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Predicting the impacts of utilizing bifacial solar modules in public buildings: A case study for Patient Friends Benevolent Society (PFBS) hospital in Gaza Strip

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Abstract:

Abstract— in this paper we will examine the impacts of replacing the installed mono-facial PV solar modules with bifacial solar panels in the Patient Friends Benevolent Society (PFBS) hospital in Gaza city as a partial green solution to the shortage of generated energy in the Gaza Strip. The PFBS was recently retrofitted by about 40.96kWp Building Applied Photovoltaic (BAPV) system as a hybrid AC-coupled SPV with battery backup. The SPV system is in operation since April 2017. Using the mono-facial traditional modules, the aggregate PV system is expected to generate a total of approximately 160kWh per day contributing to major reductions in diesel fuel consumption and Green House Gas (GHG) emissions. Using the bifacial modules taking into consideration a high ALBEDO factor and the height of the lowest point of the module from the concrete ceiling, it was calculated that the bifacial energy gain (BEG) was increased by almost 43% while the bifacial power gain (BPG) was increased by about 28% for the same roof top installation area and steel structure. Accordingly, the installed bifacial capacity shall be about 52.3kWp and the expected generated energy shall be approximately 230kWh per day contributing to higher reductions in diesel fuel consumption and Green House Gas (GHG) emissions. An additional balance of system (BOS) shall be required to accommodate the extra power generated from the bifacial SPV system.

Key words: ALBEDO, BAPV, GHG, bifacial solar modules, bifacial power gain BPG, bifacial energy gain BEG

1: Literature Review

1.1: Traditional Energy

The Gaza Strip is totally dependent on importing traditional energy such as petroleum products and electric energy. Electricity to the Gaza Strip is supplied by the Israeli Electric Corporation (IEC), the local Gaza power plant GPP with installed capacity of 140MW, and power supply from Egypt. According to [13], table (1) shows the peak demand in the Gaza Strip for year 2017 (case 1) and the impact of losing the generation of the Gaza power plant on increasing the overall power deficit (case 2).

Source of power	Case 1	Case 2
Power from the IEC	120MW	120MW
Power from the power plant	60MW	0MW
Power from Egypt	30MW	30MW
Total Available power	210MW	150MW
Peak demand 2017	550MW	550MW
Power Deficit percentage	62%	72%

Table 1: Peak load and power deficit in the Gaza Strip for year 2017 [13]

1.2: Solar Energy:

Solar energy generated from PV systems is closely related to the solar irradiance of the sun and location's latitude. Figure (1) shows that the average annual sum of global irradiance on the Gaza Strip is approximately 2050kWh/m2.

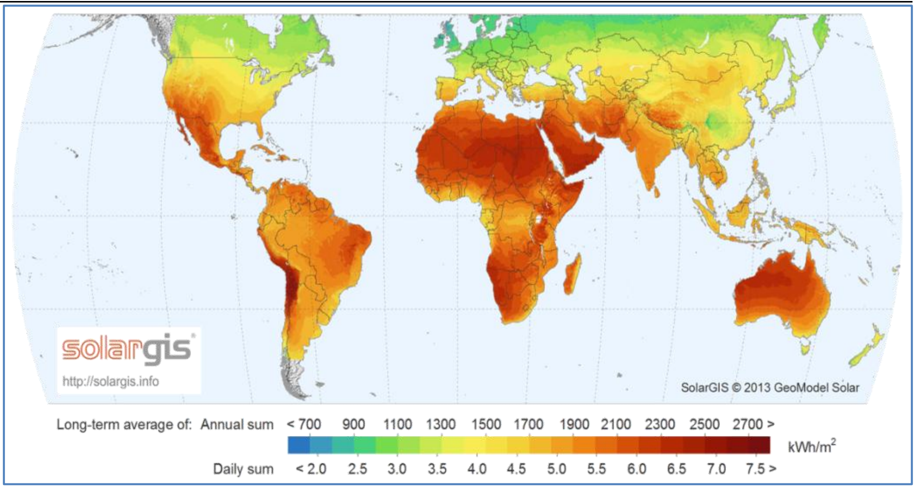

Figure 1: Average annual/daily sum of global solar irradiance worldwide [6]

Accordingly, the average daily sum of solar irradiance is found to be 5.61kWh/m2 and this value is used to estimate the energy generation of solar systems in the Gaza Strip. An overall system performance ratio (PR) of 72% shall be adopted in this paper. This value means that the AC power output is 72% of the nameplate DC power rating of the PV array evaluated at standard testing conditions (STC). This is a reasonable estimate adopted for modeling the AC energy production of the PV generator.

1.3: Possible Solar PV Systems in Gaza Strip

According to [7], the price for PV systems has decreased by more than 60% in the last three years while fuel cost for diesel generators are constantly increasing. This makes solar PV systems economical, sustainable and a clean energy share of the overall energy mix.

