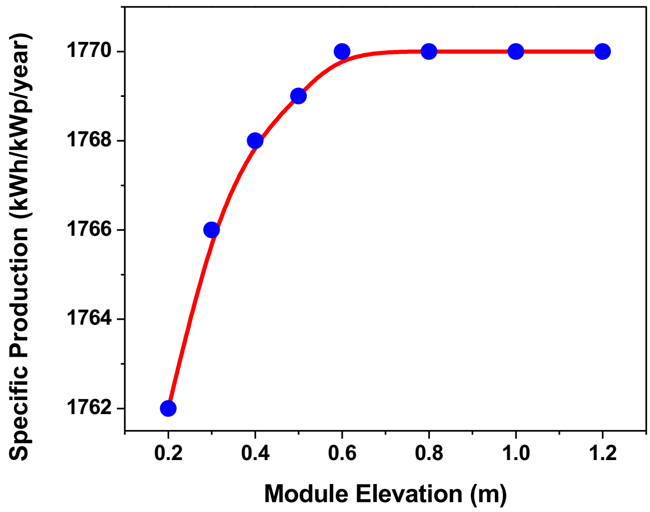

Fig. 4. Production versus Module Elevation Analysis

Installers can save installation costs by calculating the optimal height for the specific location, which will result in maximum energy yield. Higher elevation can also improve cooling [39], which will enhance module performance and energy production. The height of the module also influences the uniformity of the reflected light. On certain parts of the modules, the irradiance amount at the back varies because of its own shadow. Outdoor measurements on panels mounted on a flat roof in Jerusalem have shown that the module's cell near the highest edge receives a more significant amount of light than the other cells in the module. If the module's elevation rises, the irradiance levels are more uniform in the module [40]. The module's elevation is critical because irradiance's uniformity leads to a mismatch loss at the module and array level.

2.3. Albedo

The albedo is the proportion of reflected light energy to incident energy covering a surface area. Typically, albedo is site-specific, depending on the surface beneath the solar modules. These values also vary with daily and seasonal weather conditions. For rooftop projects, it is mainly dependent upon the texture and color of the surface. Research conducted by Jinko shows that the average albedo value for concrete material is between 0.25 and 40%[41-42].

Fig. 5. Effat University Rooftop

According to the Effat University Roof conditions shown in Fig. 5. It is assumed an albedo value of 35% for aged concrete generating 1770 kWh/kWp and 80% for white-coated surfaces culminating in 1830 kWh/kWp specific production in Fig. 6. There are multiple resources available such as Pvsyst (photovoltaic software), NSRDB, and NASA, which provide surface-based albedo estimates. Calculating albedo at the project site by installing two pyranometers that collect direct and reflected radiation is recommended.

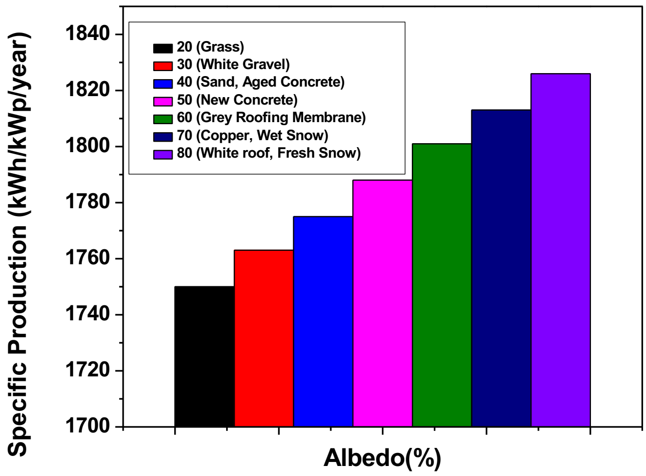

Fig. 6. Increase in Production with Albedo

A study was performed at Heriot-Watt University in the UK, which showed that dust and dirt collection decreased the albedo value from 72% to 67% quickly [43]. The impact of soiling on the albedo predominantly depends upon the location of the photovoltaic system. There will be enough rain to clear the dirt and dust away from the roof membrane[44]. However, in places like the Middle East with heavy soiling losses and low precipitation, additional roof cleaning must maintain high albedo values. It is also possible to improve albedo and boost generation by coating the ground surface with white paint or reflective surface. The selective coating is economically feasible for rooftops or small plants without impacting capital expenditure[45].

