Potential of Bifacial PV Installation and Optimization

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Abstract— This paper focuses on evaluating and analysing bifacial over monofacial PV, the ideal design to favour bifaciality and to ensure the maximization of the radiation collected, the optimum configuration for a bifacial photovoltaic module which is investigated numerically, in order to easily determine the annual yield that optimise bifacial gain. Modelling a bifacial photovoltaic system for a case study, Nanjing, China, showed that power production is highly dependent on the incident radiation, stand design and reflectivity of the ground. For a typical photovoltaic plant, the bifacial gains varies from 25%-39% for power production and from 33%-42% for the irradiation received, depending on the tilt angle. Higher stand and more reflective ground surfaces boost the bifacial gains. It is also shown that the electrical generation gain is propotional to the irradiance gain and both increase with the diffuse fraction. Finally, there is the necessity to devise an electrical model for the optimization of a bifacial PV configuration to enhance the electrical production by effortlessly and accurately predicting the energy gains and maximum power point of operation of a bifacial pv (MPP) which is the main objective of this research which aims to provide the basis of a future performance analysis of a bifacial PV technology.

Index Terms—. Bifacial module, Maximum power point (MPP), Photovoltaic system, Energy gains, Solar cells

1 INTRODUCTION

Increasing the power output of solar modules is a crucial step towards lowering the cost of electricity generated by photovoltaic plants [1]. [2]. One strategy for increased power output is the use of bifacial solar cells that are designed to accept incident light to the front and rear of the cells. This concept was already developed in the 1960s [3]. but only recently module manufacturers started selling bifacial modules as a standard technology. The gain from using a bifacial configuration often exceed the power output of monofacial solar modules by a surprising amount and values of up to 50% have been reported [4]. Nevertheless, the bifacial system modelling is more complex than that of the monofacial system due to the need to estimate the rear side illumination, which depends on the percentage of diffused radiation, the sun elevation, the background reflectance, the height of the module above the ground and the tilt angle. The geometric factors are the tilt, the height above ground, and the length of the solar modules. These geometric factors affecting the bifacial solar cell efficiency have been extensively studied elsewhere [5] - [13], and here we address the issue of the energy bifacial gain and the MPP.

While bifacial PV cells currently make up an insignificant percentage of worldwide PV cell sales, the technology is in some ways a continuation or logical extension of standard monocrystalline silicon (mc-Si) cell technology. Depending on whether the semiconductor material contains a relative abundance or deficiency of electrons, the industry broadly categorizes mc-Si cells as either n-type or p-type devices, respectively. It is possible to fabricate bifacial cells out of both p-type and n-type wafers, given high-quality silicon material, although the process requires some additional manufacturing steps compared to producing conventional monofacial cells. In practice, more than 90% of the PV cells sold worldwide are based on a p-type architecture, while the vast majority of the bifacial products are n-type devices. This underscores the fact that many n-type PV cells, which are primarily found in niche high-efficiency modules from companies such as LG, Panasonic and SunPower, are inherently bifacial.) P-type devices dominate the market because they are cost-effective to fabricate at scale. While n-type bifacial cells offer the highest efficiency, companies such as SolarWorld are predicting that p-type bifacial cells can provide a good balance between performance and cost.

The rapid growth of the solar industry in recent years has been largely premised on significant up-front cost reductions, especially lower costs for PV modules. Bifacial PV modules run counter to the grain in the market since they are inherently more expensive than conventional monofacial modules. Fabricating bifacial PV cells requires not only high-quality mc-Si wafers, but also anywhere from two to six additional manufacturing steps compared to conventional cells. The crux of the bifacial value proposition, therefore, is improved production and performance over the life of the system, which is a function of both bifacial energy gains and improved durability. Because bifacial modules offer high conversion efficiencies, they also have the potential to lower balance of system (BOS) costs, which make up an increasing percentage of up-front system costs. The ultimate goal, of course, is a lower levelized cost of energy (LCOE) which is an issue of bifacial pv.

2 PRINCIPLE AND MODELLING OF BIFACIAL SYSTEM

Along with the incident radiation on the front side, bifacial PV take advantage of the diffuse, reflected and direct radiation that reach the module's active rear side, depending on its orientation, elevation and tilt, site's characteristics and the position of the sun in the sky. Thus, the power output of the rear side is highly dependent upon the local ground's albedo and its surroundings, the module installation configuration and meteorological conditions. From the shadow region on the ground, only diffuse radiation is captured by the solar module, while in the unshaded area, both direct and diffuse radiation are reflected, affecting the rear side of the bifacial module. When considering a PV stand, the evaluation of bifacial gains becomes more complex due to the different variables involved, not only the aforementioned ones, but also the packing density (distance between and within rows), the shadows produced by the mounting, the additional shading caused by the neighbouring modules and the obstruction of reflected radiation. These considerations make bifacial PV power plants more sensitive to the installation layout than the traditional ones that integrate monofacial.