1.3.1: SPV-diesel hybrid system

In this system, solar power synchronizes with the grid and/or the diesel generator thus reducing the amount of imported electricity and diesel fuel consumption. This type requires no batteries.

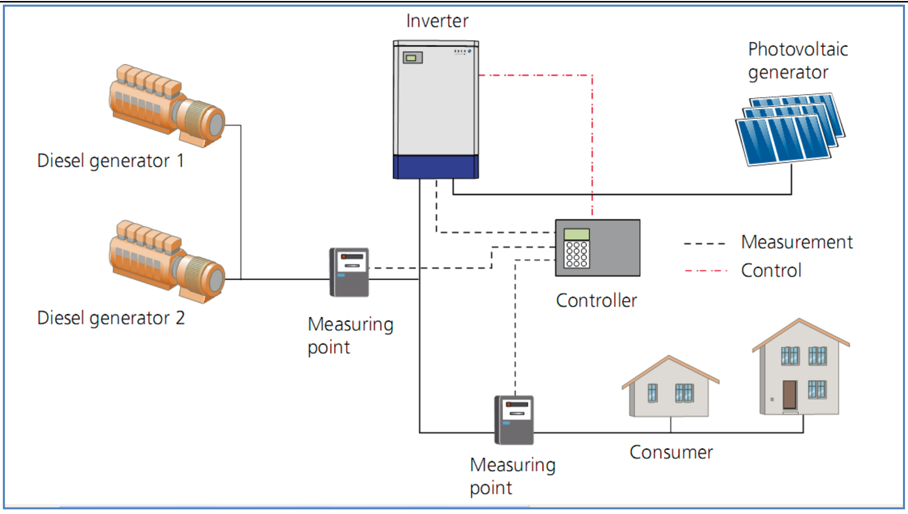

Figure 2: SPV-diesel hybrid system [5]

The solar fuel saver controller ensures that the generator is always operating at or above its minimum output which is 25-30% of its rated power. If the load drops below this value, then the solar fuel saver simply reduces the total power output of the grid inverters of the PV generator. The diesel generator must be large enough to accommodate the demand when the PV generation drops due to intermittent clouds. The diesel generator sees the PV input to the system as load reduction and reacts accordingly in order to maintain system frequency and consistent power flow.

1.3.2: AC-coupled SPV systems with battery backup

In these systems, the SPV is connected to the grid through a bidirectional battery inverter at the AC bus as shown in the following figure. The diesel generator is used as a backup power source in case the SPV system goes down or under maintenance.

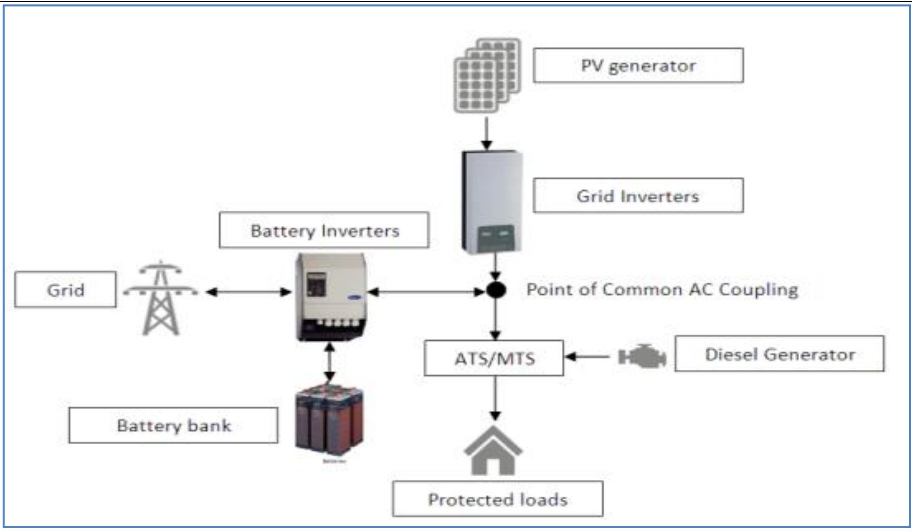

Figure 3: AC coupled SPV system

The system's first priority shall be for the solar generation. The grid shall be on the second priority supplying the balance of current when the solar power is smaller than the protected load power. If there is excess PV generation, the extra power shall be exported to the internal hospital network through the bidirectional meter. When the solar power is smaller than the protected load power and the grid is off, the battery bank shall be on the third priority supplying the balance of current. If there is excess PV power, the batteries shall be fully charged. A one way directional energy meter shall be placed at the output of the grid inverters to measure the aggregate PV generation, a bidirectional meter shall be placed at the utility side on the input of the battery inverters to measure the amount of excess solar energy fed to the internal hospital network and the amount of energy balance consumed by the protected load. Additionally, a directional meter shall be placed at the protected load side to measure the demand energy consumption.

