Energy Yield Calculation Of The Grid Connected Photovoltaic Power System

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Abstract: - A simple approach to calculate the energy yield has been obtained using mathematical equations. The proposed simple mathematical approach can be accessed the condition of PV system as well as maintaining it in good condition. From analytical results obtained, the comparison of the calculated and actual values gives the evidence and the cause of power loss in the system. One month datasets have been investigated to demonstrate and validate the concept. The results also found that a good agreement between calculated and actual values using the proposed energy yield calculation.

Key-Words: - Energy Yield; Grid-connected (GC); Monocystalline; Polycrystalline; Photovoltaic (PV);

1 Introduction

Many consumers have expressed their interest in GCPV power system especially when the introduction of the Feed-in Tariff (FiT) scheme for residential houses (4 kW + bonus BIPV) is about 1.24 Ringgit Malaysia (RM) per kWh [1]. An attractive FiT scheme provides a fixed payment from the electricity supplier for every kilowatt hour (kWh) of electricity generated from residential owners will get secure payment of a fixed premium for certain duration in every kWh exported to the grid.

However, the majority of consumers have little knowledge of the system performance. The misleading term of "free maintenance" has led to really poor maintenance on the system and most of the cases; the owner does not know what to monitor and what to look at in their system. Estimating the performance is very important to ensure shortest return-on-investment (ROI) as well as extending the lifetime of the system in good condition.

Most of them are very complicated and required in depth technical know how's to understand the concept. In practice, the consumers only rely on the output reading of energy meter. However the actual causes of low energy generated is still not known. Thus it is essential to have simple basic monitoring equipment and a simple method of analyzing the system performance. This basic monitoring effort included the collection of data, a monthly collection of customer regarding to energy production could be known by surfing the web portal, e.g. SMA Sunny Portal or site visits to make visual inspections if any failure occurs. This is a very important subject especially when it involves FiT system where the owners need to know their investment.

Many researchers were proposed the methods in determining energy yield related to GCPV system, which attempt to account for the varying operating parameters under field conditions [2-4]. On the other hand, G. Makrides et al. [5] investigated the most accurate for prediction of energy model in Cyprus for over four years by comparing four different models; single-point efficiency, single-point efficiency with temperature correction, Photovoltaic for Utility-Scale Applications (PVUSA), and one-diode model. According to author's experience, the best deal in energy yield prediction was by using one-diode model for crystalline-Silicon and CIGS PV technologies. In addition, a-Si and CdTe thin-film (TF) PV technology was more accurately predicted by the PVUSA model.

The objective of this paper is to establish a simple mathematical approach between the measured parameters related to energy and power outputs as well as to compare and validate the theoretical with the actual outputs of GCPV system in Malaysia conditions as a case study. By proposing energy yield calculation, it could be used to predict the actual performance of GCPV system and the influence of other physical factors such as dirt, shading, cloud, fault string, heat and etc

2 Problem Formulation

2.1 System Description

The study was performed for a GCPV system in Shah Alam, Selangor (3˚N, 101˚E) under the equatorial rainforest climate and fully humid (Af) [6]. Both of GC systems using crystalline PV technologies installed on the roof of a parking space at the Green Energy Research Centre with an inclination angle of 10˚, facing due south.

As case study, the detailed information from two types of crystalline PV technologies as tabulated in Tables 1 and 2.

TABLE 1. PV MODULE CHARACTERISTIC PARAMETERS FOR SYSTEM 1

Subject	*Value*
Type of PV module	Yingli YL235P (Polycrystalline)
Pmp_stc	235 W
Imp_stc	7.97 A
Isc_stc	8.54 A
Voc_stc	37.0 V
γ Voc	-0.37%/Deg.C
γ Pmp	-0.45%/Deg.C
Array configuration	2 parallel x 13 series
Inverter	SB5000TL (Single-phase)
Total array power	6.11 kWp
Type of mounting	Retrofit on metal deck
Vertical Gap distance	20 cm