The achievable of bifacial technology has been established with the aid of simulation and measurements now not only for single modules, the place strength boosts between 5% [14] up to 54% [15] have been reported, however also for small and large PV stands, with reported strength output increments between 5% and 25% [16], relying on the size of the system. However, these references from literature refer to small systems and the success of bifacial science relies upon on demonstrating the equal gains on larger scale PV strength plants. Bankability, which is the collection of real-world existing bifacial energy-yield data, is one of the challenges that bifacial PV science has to face in order to facilitate its wider deployment [14].

For a given installation, it is necessary to precisely predict the powerproduction and the Bifacial Gain (BG) expected for the various feasible stand geometries and special solar cells' architectures. The BG is defined as the ratio between the surplus power produced by way of bifacial PV and the energy yield of widespread monofacial PV, calculated using the following equation.

$$Bifacial\ Gain = \frac{e_{bi} - e_{mono}}{e_{mono}} \quad (1)$$

Where e_{bi} is the energy yield of bifacial PV and e_{mono} is the energy yield of monofacial PV. The BG can also be calculated in phrases of specific yield (Wh/Wp). The modelling of bifacial PV structures requires the development of a suitable irradiance mannequin as properly as a particular elecrical mannequin of the bifacial PV modules.

A. Irradiance Bifacial Model

The irradiance model is required for the prediction of the incident irradiance on the front and rear surfaces of the solar module. Modelling a bifacial PV device is complex, by and large due to the fact the estimation of rear radiation now not only relies upon on correlated variables, such as the location, ground albedo and design of the stand, however additionally due to uneven incident mild (caused through shadings of the mounting structure, junction boxes, module frames, irregular reflectors and even the neighbouring modules in the identical array). Thus, the model ought to consider the externalities imposed by way of the installation's design, the environment and the shading of the floor and its albedo, and is commonly based on two distinct approaches.

The "view factor method" calculates the radiation "emitted" from the underlying surface and acquired via every cell. The floor below the module is divided into two parts: the shaded and unshaded region; in the former only diffuse radiation is reflected, whilst in the latter each direct and diffuse radiation are reflected.

$$View\ Factor_{A_1 - A_2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos\theta_1 \times \cos\theta_2}{\pi r^2}\, dA_2 dA_1 \quad (2)$$

Where r is the distance between the differential areas dA_1 and dA_2 and θ_1 and θ_2 are the angles between the normal vectors of the surfaces and the line that connects dA_1 and dA_2, respectively

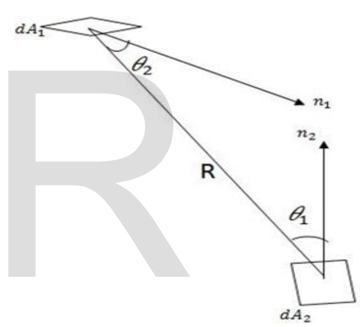

Fig 1: Basic illustration of the View Factor

B. Electrical Bifacial Model

The rear and front radiation estimated with the aid of the irradiance model will be delivered as an input in the electrical model to reap the simulated bifacial strength production. The system's characteristics that englobe the small print of the module performedand the system set up are additional protected in the electrical model.

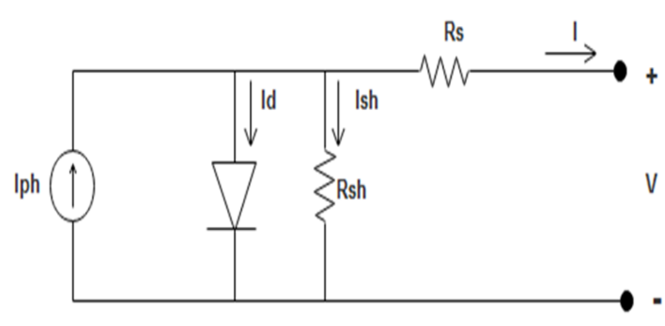

Fig 2: single diode equivalent circuit for a monofacial solar cell

Almost all electrical unit canbe represented via a minimalist digital circuit. Monofacial solar cell are typically modulated via a single diode equal circuit, because the characteristics I-V curveof an illuminated photo voltaic cell behaves as an perfect diode affected via a series and shunt resistance[16]. The I-V characteristic eguation of the single diode equivalent circuit is formulated from kirchhoff's modernlaw and given by:

$$I[A] = I_{ph} - I_0\left[\exp\left(\frac{(V+IR_s)}{nV_T}\right) - 1\right] - \frac{V+IR_s}{R_{sh}} \quad (3)$$

Where I_{ph} is the photocurrent generated, $V_T$is the thermal voltage dependent on temprature, I_0 is the diode reverse saturation and n its ideality factor.