1.3.3: DC-coupled SPV systems with battery backup

In these systems, the SPV is connected to the grid through a battery inverter at the DC bus as shown in the figure (4).

The diesel generator is used as a backup power source in case the SPV system goes down or under maintenance.

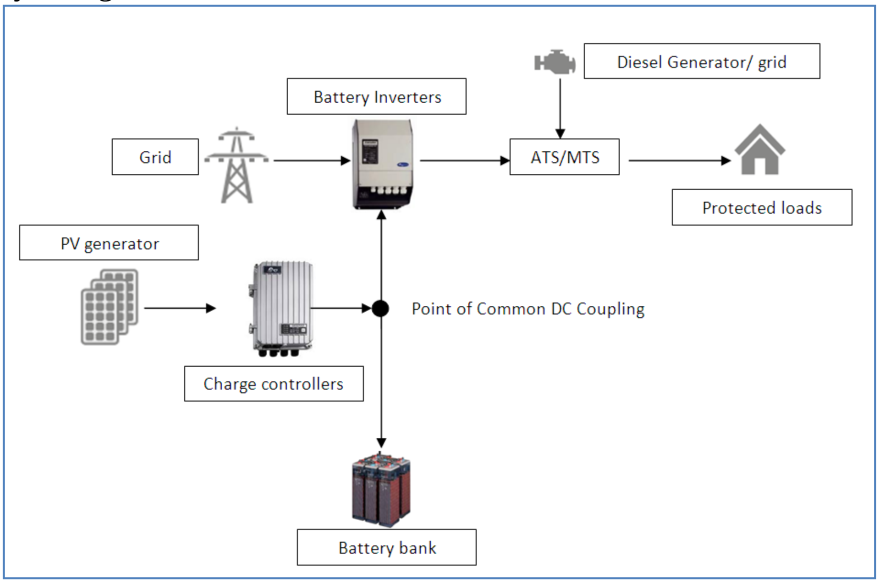

Figure 4: DC coupled SPV system

When the grid is off, the system works in inverter mode. It discharges power from the DC bus with first priority for solar generation. The battery shall be on the second priority supplying the balance of current when the solar power is smaller than the protected load power. If there is excess PV generation, the batteries are fully charged till 100% state of charge (SOC). When the batteries are full, the charge controllers shall limit the PV power. When the grid is on, the loads are supplied from the AC and DC power simultaneously using programmed smart boost feature.

1.3.4: Bifacial SPV system

As shown in figure (5), glass-glass modules provide the ideal module technology for bifacial solar cells. A second sheet of glass or transparent back sheet on the rear of the module allows reflected sunlight to reach the cells from the back. In this way, individual modules generate higher yields. Embedding the cells in a glass composite protects them from environmental and mechanical influences.

Figure 5: Glass-glass bifacial module with transparent rear side

Hybrid Cell Technology (HCT) enables thin film material on surface engineered silicon substrate to achieve high efficiency power output and reliable energy production. Heterojunction with Intrinsic Thin layer (HIT) bifacial solar cell is an example of such HCT which is composed of thin single crystalline wafer sandwiched by ultrathin amorphous silicon layers. The structure of hybrid HIT cells is illustrated in figure (6).

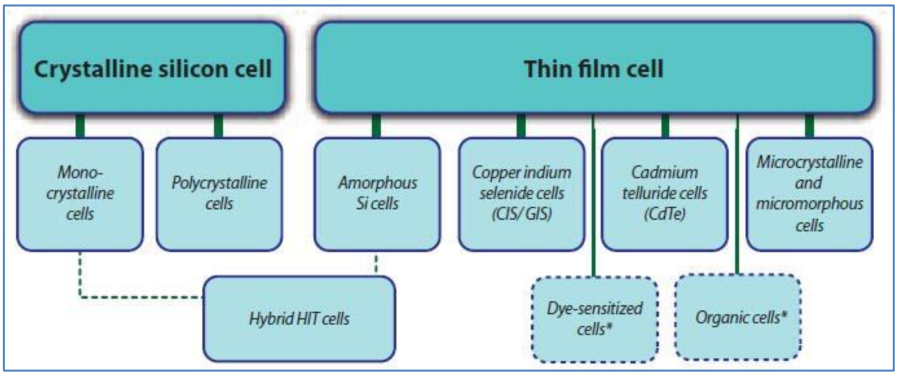

Figure 6: Types of PV cells and combinations

The following figure illustrates the HIT bifacial cell structure.