TABLE 2. PV MODULE CHARACTERISTIC PARAMETERS FOR SYSTEM 2

Subject	*Value*
Type of PV module	Yingli YL250c-30b (Monocyrstalline)
Pmp_stc	250 W
Imp_stc	8.20 A
Isc_stc	8.71 A
Voc_stc	38.1 V
γ Voc	-0.33%/Deg.C
γ Pmp	-0.45%/Deg.C
Array configuration	2 parallel x 20 series
Inverter	STP8000TL-10 (Three phase)
Total array power	10 kWp
Type of mounting	Retrofit on metal deck
Vertical Gap distance	20 cm

2.1.1 Methodology

A simple mathematical relationship to estimate the energy yield is proposed. The owner shall conduct an analysis during the initial installation where a benchmark for the system performance can be determined. This simple approach required the owner to install a few basic items. The items that is usually compatible with their existing inverter system. The owner needs to install two types of environmental sensors:

1. Solar irradiance sensor: It is recommended to use a reference cell with identical cell technology with PV modules. It should be mounted similar as the tilt angle of the PV module.
2. Temperature sensors are used from J type thermocouple should be used to measure module temperature.

Some GC inverters equipped with a monitoring system as an optional feature. The specific sensors can be connected directly to the inverter and the logging process can be set at any interval. However, some GCPV inverter system required an additional external logging system to log all the required data.

The important parameters that the owner need to be collected from the GCPV system as:

1. Solar irradiance
2. Module temperature
3. System:
   a) Total array power
   b) Number of PV module in series, Ns
   c) Number of PV module in parallel, Np
   d) Derate factor for cabling losses, f_{cable}
   e) Derate factor for accumulated dirt, f_{dirt}
   f) kWh meter reading
4. PV datasheet:
   a) Maximum power, Pmp_stc
   b) Maximum power current, Imp_stc
   c) Power tolerance, f_{mm}
   d) Power temperature coefficient, γ_{Pmp}.
5. Inverter datasheet:
   a) Maximum inverter efficiency

The mathematical relationship for estimate daily energy production can be calculated using (1);

$$E_{daily\ estimate} = \sum_{t=0}^{24} P_{array\ stc} \times \left\{\frac{G(t) \times t}{1000}\right\} \times \left\{1 + \frac{\%\gamma_{pmp}}{100}(T(t) - 25)\right\} \times f_{dirt} \times f_{mm} \times f_{cable} \times f_{inv} \quad (1)$$

Where;

$P_{array\ stc}$ Total array power (kWp)

T(t) PV module temperature at sampling time t

f_{dirt}	Dirt de-rate factor (per unit). Typically 0.97 for new installation.
f_{mm}	Module mis-match factor (per unit)
f_{cable}	Cable loss factor (per unit). Typically in the range of 0.95 to 0.99.
f_{inv}	Maximum efficiency of inverter (per unit)
$\%\gamma_{pmp}$	Temperature coefficient for Pmp (%/°C)

The mathematical relationship for estimate daily AC power generation at time, t can be computed by;

$$P_{ac\ estimate}(t) = P_{array\ stc} \times \left\{\frac{G(t)}{1000}\right\} \times \left\{1 + \frac{\%\gamma_{pmp}}{100}(T(t) - 25)\right\} \times f_{dirt} \times f_{mm} \times f_{cable} \times f_{inv} \quad (2)$$

The ability of the proposed equations could be used to explain what is actually happening in the system during its operation. The underperforming system can be easily be rectified whether it caused naturally by uncontrolled climate behaviour or could possible comes from the system itself.