Different electrical fashion of bifacial photo voltaic cells have been proposed, developed and examined to predict its strength manufaturing output. Most of the models developed consider that a bifacial photo voltaic cell can be represented as two monofacial cells in parallel, represented via the single diode or two-diodes equal circuit. The electrical design of the model is introduced in fig 3 below

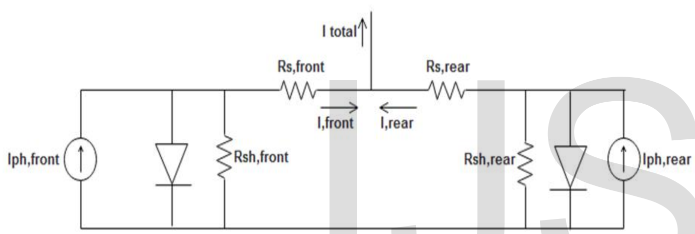

Fig 3: Typical equivalent electrical circit for a bifacial cell

The wide variety combination for the incident radiation at the front and rear facet of a bifacial module is in reality infinite, so its neither sensible nor feasible to determine the electrical parameters of the pv modulefor all those conditions.

J.Singh et al, have synthesized a approach to electrically represent bifacial PV modules for all illumination prerequisites[17]. The basis is the one-diode model of a monofacial cell and the electrical parameters given as an input to the model are extracted from the I-V curves received independently for the front and rear sides of the cell. Therefore, the interference between each sides is not considered, which can lead to mild deviations between the experimental records and the simulation results. These extracted parameters consist of the brief circuit currents, I_{sc} front and I_{sc} rear and open circuit voltages, V_{oc} front and V_{oc} rear, for the front and rear sides of the bifacial solar cell, respectively.

3. Bifacial Cell Design and Model Dynamics

A photovoltaic cell block is already drawn in MATLAB Smuilink®, which includes pohotovoltaic prompted modern-day and temprature dependence. Each block has three ports: tremendous and negative voltages and one to the account for the incident irradiance in W/m². in order to examine bifacial and monofacial electrical behaviour, two models was created. The monofacial module will consist of 60 photovoltaic cells (as those proven in fig 4(a)) linked in series. The bifacial module is similar to the preceding one however it considers every cell as a parallel of two photovoltaic cell blocks, proven in fig 4(b) while the output current for a monofacial cell is given by Equation 3, without the shunt resistance aspect due to the fact its value is commonly too large and can be neglected, for a bifacial cell its given by a way of Equation 4

$$I[A] = \left|I_{ph} - I_0\left[exp\left(\frac{(V+IR_s)}{nV_T}\right) - 1\right]\right|_{\overrightarrow{Front}} + \left|I_{ph} - I_0\left[exp\left(\frac{V+IR_s}{nV_T}\right) - 1\right]\right|_{\overleftarrow{Rear}} \quad (4)$$

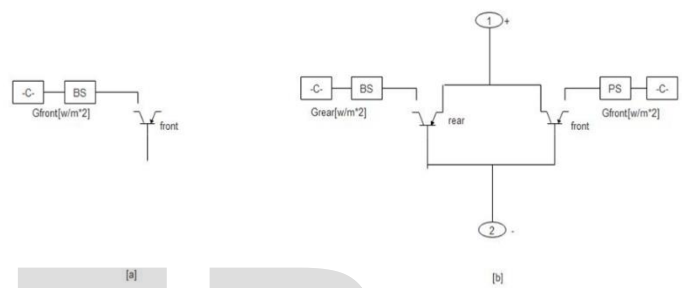

Fig 4: simulated monofacial (a) and bifacial (b) solar cells in Smuilink®. The –C- block represents the input of the hourly irradiance (W/m²) from MATLAB workspace and –BS- converts the input signal to a physical signal.

The photovoltaic cell block illustrated in figure 4 approves deciding on between an 8-parameters model (two exponential diodes) or an easier model with 5-parameters that assume the saturation modern-day of the 2d diode is zero and the impedance of the parallel resistor is endless[18].

While I_{sc} and V_{oc} had been extracted from the module's datasheet (STC), the sequence resistance was once calculated[19]

$$R_s = \frac{\alpha_{STC}\ln\left(1-\frac{I_{mpp,STC}}{I_{sc,STC}}\right) + V_{oc,STC} - V_{mpp,STC}}{I_{mpp,STC}} \quad (5)$$

Where α_{STC} is the thermal voltage timing completion thing for Standard Test Condition (STC)[19]. The value of the remaining parameters were left as default. TIPH1, TXIS1 and TRS1 are coefficients for the temprature dependence upon the solar-induced current, the diode's saturation current and the sequence resistance respectively[18].

