The Effects of Photovoltaic Panel's Temperature towards Photovoltaic Electrical Power Output

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Abstract: Photovoltaic (PV) system is recognized as one of the most current renewable energy types in producing electrical power. The theories that science explain related to the function of the sun is in accordance with what is also described in the Qur'an. There is one ayah Quran related to the Greatness of Allah and The Mercy which is "And from among His Signs are the night and the day, and the sun and the moon. Prostrate yourselves to Allah Who created them, if you (really) worship Him [Fussilat:37]. However, one of the main issues of PV system is that the performance of the system is highly dependent to environmental conditions such as weather and solar irradiance. Increases in temperature reduce the band gap of a semiconductor. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. The parameter most affected by an increase in temperature is the open circuit voltage. Temperature coefficient indicates how much will be the decrement in power output if PV module. Hence, it is important to predict the actual generating output power of PV systems. This study investigates the relationship between the temperatures of the PV panel with the PV power output. The PV systems installed at the rooftop of Mega label SDN. BHD. with type of poly-crystalline 405.72KWP has been chosen as the reference system in this study. The results have shown that the rise of PV panel's temperature will make the value of the PV electrical power output decreases.

Keywords: Photovoltaic, solar electricity, renewable energy, assured power output, predicted power output

1. Introduction

Renewable energy can be defined as the generation of electrical power from natural sources that are replenish constantly. In its various forms, it derives directly from the sun, wind, rain, tides of ocean, biomass and geothermal resources from heat produced deep within the earth (Mohtasham, 2015). Other than generating electricity, different forms of solar energy can be grouped under a few categories such as the heat from the sun's rays for various methods of heating the water, clothes, and the power provided by air and water movement caused by the effect of the sun (Bicen *et al*., 2018).

On top of that, the theories that science explain related to the function of the sun is in accordance with what is also described in the Qur'an. There is one ayah Quran related to the Greatness of Allah and The Mercy which is "And from among His Signs are the night and the day, and the sun and the moon. Prostrate yourselves to Allah Who created them, if you (really) worship Him [Fussilat:37] (Afida & Mustari, 2019). One technology that uses the source of Allah directly in daily life. Allah S.W.T given natural resources naturally as this is necessary utilized as best as possible in the field source of energy and it is obtained for free, environmentally friendly and unaffected by political power (Jasmi & Samseh, 2013). Among the clean energy resources, the conversion of the solar radiation into electricity by photovoltaic (PV) devices is a reliable choice to meet the global energy demand. Moreover, the amount of solar energy reaching the surface of the Earth every hour is greater than the amount of energy used by the earth's population over an entire year (Le Donne *et al.*, 2013).

Nowadays green campaign is one of the hot topics among the Malaysian. The main objective of green campaign is to create awareness among the public to protect our environment. Besides, price of solar energy is very reasonable and vary depending upon the amount of energy needed and the size of the panels required. Now it is set to enlarge its solar industry, from producing solar panels to producing solar power (Islam *et al.*, 2010). One of the solutions for better integration of PV power plants in the power system is forecasting their power output. Longer forecasts, such as week, season or a year ahead, are no less important and allow utilities, distributors and system operator to make long-term plans. Forecasting methods can generally be categorized as physical or statistical, depending on the type of used input information (Konjić *et al.*, 2015).

In Malaysia, the energy is available from many sources however most of the energy used to satisfy this issue on the increasing demand for electricity is still derived from fossil fuels. The continuous supplies of fossil fuels will eventually run out. In this case, when oil and coal is burnt, they emit huge amounts of carbon dioxide and other harmful gases, which have a negative effect on the environment, like sulphur dioxide. Carbon dioxide traps in the sunlight as it only lets light in, it does not allow it to leave the atmosphere which causes temperatures to rise (Manieniyan, 2009). There are many factors that are affecting which are effect of direction on PV panel, angle on PV panel, irradiance on PV panel, temperature on PV panel, shade on PV panel and load on the PV panel. PV system will not produce solar power generation value according to its rating due to the parameters of weather, sun hours and the temperature in Malaysia is averagely above 30 degrees Celsius (Saleem *et al.*, 2016).

PV power production depends strongly on solar irradiance and other environmental conditions which make it difficult to predict due to swift intermittency of solar irradiance caused by cloud motion. Producers from renewable sources, like any other electricity producers, should respect the predicted electrical power to be exact in the future hours covered by the corresponding market session. Besides, power prediction from only weather records is more accurate with added with record temperature from PV panel temperature (Grossi & Buscema, 2007).