Amongst the source of problems that could be easily identified by the proposed equation are:

a) Dirt
b) Shading or Partial shading
c) Faulty string
d) Faulty inverter
e) Faulty PV module
f) Weather

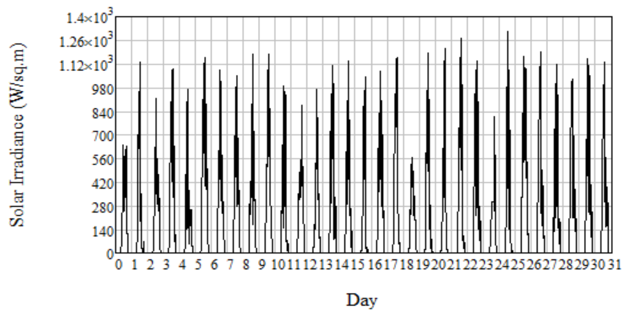
Apart from that, in this study, the measurements of solar irradiance, ambient temperature, module temperature, power generation and energy production recorded by SMA's data logger through high resolution data at 5 minute intervals were analyzed.

3 Problem Solution

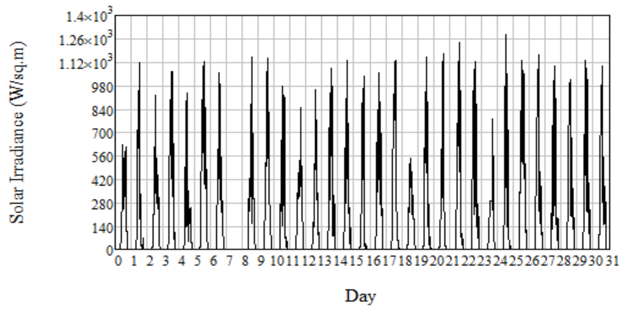
The estimated parameters using several formulas as listed in the previous section are compared with the actual data taken from the two types of GCPV systems under Malaysian climate.

3.1 Distribution of Irradiance and Module Temperature

Since there is a strong correlation between output energy and solar irradiation, the daily pattern of solar irradiance profile from January 1 to January 31, 2013, as can be shown in Fig. 1.



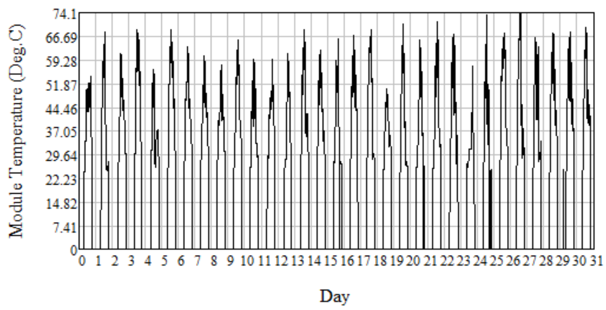
(a)



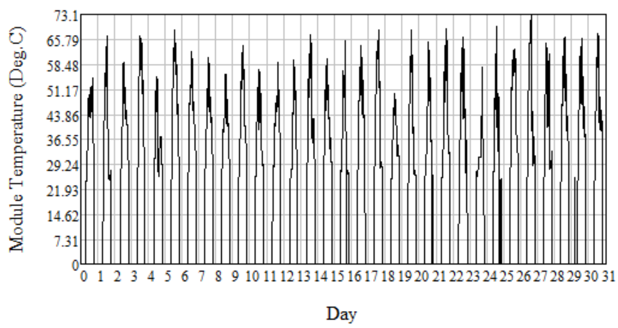
(b)

Fig. 1. Example of solar irradiance profiles for one month (a) Poly crystalline (b) Monocrystalline PV modules.

From the results obtained, the maximum solar irradiance received at noon on a clear day can achieved above 1,000 W/m^2 for this location. And, the module temperature profiles for one month under this environment as shown in Fig. 2.



(a)