For each cell, the hourly rear and front incident irradiances will be estimated based on the mean value of 16 radiation sensors distributed uniformly throughout the PV cell. These predictions are processed in MATLAB®, as well as the wind velocity and ambient temperature of China. Then, the temperature of the module is estimated based on the equations presented above and using the imported data.

The models below are the Simulink model of the bifacial and monofacial where the solar module is connected to a variable resistor. The resistance varies linearly according to an input ramp with a slope of 1 ohm. An ampere meter and a voltmeter are used to determine the photo-generated current and the voltage at the terminals of the resistor, respectively. The product of both variables is registered in a power array and sent to MATLAB's workspace. This power array consists in the power delivered by the module according to the value of the load's resistance, during a simulation time of 100 seconds.

A MATLAB® routine was developed to determine the Maximum Power Point (MPP) of operation for the solar module and the comparison between the both modules. A flowchart of the MPP tracker technique will be implemented.

Maximum power point tracking (MPPT) techniques are used in photovoltaic (PV) systems to maximize the PV array output power by tracking continuously the maximum power point (MPP) which depends on panel's temperature and on irradiance conditions. The perturb and observe (P&O) maximum power point tracking algorithm is the most commonly used method due to its ease of implementation and it's the method used in this paper. A drawback of P&O is that, at steady state, the operating point oscillates around the MPP giving rise to the waste of some amount of available energy; moreover, it is well known that the P&O algorithm can be confused during those time intervals characterized by rapidly changing atmospheric conditions. In order to limit the negative effects associated to the above drawbacks, the P&O MPPT parameters must be customized to the dynamic behavior of the specific converter adopted. A theoretical analysis allowing the optimal choice of such parameters was carried out. This algorithm uses the sign of the old perturbation and the sign of the increment in the power to decide the next perturbation. As long as there is an increment in the power, perturbation remains the same direction. However, if the power decreases, then the new perturbation goes in the opposite direction, and process is repeated until the MPP is reached.

Table 1: Input Data for the Simulation

PARAMETERS	FRONT	REAR
Bifacial Irradiance (W/m²)	1000	300
Monofacial Irradiance (W/m²)	1000	-
Short Circuit Current (A)	8.98	7.96
Open Circuit Voltage (V)	0.65	0.64
Quality Factor (Diode emission coefficient)	1.5	1.5
Series Resistance (Ω)	0.013	0.018
TXPH1 (1/k)	0	0
TXIS1	3	3
TRS1	0	0
Ambient Temperature (°c)	25	25
Simulation Time (s)	100	100
Tilt angle	15°-90°	15°-90°

4 SIMULATION RESULTS

To assess the performance of bifaciality and compare bifacial PV systems with those that use monofacial PV modulesdifferent indicators can be used. The comparison must cover efficiency and energy generation factors.

The electrical production and energy boost due to bifaciality were obtained for distinct modules' configurations, namely for tilt angles from 15° to 90°.The bifacial PV module performance will also be compared to the one of a monofacial PV module in the same conditions and with the same configuration, in order to analyse the bifaciality advantages in terms of efficiency, energy boost and mounting position. The monofacial electrical results were obtained adapting the bifacial electrical model and removing all the calculations relative to the rear side.

For readability, results are presented considering a reference Bifacial PV system configuration that is set according to the information known about the Bifacial PV plants being installed. It will be located in mainland China, with a ground surface of white gravel, the module's elevation will be about 1 m and the tilt angle will be 30º.

To imitate the bifacial architecture, the output powers of the front and rear panel are combined in series and parallel were applied. In series, the current is limited by the lowest current of the two panels, while the voltage is the sum of the two panels' voltages. In parallel, the voltage is limited by the lowest voltage of the two panels, while the current is the sum of the two panels' currents. The power gain resulted from the series or parallel connection is calculated by considering the front panel as the reference panel because the front panel is the panel of the regular direction.

Power Output vs Voltage

Similar to an I-V curve, the highest voltage occurs at the open-circuit condition and the current is zero and the short-circuit voltage is zero at the origin of the curve, but the current is maximum. Since the power is nothing but the voltage times the current (P=V*I), the power at both the short-circuit and open-circuit conditions is equal to zero since either voltage or current equals zero at each of these points.