2.4. Pitch

The distance between two rows of a photovoltaic installation plays a crucial role in contributing to energy gain is called pitch. Pitch is associated with the Ground Coverage Ratio (GCR) is shown in Fig. 7. The GCR represents the ratio between total ground area and photovoltaic modules. An increase in pitch improves rear-side visibility and enhances diffuse albedo by reducing inter-row shading.

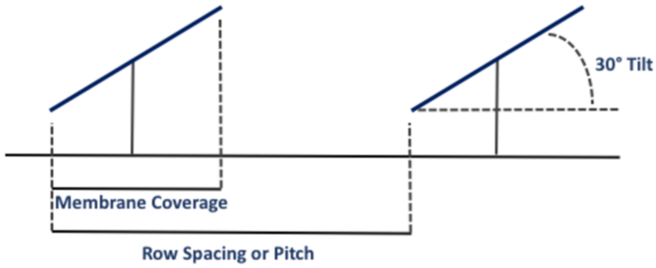

Fig. 7. General System Representation

The irradiance seen at the back of the modules is proportional to the light reflected by the module's surface. As a result, the distance between the adjacent rows increases, which means that the surface area also increases, leading to increased bifacial gain. The high pitch has a beneficial impact on the bifacial ratio, which results in higher energy production. However, there is saturation in the output above a specific value. Increasing the pitch above a certain distance poses a problem for restricted rooftops and raises capital expenditure due to wiring, infrastructure, etc. The site's optimal pitch depends on the project's position, the available roof area, and the system's tilt [46].

2.5. Soiling losses

Soiling refers to the accumulation of the photovoltaic modules of soil, dust particles, leaves, dirt, bird droppings, and various environmental contaminants, contributing to the loss of sunlight transmission. Although the Middle Eastern deserts are areas with ample sunlight for photovoltaic generation, high temperatures and extreme soiling of photovoltaic modules are causing significant output loss [47]. Due to desert areas with little rain, dust particles settle on photovoltaic modules, resulting in an optical loss. In one of Chile's studies, the rear side's rate was only 11.3% of the soiling rate on the front side [48]. The experimental data collected by K-A-CARE for one year at Rumah, Saudi Arabia, shows 3 to 40% losses due to soiling. It is observed that the soiling losses are high in the months of spring due to the usual sand and dust storms in the spring months present in the province [49]. Dust Detection System (DDS) showed a 0.3% per day soiling rate for Jeddah, Saudi

Arabia [50]. We may reduce the accumulation of dust by increasing the tilt angle. Silica nanoparticle coating for photovoltaic modules can be used to reduce soiling loss and improve the anti-reflective surface.

2.6. *Shading*

Solar irradiance can be received and converted to electricity on both the front and back sides of bifacial photovoltaic modules. As the amount of soil on the PV module grows, so makes the power loss, and the irradiance will be regular on the front side of the PV modules if there are no soiling losses. The rear-side irradiance varies because of the ground reflection variation due to self-shading and different view factor angles [51]. The bifacial photovoltaic module's rear side that depends on solar irradiation to produce electricity is shaded by the junction box on the rear side of the PV module, wiring at the photovoltaic array, and the photovoltaic racking. Racking structures are primarily responsible for blocking backside irradiance, leading to backside shading losses and decreased bifacial gain. It is also recommended that structures designed especially for the bifacial photovoltaic module be preferred, shown in Fig. 8.

Fig. 8: OPSUN Racking Structure for Bifacial System [11]

2.7. *Direct and Diffused Irradiation & Temperature*

The bifacial gain is determined by the proportion of energy generation (kWh) in the PV module's rear and front sides. One of the significant variables that significantly affect the bifacial gain is the module's height. Between the module and the ground, there should be enough room for sunlight to reflect. The meteo data from the weather station consists of the ground reflected solar radiation, diffuse radiation (global radiation), and direct beam radiation, shown in Fig. 9. As a global norm, estimating diffuse or global radiation on a horizontal surface helps connect one position against another, irrespective of latitude and the zenith-related sun location [52]. It is essential to model sky diffuse correctly, ground reflected, structure reflected, and direct irradiances, contributing to the fixed-tilt structures' backside irradiance to determine the significant gain [53].