2. Research Method

Before designing a forecasting model, a correlation between the output and input features should be investigated. This research consists of three stage, which are data pre-processing technique, Mathematical model development and comparison data of panel temperature between calculation of photovoltaic prediction power output.

2.1. Data Pre-Processing Technique

The collected variables during periods of ongoing recording data were used to achieve the actual measurement which is the target values. There are three variables to collect which are ambient temperature, plane of array irradiance and panel temperature. A period from January 2020 to December 2020 were selected for polycrystalline solar at the rooftop Mega Label Sdn. Bhd. during daylight 00:04 every day. The performance of statistical models is highly affected by the quality of actual measurement. Data collection collects from the company Mega Label Sdn. Bhd., Batu Pahat in Johor as there are 1176 pieces number of PV panel solar had been installed at the rooftop and use for generate electricity for production purpose. Mega Label Sdn. Bhd. partnered with Rich Gold Solar (M) Sdn. Bhd. to develop the solar system at the rooftop factory. Currently use SolarEdge Monitoring to monitor the solar system. From the monitor, data of solar can get the value for panel temperature as it is considered target result for this research. The placing of PV panels on the rooftop are divided into 5 sections, which are A, B, C, D and E as shown in Fig.1.
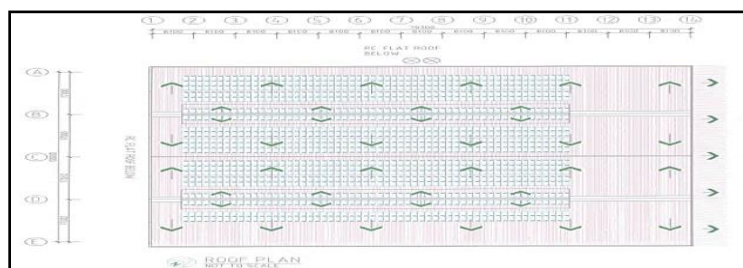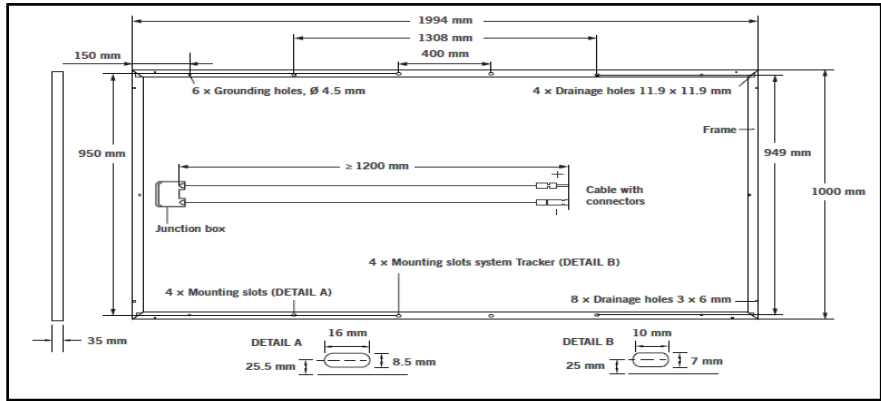

Fig. 1 - Solar at rooftop Mega Label divided into 5 sections

The size of PV panel is 1994mm x 1000mm x 35mm (including frame) with 24kg. The diagram of rooftops of Mega Label had been illustrated by Rich Gold Solar (M) Sdn. Bhd. as shown in Fig.1. Fig.2 shows the mechanical specification for PV panel.

Fig. 2 - Mechanical specification for PV Panel at Mega Label

The PV panels used for this project is poly-crystalline 345wp panel for mechanical properties as shown in Fig.2 in which generated the power 405.72KWP. The data of peak sun hours of the rooftop Mega Label was generated and obtained in SolarEdge Monitoring system as supplied by RGS company. The temperature data obtained is yearly from January 2020 to December 2020. The data variable that had obtained which are Month, Time, Gateway 1 Ambient Temperature °C, Gateway 1 Plane of Array Irradiance (W/m^2) – POA and Gateway 1 Panel Temperature °C. This is used as of one the inputs feature of rooftop photovoltaic power generation. The average temperature and plane array irradiance for every month is shown in Table 1.

Table 1 - Average temperature and plane array irradiance yearly from January 2020 to December 2020.