The power P is given by P=V*I. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

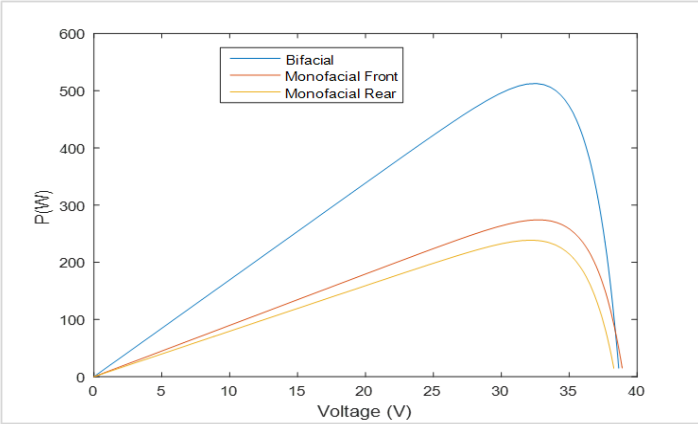

Fig 5: power output vs. Voltage

The power curve modelled here is a parabolic function of the Voltage and varies to a maximum for both the Bifacial and Monofacial PV model. The observed turning points are the recorded maximum power points (MPPs). This is illustrated in the figure 5 above. However, the shape of the power curve may be skewed to the right depending on the input value of the Series Resistance (Ω).

I-V Measurement Comparison

Solar Cell I-V Characteristic Curves show the current and voltage (I-V) characteristics of a particular photovoltaic (PV) cell, module or array giving a detailed description of its solar energy conversion ability and efficiency. Knowing the electrical I-V characteristics (more importantly P_{max}) of a solar cell, or panel is critical in determining the device's output performance and solar efficiency. The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve.

A standard module rating condition for bifacial PV modules would be a boon to the PV community as it would provide a common, accepted basis for measurement and nameplate rating of bifacial PV products. Through simulation and experiment, we have investigated back-side irradiance conditions that are appropriate for the power rating of bifacial modules.

So we measured the I-V characteristics of the front and rear side of a module as monofacial and together as bifacial to compare the determination of the device's output performance and solar efficiency.

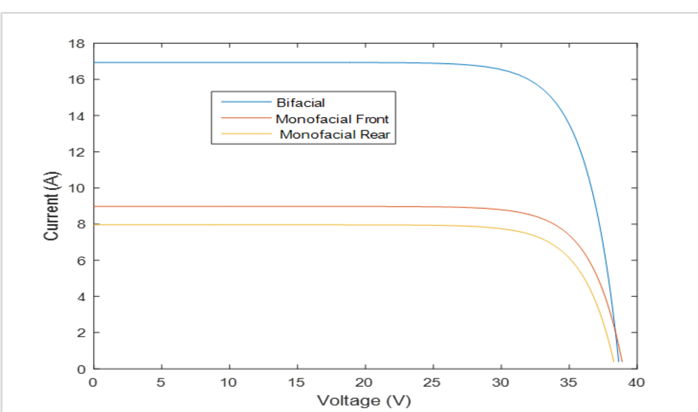

Fig 6: I-V curve variation for Bifacial and Monofacial Model

For comparing single sided measurement and bifacial measurement of commercial modules, it's important to consider the form of the I-V Curve. Most bifacial modules have distorted rear I-V curves, due to partial shading by the junction box, cabling, frame or label, or due to cell sorting by front side current only. As in the Ge method a modules IV curve is measured only under elevated front irradiance, the distortion of the rear IV curve will not be detected, due to shade of the junction box as can be seen in the figure above.

The procedure for the measurement of the electrical power (current-voltage (IV) characteristics) of bifacial solar device that have been reported in this paper is the front-side illumination only. This is a more advanced method for the characterization of bifacial solar devices based on measuring the front and rear IV characteristics at STC, likewise under single-sided illumination. As further input, this method requires the additional determination of the series resistance R_s or the pseudo fill factor of the device. After a linear dependence between current and irradiance, this method then numerically simulates the power of bifacial devices under bifacial illumination. This approach is called equivalent irradiance (G_e) method for which no additional R_s determination is required.

$$G_e = 1000\,W/m^2 + \left(\frac{I_{scRear}}{I_{scFront}}\right)\left(\frac{P_{maxRear}}{P_{maxFront}}\right) @STC * G_r \qquad (6)$$

Tilt angle Optimization and its influence on the Power Production

Elevation of the module is a key factor, along with the optimal tilt angle, in determining the power production of the module. The inhomogeneous irradiance distribution at the rear of the module influences the choice of the best tilt angle for bifacial modules. The optimum tilt angle that maximizes the annual energy yield of the module is dependent on the latitude, the albedo and the elevation of the module. The values of the optimum tilt angle decreases with the module elevation until a certain limit, depending on the other parameters. The effect of self-shading is less severe with high elevation, and a smaller tilt angle allows to take a better advantage of the reflective irradiance.