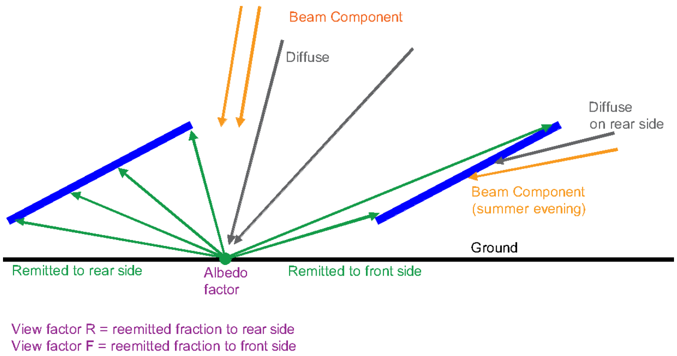

Fig. 9. PVsyst Representation of Direct and Diffused Irradiation

The system's output energy reduces as the temperature of the module raises. The low ambient temperature makes it possible to achieve comparatively high system performance. When determining energy efficiency or estimating the bifacial photovoltaic system's losses, the module's temperature distribution under different mounting positions and wind speed must be considered. The bifacial system has a low coefficient of temperature and leads to high bifacial gain [54].

3. Simulation Methodologies and Design Assumptions

Simulating the performance of bifacial solar systems is more complicated than simulating the performance of monofacial systems. The Effat University campus rooftop solar system is designed using Helioscope software. However, the Helioscope does not have the functionality to simulate bifacial gain. There is no ability to model monthly albedo values and shade from racking structures that directly affect energy production. There are some selected tools available to model bifacial systems and provide reliable bifacial gain values. PVsyst, SAM, and Bifacial Radiance are applications that allow users to simulate bifacial designs. The input parameters discussed in the previous section can all be modeled in PVsyst version 6.7 and above, which has a bifacial simulation algorithm, including evaluation of beam and diffuse components from weather data irradiation. We designed the available roof area of Effat University in Helioscope, assuming optimum design parameters for this location compatible with a bifacial system. With the Jinko 450 bifacial module's aid, we can fit 1.07 MW of DC capacity as displayed in Fig. 10. In the context of Effat University's solar PV system production modeling, we reiterate key input parameters that play a critical role in bifacial modeling and describe how these can be modified following system requirements and project location in the software. The bifacial system behaviour can be analysed by simulation utilizing PVsyst software, and simulation parameters explicit to the bifacial photovoltaic system are presented in Fig. 11 (a) and Fig. 11(b).

Fig. 10. Helioscope Detailed Layout with 1.07 MW DC Capacity

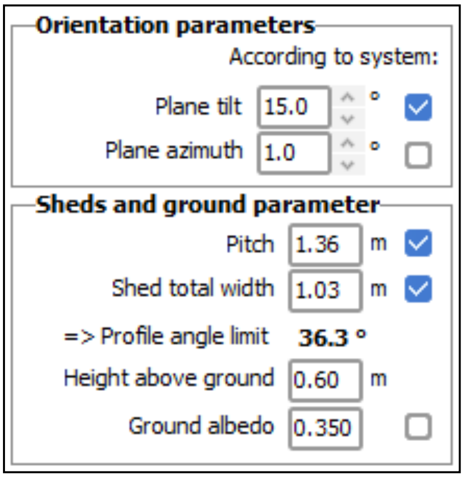

Fig. 11 (a). PVsyst Bifacial Simulation Parameters

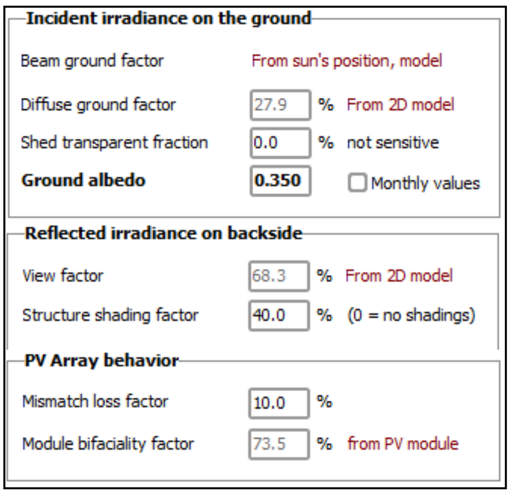

Fig. 11 (b). PVsyst Bifacial Simulation Parameters

3.1. PVsyst Simulation Parameters

3.1.1. Location: Creating a project with correct coordinates is critical in PVsyst, as the meteo data produced from the built-in Meteonorm weather source is based on project location. Meteonorm 7.2 has been used for PVsyst simulation with 7% satellite data.