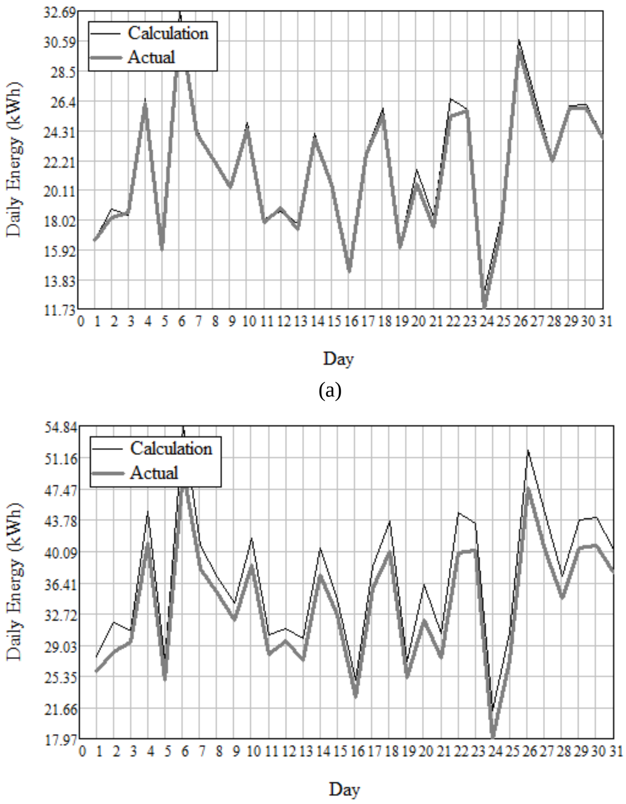
(b)

Fig. 2. Example of module temperature profile for one month (a) Polycrystalline (b) Monocrystalline PV modules.

In prediction purposes, the parameters such as solar irradiance and module temperature datasets required as input data to predict the energy output. Therefore, both inputs will be used to predict the estimated energy and then compared to the measured value in AC energy production.

3.2 The Estimation Model for Output Energy

For the validation purposes, the results obtained by analyzing performance data from systems 1 and 2. Using Eq. (1), the energy output can be estimated once the mathematical models for the output power and solar irradiance are established.



(a)

(b)

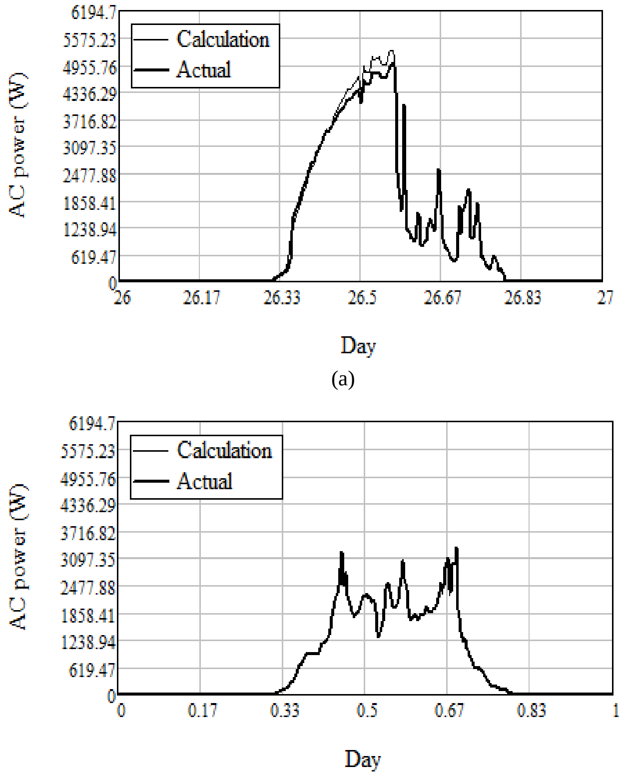
Fig. 3. Daily energy calculation and actual measurement (a) Polycrystalline (b) Monocrystalline PV modules.

Fig. 3 illustrates the calculated and actual data for daily energy as a function of exposure days. From graph 3(a), the estimate for polycrystalline shows a good agreement with the calculated energy production, except on January 2 and 22, 2013.

In the case of monocrystalline, it has demonstrated in many cases a slight variation during the peak irradiance between the calculated and actual measurements for the entire period. In general, the estimation model of polycrystalline is better than monocrystalline in predicting the energy harvesting. Therefore, to ensure that misleading estimate of why this happened, a narrow study related to the power losses will be discussed in the next section.