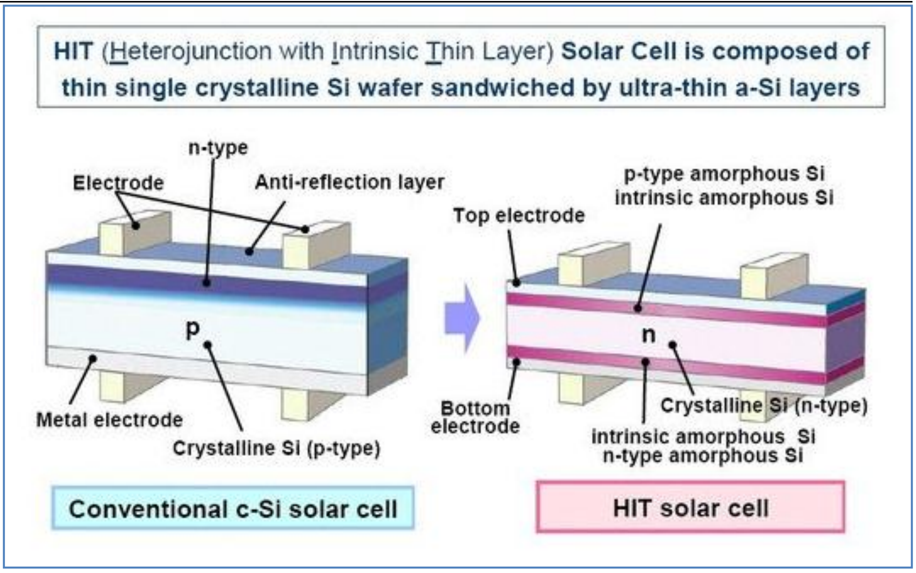

Figure 7: HIT bifacial solar cell structure [2]

The following figure shows a possible power gain of 27% using HIT bifacial solar modules over conventional crystalline modules.

Figure 8: Possible Power Gain of a HIT bifacial module [11]

1.3.5 Bifaciality

Bifaciality (B) refers to the ratio of the rear to the front maximum power measured under standard test conditions (STC) as defined in equation (1).

$$Bifaciality\ (B) = \frac{P_{mpp,rear}}{P_{mpp,front}} \leq 1$$

Equation (1) [7]

According to the equation (1), the Bifaciality of the following SANYO and PRISM solar modules is about 90%.

HIT Double195
Photovoltaic Module

Electrical Specifications

Model: HIP-195DA3	STC[1]	5%	10%	15%	20%	25%	30%
		Specifications Including Backside Irradiation Contribution in ISC as a Percent of STC					
Rated Power (Pmax)[1]	195 W	204 W	213 W	222 W	231 W	240 W	249 W
Maximum Power Voltage (Vpm)	55.8 V	55.8 V	55.8 V	55.9 V	56.0 V	56.0 V	56.1 V
Maximum Power Current (Ipm)	3.5 A	3.66 A	3.82 A	3.97 A	4.13 A	4.29 A	4.45 A
Open Circuit Voltage (Voc)	68.7 V	68.9 V	69.0 V	69.1 V	69.2 V	69.2 V	69.5 V
Short Circuit Current (Isc)	3.73 A	3.92 A	4.10 A	4.29 A	4.48 A	4.66 A	4.85 A
Max. System Voltage (Vsys)	600 V	—	—	—	—	—	—
Series Fuse Rating	15 A	—	—	—	—	—	—
Temperature Coefficient (Pmax)	-0.29% / °C	—	—	—	—	—	—
Temperature Coefficient (Voc)	-0.172 V / °C	—	—	—	—	—	—
Temperature Coefficient (Isc)	0.87 mA / °C	—	—	—	—	—	—
Warranted Tolerance	+10/-0%	—	—	—	—	—	—
Cell Efficiency	19.3%	—	—	—	—	—	—
Module Efficiency[2]	16.1%	16.8%	17.6%	18.3%	19.0%	19.8%	20.5%
Power per Square Foot	14.9 W	15.6 W	16.3 W	17.0 W	17.7 W	18.4 W	19.1 W

To Maximize Power
1. Elevate panels above a surface as much as possible.
2. Place panels over light-colored surfaces.
3. Do not allow support rails to shade the panel's back face.

Dependence on Temperature

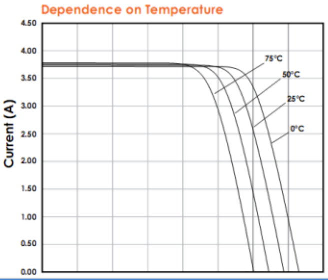

Table 2: Electrical data of SANYO bifacial module
With various backside power boost percentages [2]

Projected specifications for Front STC[1], Rear STC[1], Bifacial STC (BSTC[*])

ELECTRICAL PARAMETER		Front STC[1]	Rear STC[1]	BSTC[*]
Rated Power	Pmax (W)	285/290/295	256/261/266	362/368/375
Rated Voltage	Vmp (V)	32.4	32.4	32.4
Rated Current	Imp (A)	8.79/8.95/9.10	7.91/8.05/8.19	11.2/11.4/11.6
Open Circuit Voltage	Voc (V)	40.2	40.2	40.2
Short Circuit Current	Isc (A)	9.31/9.48/9.64	8.38/8.53/8.67	11.8/12.0/12.2
Module Efficiency	(%)	17.1/17.4/17.7	15.4/15.6/15.9	21.7/22.1/22.5

Table 3: Electrical data of PRISM solar bifacial module
With 300W/m2 backside incident irradiance [4]

The irradiance dependence of the 290/261/368Wp bifacial module is shown in the following figure based on 1000W/m2 on the front side and 300W/m2 on the back side.