3.1.2. Roof Albedo: In PVsyst, users can define monthly albedo values according to the weather conditions and seasonal changes for specific project locations. Fig. 12 shows the PVsyst Functionality to Model Monthly Albedo.

Fig. 12. PVsyst Functionality to Model Monthly Albedo

3.1.3. Structure shading factor: It is a shading factor because of any obstruction connecting the module's fragile backside and the ground. We considered this factor to be 40% as a fixed-tilt system causes higher shading due to the racking structure.

3.1.4. Mismatch loss factor: It is a loss factor made by a difference in irradiance on the backside, which should be 10%.

3.1.5. Bifaciality factor of the Module: The ratio of the nominal efficiency at the rear side concerning the front side is called the bifaciality factor. This factor is generally specified in the "PAN file" and is 73.5 % for the simulation.

3.1.6. Height above ground: It is the module's lowest height from the roof or ground surface. The optimum height above ground is considered to be 0.6 m, according to the simulation results.

3.2. Equipment selection

3.2.1. Bifacial module:

Bifacial panels typically are made of monocrystalline cells, but there are also polycrystalline designs. A slim profile is one of the most prominent physical features of the bifacial panels – several bifacial designs need minimal framing. The panels themselves are fitted into a thin transparent layer that can either be built-in dual glass or manufactured with a clear back sheet. Due to the greater durability of the dual-glass design. It is more desirable than other design types. Annual degradation rate is 0.5% for dual glass and 0.7% for polymer back sheets [55]. We used Jinko 450Wp bifacial module with a bifacialty factor of 73.5%. The first-year degradation of this module is 2.5%, and the linear degradation of 0.55%. This module has temperature coefficients of -0.35%/°C at Pmax. (Jinko Bifacial Datasheet).

3.2.2. String Inverters

The Bifacial photovoltaic panel's current (Isc) value increases by the backside boost, where the bifacial voltage is constant. Therefore, it is crucial to consider the maximum input current limit when selecting an inverter for the bifacial photovoltaic system. However, it is regularly suggested to use the actual power with gain rather than the bifacial photovoltaic module's nominal power for inverter sizing. For instance, if a 10 percent gain is predicted, refer to the 10 percent gain's power rather than the module's nameplate rating. When selecting the inverter's size, it's essential to consider the clipping losses and DC/AC ratio, which rise when the gain increases. However, if the clipping loss only increases marginally, it's possible that using the same inverter power without sizing will be more effective. The inverter type, via multiple MPPT input and control, bifacial modules with string inverter can mitigate the mismatch loss in the area with non-uniform albedo. We used 3 SMA string inverters rated at 15, 30-and 50-kW AC as arrays are spread throughout the Effat university campus and offered us a better stringing option and were responsible for the low voltage drop.

3.2.3. Mounting Structure

The architecture of bifacial solar panel mounting systems varies from that of conventional solutions. Racking systems with support rails typically covered by the backsheet of the monofacial module will block the reflected sunlight on the module's rear side. Bifacial panels need to be less shaded from the front of the surface and back to absorb the most sunlight. New racking solutions for bifacial panels can employ narrower support rails, small junction boxes, vertical supports at the racking system's right edges to decrease shading on the panels' backside.

3.3. Project Simulation and Loss Analysis

Considering the optimal tilt of 15 degrees, 0.6 m height above the roof, and 1.2 ft row spacing, simulated two design variants. Initially, considered 35% albedo value for the aged concrete roof, and the system produced 1897 MWh/year energy, as shown in Table 1. Additionally, coating the entire roof with white paint was proposed to increase the surface reflectivity and the second iteration with an albedo value of 80% produced 1958 MWh/year energy. A substantial increase in bifacial gain was observed between the two versions, with gain rising from 5% to 8.48 % shown in Fig. 13. PVsyst considers losses due to aging, unavailability, thermal, soiling, irradiance, wiring, mismatch, shading, and photovoltaic conversion losses. However, losses significant to the simulation are soiling loss, thermal loss, shading loss, and mismatch loss.