Results show those optimal tilt angles are smaller for higher albedo. This is due to the more uniform irradiance if the module has a smaller tilt angle, which increases the electrical performance. However, according to previous Matlab simulations, the optimum tilt angle increases with the albedo. In this former model, non-uniformity of the back irradiance is taken into account but is not converted to the corresponding energy production losses. This could explain the difference and also only direct irradiance were considering in the Matlab code. The figure 7 below presents the simulation results for the power production of a bifacial and monofacial PV module as a function of the power with the tilt angle.

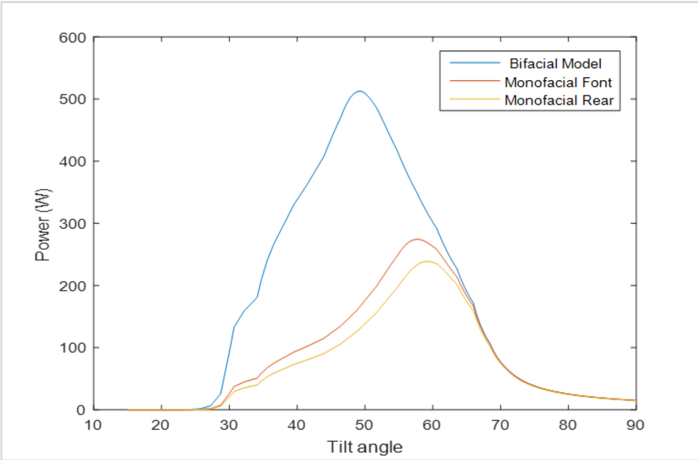

Fig 7: Variation of daily power production vs. the tilt for the PV array.

As we can see that under the same condition with the same configuration and area there is production of a 512.77W power of the bifacial module compared to the 274.3W front and 238.76W power of the monofacial front and rear. As we know taking advantages of the incident radiation on the rear side of the module significantly improves the total power and overall total energy production. Although the lack of standards for bifacial PV modules affect these values, a tenuous advantage due to bifaciality and associated to the system costs can be confirmed. As we can see from the result we know that the optimal tilt angle for the bifacial model is 49° that of the monofacial front is 58° and that of monofacial rear is 60° respectively. The main issue between bifacial optimal tilt angle and that of the monofacial is the rear side. The rear side ability for diffuse irradiance is really low but these simulation takes into account both the direct irradiance and the diffuse irradiance.

The optimal tilt angle for monofacial front module, which can only utilize front illumination is about 58° and it's mainly determined by direct sunlight. For back illumination height increases significantly with the module inclination angle. Hardly any direct current light reaches the module at the back, but contribution from diffuse current and reflected from the ground gives the back or rear module the required irradiance which allow us to have an optimal tilt angle of 60°. Increasing the module tilt further reduces the shaded area on the ground and therefore increases ground illumination. The optimal module tilt angle for the bifacial is a compromise between optimal tilt angle for the front and beneficial higher tilt angle for the back contribution which we can see from the graph is about 49°. Overall the optimal tilt angle for bifacial modules is significantly lesser than that for monofacial module. There is about 9°.

Operating Variable with respect to the simulated Time

As it was previously described, the PV operating temperature greatly influences the yield of electrical conversion. This yield decreases dramatically as the temperature increases, which in most cases occurs when the panel is subjected to the maximum isolation. Electrical power produced by a PV device not only is linked to the solar irradiance on the panel and to the cell temperature but also depends on current voltage.

The effect of the input simulation time on the current(I), voltage (V) and the daily power (P) production is shown in the figure below, and shows that the MPP is reached in less than 10s and this is mainly because of the spectral mismatch.

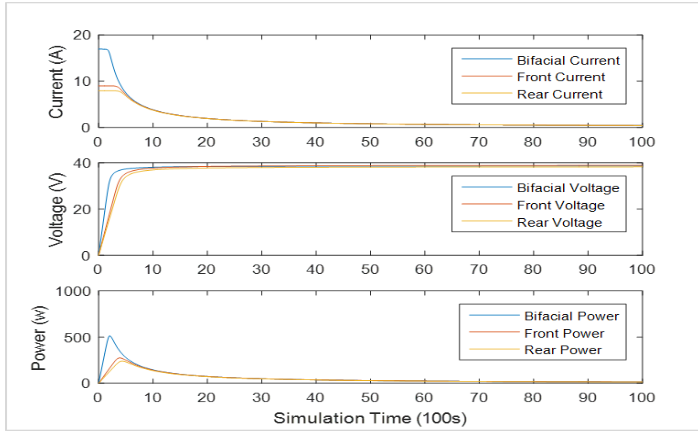

Fig 8: Operating variable vs. Time

The graph above is the simulation time with respect with the power, voltage and power for the proposed module and we can see the difference between the bifacial and monofacial front and rear. From the graph the simulation time for the bifacial and front and rear module to reach its peak is almost the same time which is around 0 to 10 seconds.

