Investigation on Temperature Coefficients of Three Types Photovoltaic Module Technologies under Thailand Operating Condition

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Abstract

This article describes a methodology to find the temperature dependence coefficients of amorphous silicon, poly crystalline and Heterojunction Intrinsic thin layer photovoltaic (PV) module. There are measured under Thailand Operating Condition. This study present three technologies of photovoltaic modules using 3.67 kWp (68 modules) of Amorphous Silicon Solar Cell (a-Si), 3.60 kWp (45 modules) of Poly Crystalline Silicon Solar Cell (p-Si) and 2.88 kWp (16 modules) of Heterojunction Intrinsic Thin Layer (HIT). There were installed at Energy Park, School of Renewable Energy Technology, Naresuan University (north latitude 16°47’, east longitude 100°16’). The 10 kW PV power station data have been recorded since year 2008 January to 2009 December. It is analyzed by linear regression technique. In addition, an average solar irradiance value in 2008 was 660 W/m² and 640 W/m² in the year 2009. Upon analysis, the study will show the Temperature coefficient of current, voltage, power and efficiency on array temperature obtained from liner regression. These findings of field test investigation found that the temperature coefficient value of PV array different from the factory value and the temperature coefficients in the year 2009 is higher than the year 2008. These results have an impact on systems design and sizing in similar climate regions. Thus, recommended that design and sizing of PV system in Tropical climate regions of the world take due address to these results.

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1. Introduction

In the present day, the global markets of photovoltaic cell system (PV) and production technology have amorphous thin film module (a-Si) and crystalline silicon module are mainly world market share. In hot weather, amorphous thin film is more popular than another type of PV module. Moreover, several researches studies apply PV for use. In several parts about efficiency of photovoltaic cell and behaviour of photovoltaic cell are different in type of photovoltaic module, which a-Si and crystalline module have been found in several paper [1-3]. Installation PV has temperature coefficient to be an important parameter for determine and evaluate appropriateness of use for each climate. The weather of installation site has different value each PV module types. Temperature coefficient values in field test have different with measured at standard test condition (STC: irradiation 1000 W/m², Air mass 1.5 and a module temperature of 25°C), which can found in several research and various of weather in the world [4-8,15] but in hot humid weather that similarly Thailand is very hard to be found. This study is one of work that studied specific issues with temperature coefficients of PV module system in hot humid weather. The result of this found has been useful to determine about deployment of solar cells technology, design, sizing and investment in PV power system in hot humid climate similarly Thailand regions. This paper presents method and summary of result about temperature coefficient of photovoltaic cell type a-Si, p-Si and HIT PV module in filed test on 10kW solar power system under condition of hot and humid weather in Thailand.

2. Materials and Methods

2.1. Materials and Systems installation

In this field test, three different types of stand-alone photovoltaic power systems were installed using the: amorphous thin film (a-Si) 3672W of 54Wp 68 modules are connected into 17 strings, 4 modules each. Second, polycrystalline (p-Si) 3600W of 80 Wp 45 modules are connected into 3 strings, 15 modules each and the last is Heterojunction Intrinsic thin layer (HIT) 2880W of 180 Wp 16 modules connected into 2 strings, 8 modules each. The modules facing due South and tilted at 16° from the horizontal. There modules were installed in 10Kw power station system on the Energy Park at the School of Renewable Energy Technology (SERT) in Naresuan University, Phitsanulok Province. The power conditioning system is composed of three grid-connected inverter (GI) 3.5 kW each, and three bi-directional inverter (BI) 3.5 kW. The energy storage system is 100 kWh batteries, 2V2000Ah 24 cells [9]. The schematic block circuit diagram of the 10 kWp stand-alone PV power system is shown in Fig. 1. This system has been installed and operated since June 2005. The sizing parameters and temperature coefficient is shown in Table 1.

| Parameters                  | Unit | a-Si | p-Si | HIT |
|-----------------------------|------|------|------|-----|
| Maximum power (W)           | Wp   | 54   | 80   | 180 |
| Open circuit voltage (Voc)  | V    | 62.2 | 44.9 | 45.5|
| Short circuit current (Isc) | A    | 1.14 | 5.75 | 5.49|
| Maximum power voltage (Vpm) | V    | 44.8 | 36.2 | 36.5|
| Maximum power current (Ipm) | A    | 0.93 | 5.11 | 4.93|
2.2. Monitoring Systems

The 10Kw monitoring system is fully assessed the potential of PV technology and performance of the system. The monitoring system was designed depend on IEC 61724 standard [10] and the International Energy Agency Photovoltaic Power System (IEA PVPS) Program task 2 [11-13]. For the general data recorder, a multi-function measuring device measures the parameters.

![Schematic block circuit diagram of the PV system](image)

Fig. 1. Schematic block circuit diagram of the PV system

2.3. Experimental Techniques

The values of parameters that effect to module temperature are solar radiation and ambient temperature, which is different each type of solar panel.