Table 1: Simulation Variants with Design Parameters

Design Simulations	Albedo (%)	Specific Production ((kWh/kWp/year)	Energy Produced (MWh/year)
Variant 1	35	1771	1897
Variant 2	80	1829	1958

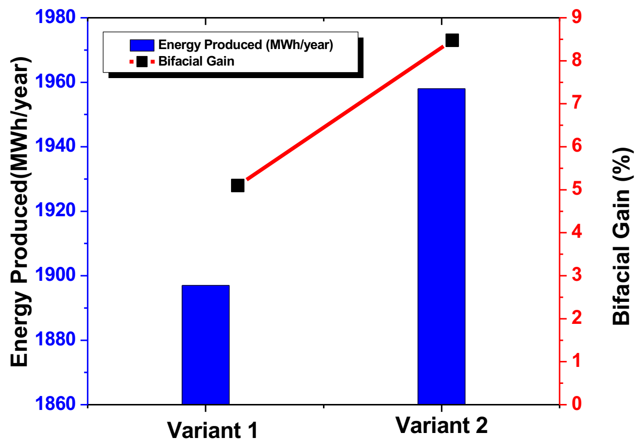

Fig. 13. Produced Energy and Bifacial Gain

3.3.1. Soiling losses: The average soiling loss for Jeddah is in the range of 8-9% due to a desert area with less precipitation. Frequent cleaning cycles are mandatory for this location to maintain system production.

3.3.2. Thermal losses: The thermal losses are dependent on the ambient temperature, the module irradiance, the performance of the photovoltaic, and the U-value. We observed a 10.92% loss due to temperature in the simulation results.

3.3.3. Shading losses: Usually, row to row shading, nearby buildings, or trees lead to shading losses. We can simulate a 3D shading scene to analyse shading losses from nearby objects. The near shading loss for this system is 1.60%

3.3.4. Mismatch losses: The mismatch loss is a comprehensive product of front-and backside energy generation. In addition to the installation height, the end result is a non-uniform rear side irradiance; the modules at the array edges absorb more backlight than the modules in the middle of the array. Uneven soiling cover and partial shading also contribute to the mismatch losses. The mismatch loss is 2% of the total system losses.

4. Power Flow Modeling and Loss Calculation

The previous section modeled the photovoltaic production and power output from the solar system, assuming no reactive power losses. However, the net power available at the grid is affected by the power factor of the underlying electrical system. An analysis is carried out in this section to showcase how the solar generator interacts with the electrical system at Effat University. In the case of large-scale commercial and utility-level solar projects, grid interconnection studies provide insights into the feasibility of locating a new generator at a given point on the power grid [IEEE 1547] [56]. One of the critical areas of study during the grid interconnection review is understanding the Steady State and Dynamic State Stability of the solar system. Power Flow analysis enables us to carry out these studies by defining the electrical configuration from the source circuits to the grid injection point. By monitoring the voltage, active and reactive power flows at critical points, such as nodes in the power system network.

The supply of reactive power is an important variable to monitor in a dynamic AC system such as the power grid. Inductive loads in a typical electrical power system create an extremely undesirable low lagging power factor. Loads with a higher power factor attract a limited current than loads with a power system with a low power factor for the equivalent quantity of adequate power transmitted. Consequently, the distribution system's energy loss increases and requires larger cables and higher capacity rated equipment [57]. Generally, a low power factor drives an ineffective electric power system due to increased cable losses, decreased voltage, and drop ineffective cable ampacity. For end-users and operators of the system, the net result is economically inefficient.

Nevertheless, a suitably designed power factor enhancement system may regulate the power factor. Consequently, enhancing the power factor plays a significant part in the system's efficient performance and reduces electricity consumption [58]. Saudi Arabia's Power & Utility Firms have steadily started to penalize business and commercial consumers with a power factor of less than 0.95 [59-68].

The "PowerWorld" Simulator is an interactive power system simulation platform designed to simulate power systems' operation and performance, including all electrical sub-components such as generators, transformers, capacitor banks, transmission lines, etc. The Power Flow analysis simulation in "PowerWorld" allows the designer to know the electrical stresses observed in the system and develop a strategy to mitigate them using the appropriate stabilizing equipment. In this case study, the capacitor bank showed on the load side (see Fig. 17) was added after observing the Power Flow study results. For Effat University, a usual scenario was created where assumed the university load to draw total active power of 2.53 MW and reactive power of 1.29 MVAR, having a power factor at 0.89 based on reactive loads connected in Electrical labs and HVAC systems [69-72].