The electrical behaviour of the PV module is really different when the module is working in different operating regimes. If the panel is connected to an optimized and variable electrical load (with a maximum power point tracking system), the output power is quasi-linear to solar irradiance. If the MPPT device is not present, depending on the connected electric load, the relation between power output and solar irradiance could be no longer linear.

Bifacial Gain Effect

The term bifacial gain comes into picture here as it a common parameter that give the amount of energy gained through the rear side in comparison to the front side. Another term important in the bifacial PV field is 'albedo'. It gives the fraction of light that would be reflected back from a ground surface. The Bifacial gain, also referred to as the additional energy yield, represents the amount of power produced by the backside of the cells and can be calculated using equation below,

$$Bifacial\ Gain = \frac{Y_{bifcial}/Y_{monofacial}}{Y_{monofacial}} \quad (7)$$

Where $Y_{bifcial}$ and $Y_{monofacial}$ are the electricity yield in kWh for bifacial and monofacial solar modules respectively. The bifacial gain at the scale of a power plant is of prime interest for the solar industry but is hard to estimate in real conditions. Thus, an accurate model of the bifacial PV plant is required, and an optimized design to calculate the bifacial gain was researched.

The figure 9 below represent the result of the simulated bifacial gain from the parameters given from a solar company in china to get the optimum tilt angle with the highest gain over front and rear. The figure 9 below is to explain the relationship between the front and rear.

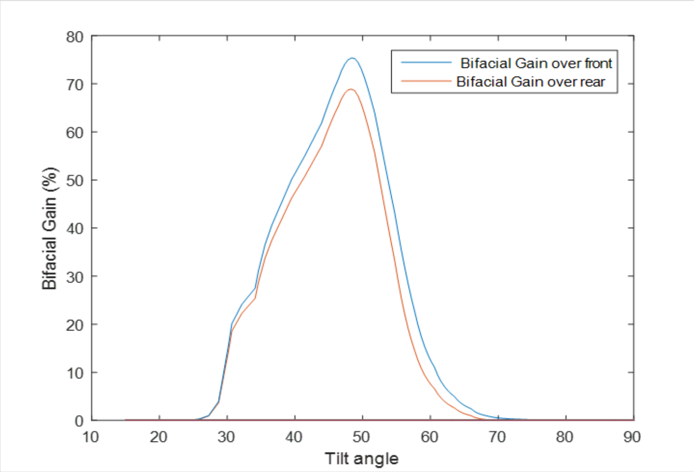

Fig 9: Bifacial gain effect on the monofacial front and rear

It can also be noticed from the figure that the amplitude and variation of the bifacial gain density for the rear side with the tilt angle of the module is lower when compared to the front side. Consequently, the front side is decisive for the quantification of the total solar energy received and intercepted by the PV module. As we can see the optimal tilt angle is same but the main reason of the difference between the bifacial gain of the front and rear is the tilt and the irradiance received.

As mentioned earlier the surrounding of the module has a strong influence on the energy yield, and for a stand-alone module, this leads to unrealistically high illumination of the module rear side. It is also important to be sceptical about reports collected during a short period of time. Both weather as well as seasonality has a significant impact on the bifacial gain. That said, there are many publications available that allow for reasonable estimations for commercial installations. There are many influencing factors and therefore the range of potential bifacial gain is wide

So according to the results the Small experimental or demonstration systems show bifacial gains of 15% to 25% With larger commercial systems, realistic bifacial gains are expected in a range from 5% to 15% as we can see from the figure above. Optimization of mounting geometry and mounting structure is essential in order to draw the full benefits from bifacial PV modules.

Table 2: Maximum Power Point (MPP) from Simulation

SYSTEM CHARACTERISTICS	BIFACIAL MODEL	MONOFACIAL FRONT	MONOFACIAL REAR
MPP(W)	512.7668	274.3697	238.7628
Vmax(V)	32.5736	32.6157	32.11877
Imax(A)	15.7418	8.4122	7.4338
Optimal Tilt Angle	49°	58°	60°

According to the simulation and taking in environmental temperature factor these are the values for energy output optimization. The Bifacial PV module performance was also compared to the one of a monofacial PV module in the same conditions and with the same configuration, in order to analyse the Bifaciality advantages in terms of efficiency, energy boost and specific production. The monofacial electrical results were obtained adapting the Bifacial electrical model and removing all the calculations relative to the rear side and also removing the front side for calculation of the rear side.

5. Conclusion

The aim of this research paper was to compare the response of bifacial solar module with monofacial PV modules, in terms of incident radiation and electricity generation. Based on these theoretical results, bifacial gain was quantified and the optimal configuration of a single bifacial module and a PV system was proposed.