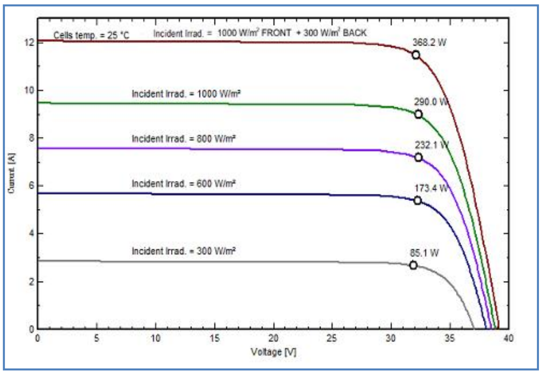

Figure 9: irradiance dependence of a bifacial module [4]

Considering the following AE solar bifacial module, the Bifaciality is found to be 100%.

ELECTRICAL DATA		AE SOLAR	Considering the power gain from rear side				
			5%	10%	15%	20%	25%
Nominalpower	Pm (Wp)	280	294	308	322	336	350
Open circuitvoltage	Voc (V)	38.8	38.8	38.8	38.8	38.8	38.8
Short-circuit current	Isc (A)	9.25	9.71	10.2	10.6	11.1	11.6
Voltage at max power	Vmp (V)	31.7	31.7	31.7	31.7	31.7	31.7
Current at max power	Imp (A)	8.83	9.27	9.71	10.2	10.6	11.0
Module Efficiency	(%)	17.00	17.9	18.7	19.6	20.4	21.3

Table 4: Electrical data of AE solar bifacial module
With different backside power boost percentages [3]

1.3.6: Ground reflectance (ALBEDO)

In contrast to mono facial cells, bifacial solar cells collect sunlight not only on the front but also on the rear side as they capture light reflected from the surface beneath the module and from the surrounding environment as shown in the following figure.

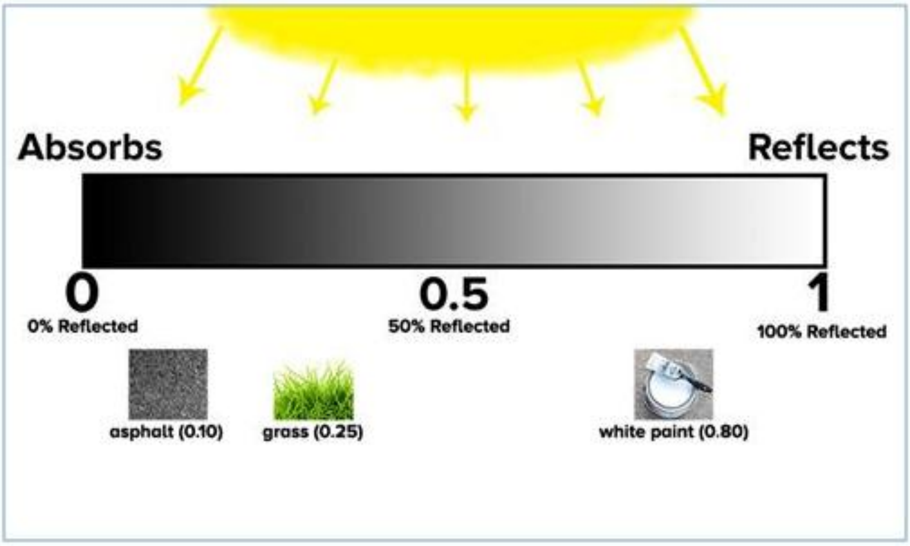

Figure 10: Different Albedo values for different surfaces

Albedo is a dimensionless quantity and is usually expressed as a percentage. For example, a black surface that absorbs a large amount of light has a low albedo, while a white surface that reflects a large amount of light has a high albedo. The following table shows the link between the reflectance of different surfaces and the amount of solar irradiance collected from the rear side of a bifacial module when 1000W/m2 is directed on its front side.

Ground Material	Ground average reflectance (ALBEDO)	Rear irradiance W/m2 at 1000W/m2 on front of module
Asphalt	0.1	70
Light soil	0.21	130
Unpainted Concrete	0.28	170
Painted concrete (white roof)	0.80	430

Table 5: Albedo factor impact on rear irradiance [9]

The following figure illustrates the types of direct and reflected sunlight on a bifacial module.