3.3 The Estimation Model for Output Power

To investigate further the cause of the power losses in both systems, AC power generation was estimated by using Eq. (2). The two systems were compared and divided into two types of irradiance conditions, as discussed below.



(a)

(b)

Fig. 4. Comparison of AC power produce by Polycrystalline PV modules (a) at high solar irradiance (b) at low solar irradiance.

Fig. 4 indicates a good correlation between the calculated and actual results in both conditions for polycrystalline. However, different measurements observed during the peak irradiance as illustrated in Fig. 4(a). The calculated AC power demonstrated by about 5,300W and the actual AC power generated at 4,955W. Under low solar irradiance, the plotted graph shows a good agreement with the calculated results.

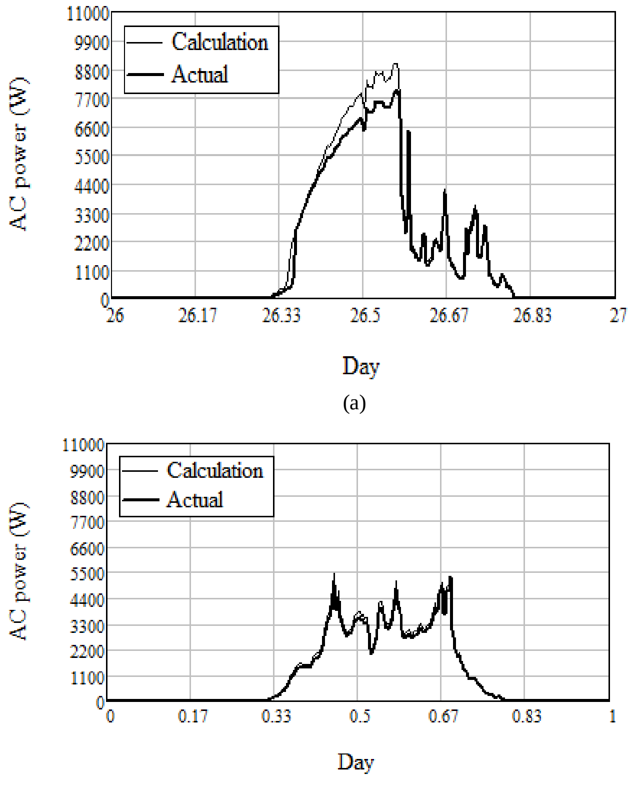
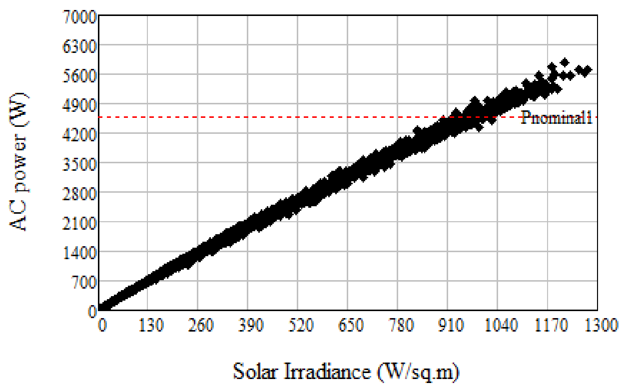


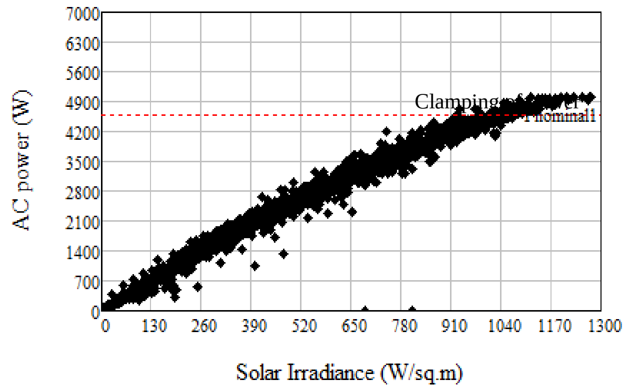
Fig. 5. Comparison of AC power produce by Monocrystalline PV modules (a) at high solar irradiance (b) at low solar irradiance.