Month	Gateway 1 Ambient Temperature, °C	Gateway 1 Plane of Array Irradiance (W/m^2) - POA	Gateway 1 Panel Temperature °C
January	29.23	186.52	31.42
February	29.26	210.14	31.93
March	30.50	215.35	33.06
April	30.50	215.41	33.12
May	30.41	180.45	32.61
Jun	29.02	165.87	31.03
July	29.81	177.93	31.01
August	29.53	202.54	32.07
September	28.76	191.47	31.12
October	30.42	201.46	32.61
November	28.67	162.86	30.54
December	28.58	161.24	30.53

2.2. Mathematical Model, *Tc*

This research required several input variables to complete the mathematical model. First step to calculate the PV predicted power output is to get the value of assured power. This step can be determined by using Eq. 1.

$$PV_{AP} = PV_{rated} \text{ X G QPV} \tag{1}$$

where,
PV_{AP} = PV assured power output [*W*]
PVrated = PV panel's rated power [*W*]
G = PV panel's manufacturer power guarantee
QPV = Quantity of the PV panels

From the data collection at Mega Label Sdn. Bhd. as from Table 1, then calculate and key in the formula of PV_{AP} and the output calculation which is PV assured power output (PV_{AP}) will be added into the PV predicted power output (PV_{out}) formula through each month from January 2020 until December 2020. Based on the datasheet of solar panel, the PV

assured power output is 345W and the value for manufacturer power guarantee is 97%. Fig. 3 shows the datasheet for the solar panel (Panel, 2014):
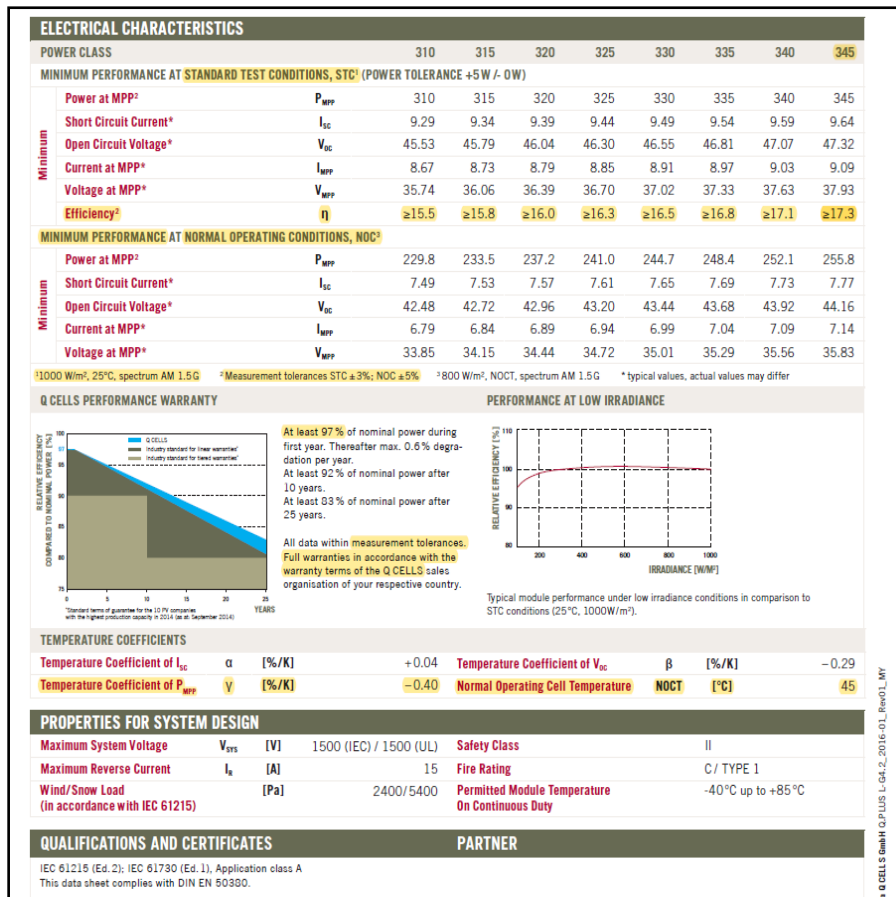
ELECTRICAL CHARACTERISTICS