The three transformers that supply power to university loads are 1.Transformer One (X1), supplies to recreation club, computer lab, libraries, medical center, and laboratory. 2. Transformer Two (X2), supplies to student cafeteria, registration office, architectural and electrical laboratory, several offices, and university street lighting. 3. Transformer Three (X3), supplies to administrative buildings, classrooms, student hostels, and nearby lighting and shops.

According to the requirement of the grid to maintain a power factor above 0.95, 1. We simulated four cases to observe the grid-connected electrical system's power factor in the absence of the power factor correction equipment, 2. The pre-and post-connection power flow characteristics of the photovoltaic system to the Effat university network is simulated, and 3. Added a capacitor to enhance the power factor. In the simulations linked to the grid, all the inverters in the photovoltaic system were configured as individual generators, and their output is observed under different loading conditions. The power flow case studies are shown in Table 2.

Table 2: Power Flow Case Studies

Case No.	**Capacitor Bank**	**Photovoltaic System**
Case 1	☒	☒
Case 2	☑	☒
Case 3	☒	☑
Case 4	☑	☑

☑ - represents a component connected to the system.
☒ - represents a component disconnected from the system.

Case 1

While modeling this case, connected no power factor correction equipment to the system, and simulation was performed to analyse the system behaviour (Fig. 14). The “PowerWorld” result showed that for the supply of 2.53 MW of active power and 1.29 MVAR of reactive power to the university, the system drew 2.56 MW and 2.64 MVAR at a power factor of 0.7 due to cables drawing reactive power from the grid to supply the load. The key observations and associated issues from this simulation that had to be rectified were –

a. The load terminal voltage of 180 V, as shown in Fig. 14, was well below the required voltage of 220 V, resulting in the equipment's under-voltage operation.

b. The conductors were also overloaded by 23%, as seen in Fig. 14, which causes cable insulation degradation.

As a result, the analysis suggested the need for power factor correction at the Effat University Campus to mitigate the points above.

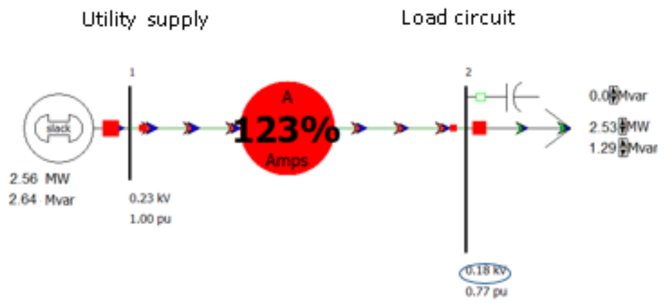

Fig. 14. Power Flow Model (Case 1 - PF 0.7)

Case 2

In this instance, to enhance the power factor and fulfill the requirements for utilities, connected the capacitor banks to the system. After increasing the capacitor bank's capacity in incremental steps of 13 KVAR per phase, needed the capacitor bank of 1.328 MVAR to maintain the power factor above the 0.95 thresholds shown in Fig. 15. Furthermore, the results suggested, cables were loaded at a capacity of 88% while providing the marginal protection of 12%. The resultant PF was 0.97. Consequently, a 1.328 MVAR capacitor bank would eliminate the grid's penalties for not maintaining the required power factor and preventing cable infrastructure deterioration. Cases 3 and Case 4 evaluate the Effat university network's efficiency after the injection of the photovoltaic system.

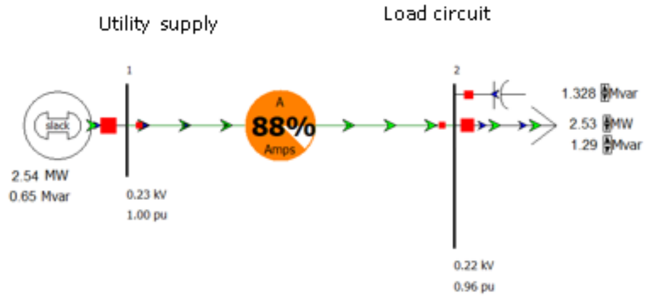

Fig. 15. Power Flow Model (Case 2 - Shunt Capacitor)

Case 3

After connecting an 800 kW photovoltaic system operating at unity PF to the Effat University network, the simulation in Fig. 16 showed that the university drew power at 0.66 PF, which was below standard utility requirements. Furthermore, a load terminal voltage of 190 V was observed, resulting from the equipment's under-voltage operation. The grid's active power was reduced by 47 percent with the introduction of the photovoltaic system, while reduced the reactive power by 32.7 percent concerning case 1. The net effect is a lower power factor from the grid.