So, module temperature is a function of solar radiation and ambient temperature.

\[ f(T_m) = f(G_t, T_a) \]  \hspace{1cm} (1)

For this study, we used the relationship between module temperatures differential and solar irradiance to find the temperature dependence models is given as: [14]

\[ T_m = T_a + k G_t \]  \hspace{1cm} (2)

Where:

- \( T_m \) = Module Temperature (°C)
- \( T_a \) = Temperature surrounding (°C)
- \( G_t \) = Solar irradiance (kWm\(^{-2}\))
- \( k \) = Relationship Coefficient (°Cm\(^2\)/W)
In addition of the current, voltage and power dependences on temperature are often presented as [15]:

\[
\frac{\Delta I}{\Delta T} = +\alpha mA/°C \\
\frac{\Delta V}{\Delta T} = -\beta mV/°C \\
\frac{\Delta P}{\Delta T} = -\gamma W/°C
\]

(3)  (4)  (5)

Where:
\(\Delta I, \Delta V, \Delta P\) and \(\Delta T\) are the augmentation in current (mA), voltage (mV), power (W) and temperature under module (°C) respectively, \(\alpha, \beta, \gamma\) are coefficients value that depend on module temperature.

From equation 3-5 was presented electric current, voltage and power that varies depends on module temperature of solar panel. Only electric current has a positive temperature coefficient but voltage and power have negative coefficients [15].

In this field test study, these data are studied and analyzed to obtain information with useful to performances based on temperature impact using specific hot and humid as Thailand field data.

3. Results and Discussion

The 10 kW PV power station data have been recorded since January 2008 to December 2009. The data of electric current, voltage and power were used to analyze in this study. In addition, an average solar irradiance value in 2008 and 2009 were 660 W/m² and 640 W/m² respectively, which this solar irradiance value is the average in 2008 and 2009 at 8.00-16.00 pm.

From this data, we can plots graphical data of Thailand field test of solar irradiance, operating temperature and surrounding temperature of PV systems in this field test are shown in Fig. 2.

Fig. 2. The Averaged of solar irradiance, module temperatures and surrounding temperature for 10kw PV system from January 2008 to December 2009
As shown in Fig. 2, the solar irradiance had maximum value at 11.00-13.00. This trend has related to module temperature three types of PV cell and ambient temperature, which effect to power outputs are very close. From consideration, the power outputs doesn’t resemble with ambient temperature trend, which reached peak values at 13.00-16.00 pm. The maximum average of solar irradiance was 764 W/m². The maximum average module temperature of a-Si, p-Si, HIT and ambient temperature were 58.6°C, 58.3°C, 55.7°C and 32.5°C respectively.

3.1. Relationship between current and operating temperature

In this part, graphical relationship between arrays current and operating temperature was analyzed by regressions technique. This plot shown in Fig. 3, which shown scatter plots average of array current about a-Si, p-Si and HIT and operating temperature by using data range of solar irradiance 660 W/m²±3% and 640 W/m² ±3% (The Expected accuracy for daily sums of CM11 pyrometer is ±3%) in 2008 and 2009 respectively.

![Graphical plot between array current and operating temperature for three type PV system from Jan2008-Dec2009](image)

From the relationships of Fig. 3 was shown in Table 2. These values in 2008 presented that the generated array current per degree increase in operating temperature of array. The first high rise value is a-Si array. The second is HIT array and last is p-Si as 71.6 mA/°C, 23.6 mA/°C and 35.8 mA/°C respectively.

In 2009, trend has similar result in 2008 but increasing of current per degrees is reducing than 2008 for all three types of systems.

| Photovoltaic system | Linear model 2008 | Linear model 2009 | (mA/°C) 2008 | (mA/°C) 2009 |
|---------------------|-------------------|-------------------|--------------|--------------|
| a-Si                | $I_{a-Si} = 0.0716x + 6.3506$ | $I_{a-Si} = 0.0419x + 7.2942$ | 71.6         | 49.1         |
|                     | $R^2 = 0.9444$    | $R^2 = 0.9941$    |              |              |
| p-Si                | $I_{p-Si} = 0.0236x + 7.5508$ | $I_{p-Si} = 0.0121x + 7.9092$ | 23.6         | 12.1         |
|                     | $R^2 = 0.9675$    | $R^2 = 0.9945$    |              |              |
| HIT                 | $I_{HIT} = 0.0358x + 4.7517$ | $I_{HIT} = 0.0113x + 5.7585$ | 35.8         | 11.3         |
|                     | $R^2 = 0.9911$    | $R^2 = 0.9763$    |              |              |
3.2. Relationship between voltage and operating temperature

In this part, graphical relationship between arrays voltage and operating temperature was analyzed by regressions technique. This plot shown in Fig. 4, which shown scatter plots average of array voltage about a-Si, p-Si and HIT and operating temperature by using data range of solar irradiance 660 W/m²±3% and 640 W/m²±3% in 2008 and 2009 respectively.