POWER CLASS			310	315	320	325	330	335	340	345
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC¹ (POWER TOLERANCE +5 W /- 0W)										
Power at MPP²	P_{MPP}		310	315	320	325	330	335	340	345
Short Circuit Current*	I_{SC}		9.29	9.34	9.39	9.44	9.49	9.54	9.59	9.64
Open Circuit Voltage*	V_{OC}		45.53	45.79	46.04	46.30	46.55	46.81	47.07	47.32
Current at MPP*	I_{MPP}		8.67	8.73	8.79	8.85	8.91	8.97	9.03	9.09
Voltage at MPP*	V_{MPP}		35.74	36.06	36.39	36.70	37.02	37.33	37.63	37.93
Efficiency²	η		≥15.5	≥15.8	≥16.0	≥16.3	≥16.5	≥16.8	≥17.1	≥17.3
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NOC³										
Power at MPP²	P_{MPP}		229.8	233.5	237.2	241.0	244.7	248.4	252.1	255.8
Short Circuit Current*	I_{SC}		7.49	7.53	7.57	7.61	7.65	7.69	7.73	7.77
Open Circuit Voltage*	V_{OC}		42.48	42.72	42.96	43.20	43.44	43.68	43.92	44.16
Current at MPP*	I_{MPP}		6.79	6.84	6.89	6.94	6.99	7.04	7.09	7.14
Voltage at MPP*	V_{MPP}		33.85	34.15	34.44	34.72	35.01	35.29	35.56	35.83

¹1000 W/m², 25°C, spectrum AM 1.5G ²Measurement tolerances STC ±3%; NOC ±5% ³800 W/m², NOCT, spectrum AM 1.5G * typical values, actual values may differ

Q CELLS PERFORMANCE WARRANTY

At least 97 % of nominal power during first year. Thereafter max. 0.6 % degradation per year.
At least 92 % of nominal power after 10 years.
At least 83 % of nominal power after 25 years.

All data within measurement tolerances. Full warranties in accordance with the warranty terms of the Q CELLS sales organisation of your respective country.

PERFORMANCE AT LOW IRRADIANCE

Typical module performance under low irradiance conditions in comparison to STC conditions (25°C, 1000W/m²).

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[%/K]	+0.04	Temperature Coefficient of V_{OC}	β	[%/K]	−0.29
Temperature Coefficient of P_{MPP}	γ	[%/K]	−0.40	Normal Operating Cell Temperature	NOCT	[°C]	45

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1500 (IEC) / 1500 (UL)	Safety Class	II
Maximum Reverse Current	I_R	[A]	15	Fire Rating	C / TYPE 1
Wind/Snow Load (in accordance with IEC 61215)		[Pa]	2400/5400	Permitted Module Temperature On Continuous Duty	-40°C up to +85°C

QUALIFICATIONS AND CERTIFICATES   PARTNER

IEC 61215 (Ed. 2); IEC 61730 (Ed. 1), Application class A
This data sheet complies with DIN EN 50380.

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Fig. 3 - Datasheet of Solar Panel at Mega Label Sdn. Bhd.

From the values that can get through datahsheet, then it can be calculated through the formula, the calculations are shown as follows.

$PV_{AP} = PV_{rated}$ X G QPV
PV_{AP} = 345 X 0.97 x 1
PV_{AP} = 334.65W

PV predicted power output can be determined by using the calculation of PV assured power output through Equation 2 (Wee *et al.*, 2020).

$$PV_{out} = PV_{AP} + [PV_{AP} \text{ X } (t - 25°C) \text{ X } t_{co}] \tag{2}$$

where,
PV_{out} = PV predicted power output [W]
T = Temperature value [°C]
t_{co} = Temperature coefficient (Refer solar panel datasheet)

Based on the datasheet of solar panel, the temperature value uses the panel temperature through Table 1 and the value of temperature coefficient which is -0.4% and when convert into temperature unit can get -0.004°C.

$PV_{out} = PV_{AP} + [PV_{AP} \text{ X } (t - 25°C) \text{ X } t_{co}]$
PV_{out} = 334.65 + [334.65 X [31.42 - 25°C] X (-0.004)]
PV_{out} = 326.05W

2.3. Comparison between Panel Temperature and PV Prediction Power Output

This method will be used at the end section of the project as to compare between Panel temperature [°C] and PV predicted power output [W] through the calculation method. This step will require all the variable as to find the finding between temperature and predicted output power.