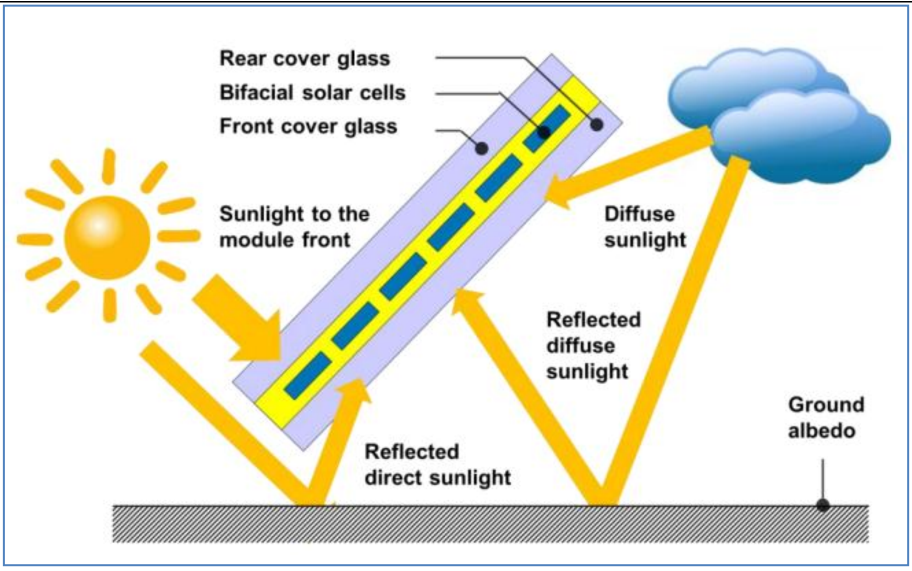

Figure 11: Direct and reflected sunlight on a bifacial module [12]

1.3.7 Bifacial Energy Gain (BEG) and Bifacial Power Gain (BPG)

The transparent active rear sides of bifacial photovoltaic modules enable an additional energy yield, also known as the “energy boost”. This is the name given to the increase in specific energy yield (kWh/kWp) of the bifacial module compared with the mono facial module with the same nominal power as the front of the bifacial module. The amount of additional energy yield of a bifacial module depends on two main factors:

- Ground reflectance (albedo factor) of the surface beneath the module and
- Height of the module (height of the lowest point above the roof).

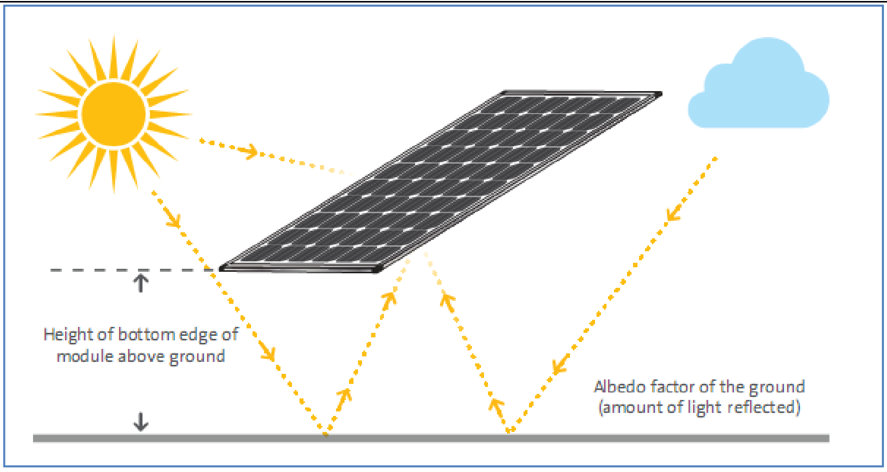

Figure 12: Factors affecting additional energy yield of a bifacial module [7]

According to [7], the approximate amount of additional energy yield or bifacial energy gain (BEG) that will be produced by the bifacial PV system is estimated. According to [8], bifacial Energy Gain above 18% indicates an excellent application of the system. The equation applies to installations under the following conditions:

- Module tilt: 10 to 30 degrees
- Module orientation: South
- Module mounting: landscape or portrait

$$\mathrm{BEG} = \mathrm{Albedo.\,bifaciality.}\left[\mathrm{a.}\left(1-\frac{1}{\sqrt{\mathrm{A}}}\right).\left(1-\mathrm{e}^{-\frac{\mathrm{b}-\mathrm{H}}{\mathrm{A}}}\right) + \mathrm{C.}\left(1-\frac{1}{\mathrm{A}^4}\right)\right] \quad \text{Equation (2) [7]}$$

The bifacial power gain (BPG) can then be estimated from the following equation:

$$BPG = 0.65 * BEG \quad \text{Equation (3) [8]}$$

Additionally, the max STC power of the bifacial system is calculated from the following equation to be used to size the system's grid inverters.

$$P_{max} = P_{front\ (STC)} * (BPG + 1) \qquad \text{Equation (4) [8]}$$

2.0 Model application impacts

The following picture shows the installation of 40.96kWp SPV monofacial system on the rooftop of the Patient friends benevolent society hospital. This paper examines the impacts of replacing the 128*320Wp Canadian solar monofacial modules with 128*320Wp SUNPREME bifacial modules using the same steel structure and tilt and azimuth angles.