Energy yield for bifaciality is very much location dependent and highly influenced by how they are setup and installed. Besides, a ground surface with high reflectivity is desirable and its one of the key parameters for bifacial module electrical performance. It is important to highlight the proportionality between the irradiation (IBG) and the energy (EBG) bifacial gain, since it implies that the boost for the collected irradiation discussed can be extrapolated in terms of maximum power point (energy output). However, this proportionality does not assure that the optimum IBG configuration also maximizes the overall energy conversion. Indeed, the optimum tilt angle for a bifacial module was found to be similar to the monofacial case.

However, after analysing the principal model for optimization of energy yield we can show that the model has the capability of prediction of the maximum power point for better energy yield for bifacial PV systems.

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REFERENCES

[1] R. Kopecek *et al.*, "Bifaciality: One small step for technology, one giant leap for kWh cost production," Photovoltaic. Int., vol. 26, pp. 32-45, 2014

[2] F. Fertig *et al.*, "Economic feasibility of bifacial silicon solar cells." Prog Photovoltaic. Res. Appl., vol. 24, pp. 800-817, 2016

[3] M. Hiroshi, "Radiation energy transducing device," US Patent 3278811A, Oct. 11, 1966.

[4] A. Cuevas, A. Luque, J. Eguren, and J. Del Alamo, "50 Per cent more output power from an albedo-collecting flat panel using bifacial solar cells." Sol. Energy, vol. 29, pp. 419-420, 1982

[5] B. Soria, E. Gerritsen, P. Lefillastre, and J. E. Broquin, "A study of the annual performance of bifacial photovoltaic modules in the case of vertical façade integration." Energy Sci. Eng., vol. 4, pp. 52-68, 2016.

[6] L. Kreinin, A. Karsenty, D. Grobgeld, and N. Eisenberg, "PV systems based on bifacial modules: Performance simulation vs design factors," in Proc, 2016 IEEE 43rd Photovoltaic spec. Conf., 2016, pp. 2688-2691.

[7] C. Deline *et al.*, "Evaluation and field assessment of bifacial photovoltaic module power rating methodologies," in Proc, 2016 IEEE 43rd Photovoltaic spec. Conf., 2016, pp. 3698-3703

[8] C.W. Hansen *et al.*, "Analysis of irradiance models for bifacial PV modules." In Proc. 2016 IEEE 43rd Photovoltaic Spec. Conf., pp. 0138-0143

[9] U.A. Yusufoglu *et al.*, "Analysis of the annual performance of bifacial modules and optimization methods." IEEE. J. Photovoltaic., vol. 5. No. 1, pp. 320-328, Jan, 2015

[10] C.K. Lo. Y. S. Lim, and F.A. Rahman, "New integrated simulation tool for the optimum design of bifacial solar panel with reflectors on a specific site," Renewable Energy, vol. 81. Pp. 293-307, 2015.

[11] A. Krenzinger and E. Lorenzo. "Estimation of radiation incident on bifacial albedo collecting panels." Int. J Sol. Energy. Vol. 4. pp. 297-319, 1986.

[12] S. Guo. T.M. Walsh, and M. Peters. "Vertically mounted bifacial photovoltaic modules: A global analysis" Energy, vol. 61, pp. 447-454, 2013.

[13] M. Brennan. A. Abramase. R.W. Andrews and J.M. Pearce. "Effects of spectral albedo on solar photovoltaic devices." Sol. Energy Mater.Sol.Cells. vol. 124. pp. 111-116, 2014.

[14] S. Chunduri and M. Schmela, *Bifacial Solar Module Technology*. TaiyanNews, 2017

[15] C. Comparotto *et al. Energy Yield Estimation of Monofacial and Bifacial Solar Modules.* 31st European Photovoltaic Solar Energy Comference and Exhibition, pp. 1858-1862. 2015

[16] A. Smets *et al. Solar Cell Parameters and Equivalent Circuit.* Sol, Energy Phys. Eng. Photovoltaic Conversion. Technol. Syst. Pp. 111-124. 2016

[17] J. P. Singh, A. G. Aberle, and T. M. Walsk. *Electrical Characterization method for bifacial photovoltaic modules.Sol.Energy Matter.* Sol. Cells, vol. 127, pp. 136-142. 2014

[18] Datasheet *PrismSolar® Bi*60343BSTC

[19] MINISTÉRIO DO AMBIENTE ORDENAMENTO DO TERRITÓRIO. *Produção de Energia Distribuída: Decreto-Lei n.o 153/2014* Diário da República - I Série, vol. N.o 202, pp. 5298–5311. 2014.