Fig. 5 presents the AC power generation for monocrystalline response. During high solar irradiance, it clearly showed that the calculated value at 8,800W higher than the actual AC power generated by about 7,700W. However, the calculation value measured very close to the actual AC power produced at low solar irradiance. Both systems using polycrystalline and monocrystalline PV modules showed that the calculated values are not followed during the peak irradiance conditions.

Consequently, to investigate the cause of the reduction in power, AC power versus solar irradiance is plotted for both GC systems, as shown in Fig. 6.



(a)



(b)

Fig. 6. Comparison of AC power versus solar irradiance for Polycrystalline PV modules (a) calculated (b) actual measurements.

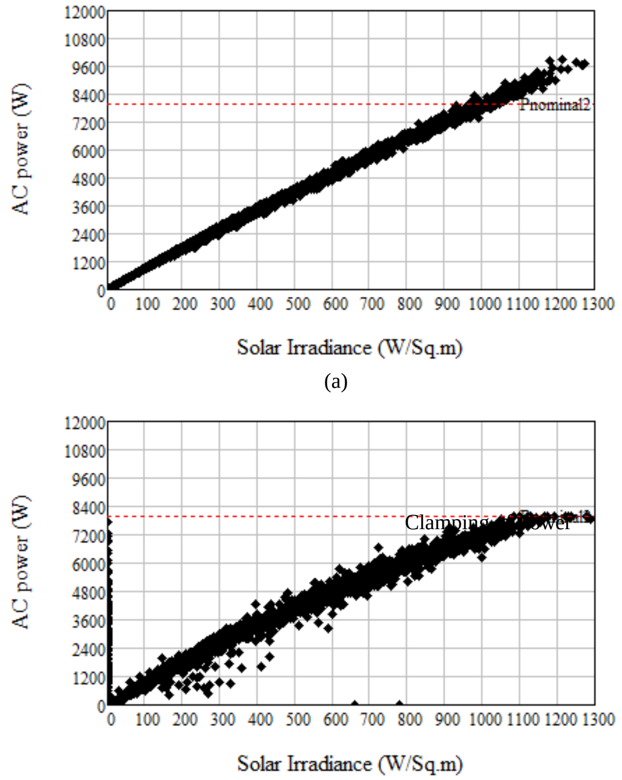


Fig. 7. Comparison of AC power versus solar irradiance for Monocrystalline PV modules (a) calculated (b) actual measurements.

Figs. 6(a) and 7(a) show the calculated AC power generations showed higher than actual measurements under field exposure. According to the power reduction's cases, it could be indicated by the improper sizing related to the inverter size matching to the PV array rating [7].

From both cases revealed that the losses of power due to the power clamping as clearly shown in Figs. 6 (b) and 7(b). This power clamping phenomenon could be observed when the levels of solar irradiance exceed 1kW/m^2. Although the crystalline do not have LID phenomenon that generally appears in TFPV technology, it is also should be taken into consideration whenever the PV installation under high irradiance, cloudy and low latitude areas [8-10].

One of the reasons, the inverter started to limit the amount of the power transfer to the grid when the power exceeds the nominal power rating. However, in practice, some GCPV inverters do not clamp the power but regulate its power until the inverter temperature falls within allowable range. In addition, the clamping of power by inverter might create thermal stress to the inverter in the long run.

4 Conclusion

A simple mathematical approach was successfully demonstrated as a method of calculation used to predict energy yield and power generated by a GCPV system. This approach makes use of instant irradiance and module temperature as the input parameters for estimation purposes. From the obtained results, the estimated value is quite close to the actual measurement under field exposure. In addition, the estimated value could also be determined the output of PV system and all related losses of energy due to the inverter operation. From this study, it gives information about the de-rating factor could be used by the system designers in an effort to provide the proper design in the future. The estimated value can be used as a benchmark for assessing the performance of a system. Therefore, the system underperforming could be easily identified.

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