Figure 13: Existing monofacial PV installation On PFBS hospital

ELECTRICAL SPECIFICATIONS[1]	320
STC rated output P_{MPP} (W)	320
Cell Efficiency	22.0%
Module Efficiency STC	19.2%
Standard sorted output	-3%/+5%
Open Circuit Voltage V_{OC} (V)	44.0
Short circuit current I_{SC} (A)	9.34
Rated Voltage V_{MPP} (V)	36.5
Rated Current I_{MPP} (A)	8.8
1: Standard Test Conditions for front-face of panel: 1000 W/m	
BI-FACIAL OUTPUT*	
With 10% Backside Power Boost	
Power Output (W)	352
Module Efficiency	21.1%
With 20% Backside Power Boost	
Power Output (W)	384
Module Efficiency	23.1%

Table 6: Electrical data of the SUNPREME bifacial module [1]

The following 3-D image shows the installation of the new 128*320Wp bifacial modules on the same steel structure raking into consideration that the bifacial module area is only 84% of the monofacial module area thus allowing sunlight to hit the roof from the new created space on the steel structure between the modules. The roof is also painted white so that the ALBEDO factor increases to 80%.

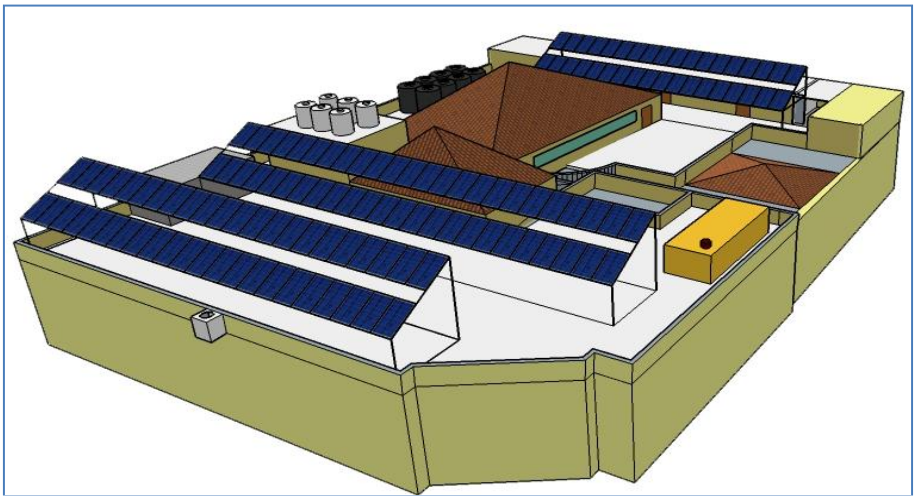

Figure 14: 3-D image of the bifacial system on the PFBS rooftop

The inter row spacing (A) is taken to be 4meters while the height of the lowest point of installation (H) is taken to be 2meters. The Albedo factor was taken to be 0.8 while the Bifaciality was taken to be 1. The following fixed values were also used [7]:

a	**1.037**
e	2.718
b	8.691
C	0.125

The above parameters were plugged into equation (2). The result of the calculation is an additional energy yield of 43.65%. This calculated value is found to be close to the bifacial energy gain percentage worldwide calculated for an albedo of 0.75 and module height of 2 meters above the ground as shown in the following figure.

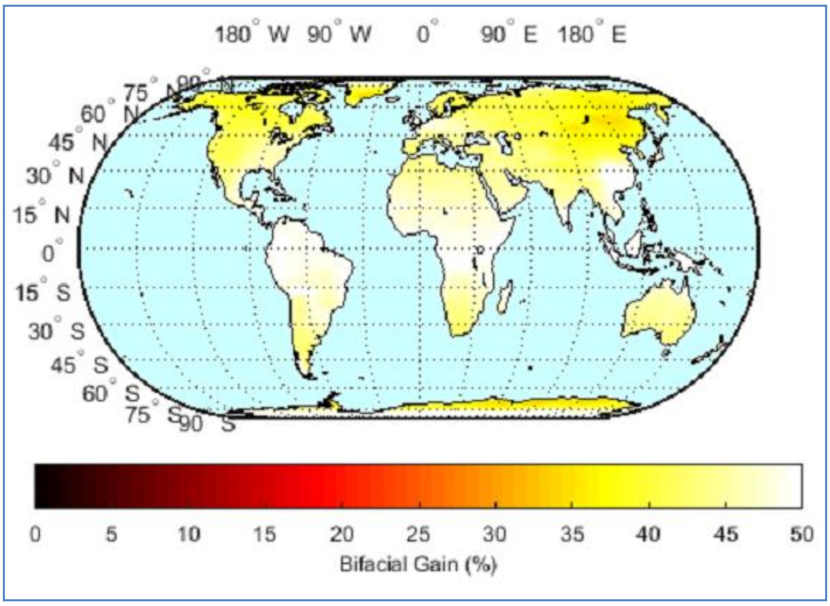

Figure 15: Bifacial Energy Gain worldwide [10]