3. Results

### 3.1. Generate Mathematical Model

The total average panel temperature, PV assured power output and PV predicted power output from January of 2020 to December of 2020 using all of the equations and steps in the methodology section is shown in Table 2. From the table, the highest total of panel temperature is on April which is 33.12 Degree Celsius. On the hand, the lowest total of panel temperature which is on November, 30.54 Degree Celsius. These values can get through the system SolarEdge monitoring and average every month for per year. Moreover, from Table 2, the values of PV predicted power system can get through mathematical method as had been show at research method. In order to facilitate the analysis process, the value from calculated value mathematical model PV_{AP} and PV_{out}, is placed next to each other. As can be observe, the value of assured power output is higher compared to predicted power output.

Table 2 - Total average panel temperature, PV assured power output and PV predicted power output from January 2020 to December 2020

Month	Average Total Panel Temperature, °C	Assured Power Output, W	Predicted Power Output, W
January	31.42	334.65	326.05
February	31.94	334.65	325.36
March	33.06	334.65	323.87
April	33.12	334.65	323.78
May	32.06	334.65	324.47
Jun	31.03	334.65	326.74
July	31.01	334.65	326.60
August	32.07	334.65	325.18
September	31.12	334.65	326.46
October	32.61	334.65	324.47
November	30.54	334.65	327.23
December	30.53	334.65	327.25

3.2. Comparison Panel Temperature and PV Prediction Power Output Values

Fig. 4 shows the results of combination of bar graph of Average Panel Temperature versus line graph of Predicted Power Output with the average from January 2020 to December 2020. The data had been taken for yearly 2020 every month at Mega Label Sdn. Bhd. In order to facilitate the analysis process, Fig. 4 also shows the combination graph of bar graph (average panel temperature) and line graph (predicted PV power output). As shown in this figure, the predicted power output seen starts to be decreased when the panel temperature increasing. The maximum panel temperature was produced during March by 33.12 Degree Celsius which is 323.78 W whereas the minimum was identified at 30.53 Degree Celsius which is 327.25 W (Amelia *et al.*, 2016).
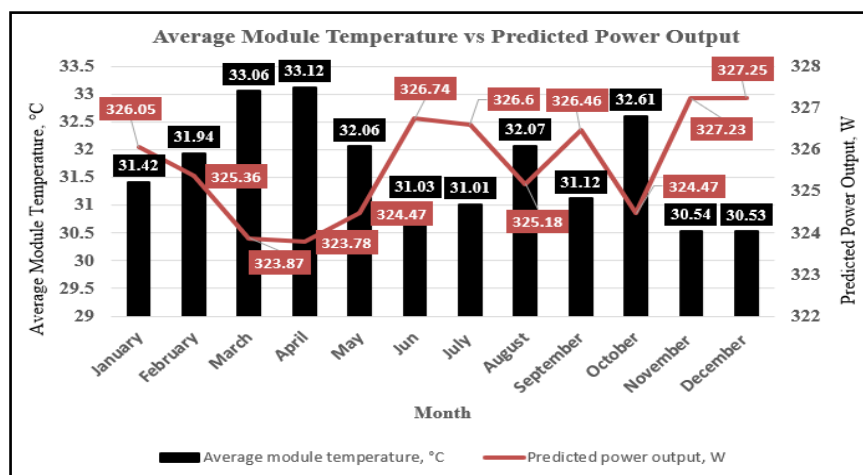
Fig. 4 - Combination of bar graph of average panel temperature vs. line graph of predicted power output with the average from January 2020 to December 2020

4. Conclusions

The study conducted in this paper show that the power forecasting from a real 405.72KWP located on the rooftop Mega Label Sdn. Bhd., Batu Pahat, Johor. The collected data cover all the daylight on 00.04 of following day at each month year 2020. Then contribute simple mathematical model involve a fewer number of actual input variable generally variable in weather observatory such as ambient temperature, POA solar irradiance and panel temperature. Thereafter, a set of forecasting models widely presented in the mathematical model method to compare between panel temperature and PV predicting power output. PV predicted power output depends on the panel temperature and this research show the relationship between both variable in solar panel system and one of the important reasons why predicting PV power output is very crucial especially in PV system design. Increases in temperature reduce the band gap of a semiconductor. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. The parameter most affected by an increase in temperature is the open circuit voltage. Temperature coefficient indicates how much will be the decrement in power output if PV module temperature varies from STC. Moreover, it is to find an optimal energy production or consumption ratio for consumer.

Acknowledgement

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