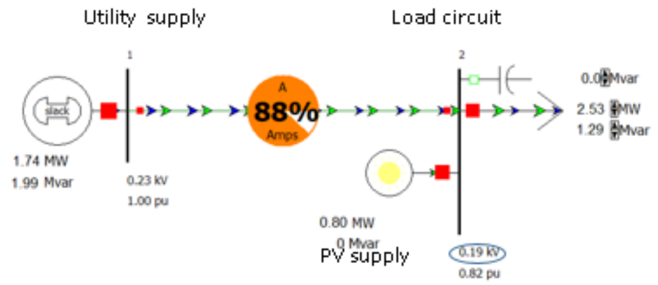

Fig. 16. Power Flow Model (Case 3 - with photovoltaic Plant)

Case 4

A photovoltaic system was configured along with the capacitor bank and observed the 1.23 MVAR capacitor was sufficient to maintain PF above 0.95 to meet the utility criteria in a final simulation. The busload voltage was 220 V, meeting the typical equipment specification. Simulation in Fig. 17 showed that, following the installation of a photovoltaic system with a 1.23 MVAR capacitor bank, the cable was loaded at 59 % with 0.98 PF, which provided the additional load potential introduced without modifying the existing network.

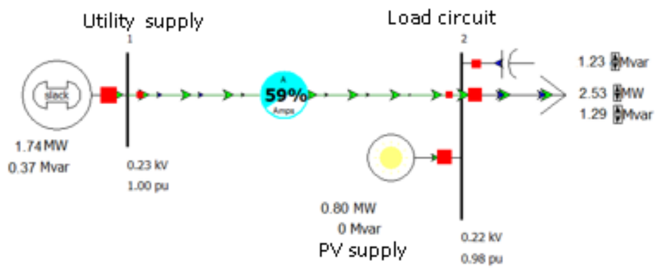

Fig. 17. Power Flow Model (Case 4 - photovoltaic Plant with PF correction)

To summarize, the analysis combined the load, generator, and transmission lines to analyse and represent the simple power system of Effat University. The advantage of reactive power compensation is that the power factor penalties are minimized below 0.95. Furthermore, the power factor correction would improve the power system's overall efficiency, which would increase the life of the connected load, switchgear, transformer, bus bar, and transmission line. The power factor correction allows the designer to combine the photovoltaic production simulation's technical aspects in the previous sections with the power flow characteristics to study the complete picture of energy transmission from the solar panels to the electrical power network.

5. Conclusion and Future Scope

The case study covered the critical input parameters that affect the bifacial gain of photovoltaic systems. Specifically, the analysis quantified the impact of albedo changes on the Effat university rooftop solar system and observed an increased albedo could improve the gain by over 3%. Besides, to examine the consequence of the module elevation on the gain, we conducted sensitivity analyses. The results suggested tapering off the gain beyond a specific module elevation (0.6 m in the case study). Lastly, the study covered critical simulation methodologies for solar production modeling with bifacial panels in PVsyst. It concluded with a discussion of the power flow injection studies in “PowerWorld” required to interconnect the system to the utility grid. The paper described some of the critical design considerations that solar development teams have to encounter given the changing landscape of equipment options, modeling strategies, and grid interconnection rules. For future scope, an essential expansion of the study could be performed using a single-axis and double-axis tracking system to analyse the enhanced gain provided by combining the bifacial capture gain and tracker system gain.

Acknowledgments

The authors gratefully acknowledge the support provided by the Research Consultancy Institute (RCI) of Effat University, Saudi Arabia, Engineering, Globus Thenken, Pune, India. Furthermore, Vinayaka Mission's Kirupananda Variyar Engineering College, Vinayaka Mission's Research Foundation (Deemed to be University), Salem, Tamil Nadu, India.

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