Using equation (3), the backside power boost is calculated to be about 28%. Using equation (4), and taking into consideration that the monofacial system STC power was (40.96kWp), the result of the new bifacial STC power is found to be 52.3kWp. Accordingly, an additional 10+kVA grid inverter a combiner box are needed to accommodate the additional power of the bifacial system.

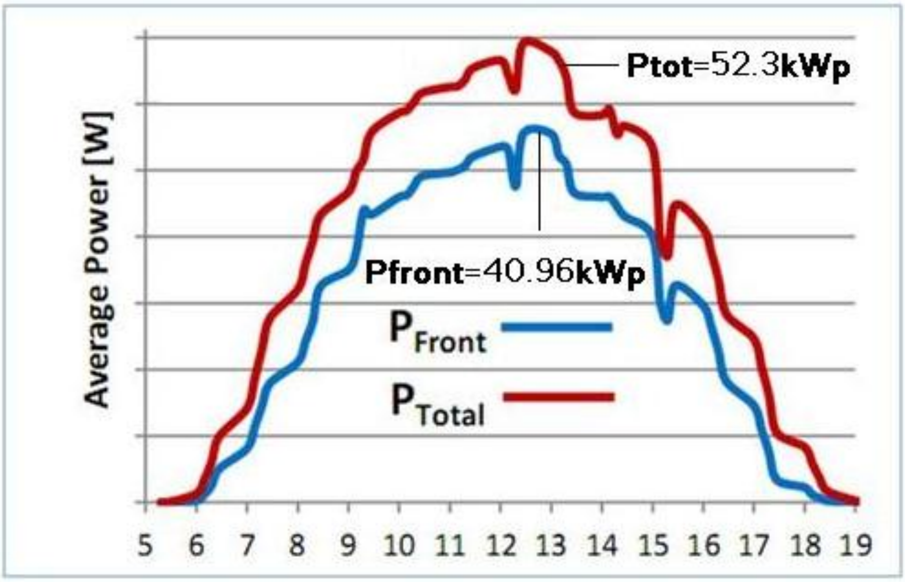

Figure 16: Bifacial power versus monofacial power

The bifacial power gain of the system is verified from equation (5) to be about 28%.

$$\boldsymbol{Bifacial\ Power\ Gain}\ (\%) = \frac{\boldsymbol{P_{BI} - P_{mono}}}{\boldsymbol{P_{mono}}} \qquad \boldsymbol{Equation}\ (\mathbf{5})\ [\mathbf{10}]$$

The following table summarizes the findings of the energy and power yield.

Front side energy production net	**160kWh/day**	
Rear side energy production net	70kWh/day	+43% of front side energy
Bifacial energy production net	230kWh/day	
Bifacial power gain %	11.34kWp	+28% of front side power

Table 7: findings of the additional energy and power yield

3.0 DSCUSSION AND CONCLUSION

Solar Photovoltaic systems has played an important role in the solar industry because solar PV systems are clean, environment friendly and considered secure energy sources. This paper compared different types of SPV systems implemented worldwide and focused on the advantages and disadvantages of each system while discussing the suitability and conformity of each system to local electrical environment in the Gaza Strip. The case study presented in this paper dealt with retrofitting PFBS hospital in Gaza by 52.3kWp Building Applied Photovoltaic (BAPV) bifacial design featuring AC-coupled SPV system with battery backup. It was calculated that the bifacial energy gain (BEG) was increased by almost 43% while the bifacial power gain (BPG) was increased by about 28% for the same roof top installation area and steel structure. The aggregate PV system is expected to generate a total of approximately 230kWh per day contributing to major economic impacts comprising reductions in electricity bill and diesel fuel consumption and Green House Gas (GHG) emissions. General findings show that the greater the installation height of the bifacial module, the higher the energy yield. The same rule applies for the albedo as for the installation height: the higher the albedo, the higher the energy yield. An equally important factor in the design of a photovoltaic system is inverter sizing. Here, it is recommended that the inverter be sized for the new bifacial module power. An additional balance of system (BOS) equipment such as a 10kVA STECA grid inverter and a combiner box shall be required to accommodate the extra power generated from the bifacial SPV system. Based on the findings of SPV integration in existing power systems, it is highly recommended to utilize solar Photovoltaic system in a public building as a partial green solution to the shortage of generated energy in the Gaza Strip.

4.0 References

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