![Graphical plot between array voltage and operating temperature for three type PV system from Jan2008-Dec2009](image)

From the relationships of Fig. 4 was shown in Table 3. These values in 2008 presented that the generated array voltage per degree decrease in operating temperature of array. The first high reduce value is p-Si array. The second is HIT array and last is a-Si as -49.5 mV/°C, -117.9 mV/°C and -71.6 mV/°C respectively.

In 2009, trend has similar result in 2008 but decreasing of voltage per degrees is rise than 2008 for all three types of systems.

Table 3. Summary of linear models for array voltage and operating array temperature.

| Photovoltaic system | Linear model                      | (mV/°C)       |
|--------------------|-----------------------------------|---------------|
|                    | 2008                              | 2009          | 2008      | 2009      |
| a-Si               | $V_{a-Si} = -0.495x + 241.41$    | $V_{a-Si} = -0.7793x + 257.85$ | -49.5     | -77.93    |
|                    | $R^2 = 0.9864$                    | $R^2 = 0.9970$ |           |           |
| p-Si               | $V_{p-Si} = -1.1799x + 300.15$   | $V_{p-Si} = -1.2393x + 304.03$ | -117.9    | -123.9    |
|                    | $R^2 = 0.9997$                    | $R^2 = 0.9982$ |           |           |
| HIT                | $V_{HIT} = -0.7163x + 296.7$     | $V_{HIT} = -0.8941x + 306.19$ | -71.6     | -89.4     |
|                    | $R^2 = 0.8764$                    | $R^2 = 0.9972$ |           |           |

3.3. Relationship between power output and operating temperature

In this part, graphical relationship between arrays power and operating temperature was analyzed by regressions technique. This plot shown in Fig.5, which shown scatter plots average of array voltage
about a-Si, p-Si and HIT and operating temperature by using data range of solar irradiance 660 W/m² ±3% and 640 W/m² ±3% in 2008 and 2009 respectively.

From the relationships of Fig. 5 was shown in Table 4. These values in 2008 presented that the generated array voltage per degree rise in operating temperature of array in a-Si and HIT but reduce in p-Si. The first high reduce value is p-Si array. The increasing value of a-Si array and HIT array are 0.0076 W/°C and 0.0040 W/°C respectively and the decreasing value of p-Si array is -0.0054 W/°C.

In 2009, trend has similar result in 2008 in a-Si and p-Si array but the value per degree has difference trend in HIT array as reducing in year 2009.

**Fig. 5. Graphical plot between array power and operating temperature for three type PV system from Jan2008-Dec2009**

Table 4. Summary of linear models for array voltage and operating array temperature.

| Photovoltaic system | Linear model 2008        | Linear model 2009        | (W/°C) 2008 | (W/°C) 2009 |
|--------------------|-------------------------|-------------------------|-------------|-------------|
| a-Si               | $P_{a-Si} = 0.0104x + 1.6321$ | $P_{a-Si} = 0.0031x + 1.974$ | 0.0104      | 0.0031      |
|                    | $R^2 = 0.9596$          | $R^2 = 0.9761$          |             |             |
| p-Si               | $P_{p-Si} = -0.0048x + 2.3414$ | $P_{p-Si} = -0.0077x + 2.4423$ | -0.0048     | -0.0077     |
|                    | $R^2 = 0.9746$          | $R^2 = 0.9934$          |             |             |
| HIT                | $P_{HIT} = 0.0046x + 1.4748$ | $P_{HIT} = -0.0027x + 1.7883$ | 0.0046      | -0.0027     |
|                    | $R^2 = 0.9013$          | $R^2 = 0.9932$          |             |             |

**4. Conclusion**

From this study found that the coefficients depend on module temperature parameter of a-Si, p-Si and HIT in field test have difference from standard test (STC: irradiation 1000 W/m, Air mass 1.5 and a module temperature of 25°C), which specified in PV module from production company. The evaluation from standard test was used three stand-alone 10Kw photovoltaic power systems and recorded values in Thailand’s hot and humid weather condition. Using linear regression technique to analyze the relationship between array current, voltages, power and operating temperature and determine temperature coefficient. The summary of study is shown in Table 5.
The values from Table 5 shown that a-Si module has been received effect from rising of module temperature in negative part less than HIT module and p-Si module respectively. So that a-Si module has been best signal significantly in term of current generated, voltage, power outputs and lowest negative coefficients for long term installation in Thailand’s hot and humid climate. This result has been beneficial for determine to design, sizing and investment in PV power system in hot and humid climate like Thailand in another part of the world.

Table 5. Summary of field test result from Thailand climate regions

| Parameter          | Unit      | 2008   | 2009   | 2008   | 2009   | 2008   | 2009   |
|--------------------|-----------|--------|--------|--------|--------|--------|--------|
| Current coefficient| mA/°C     | 71.6   | 49.1   | 23.6   | 12.1   | 35.8   | 11.3   |
| ( %/°C )           |           | 0.48411| 0.33198| 0.16845| 0.08181| 0.36308| 0.11460|
| Voltage coefficient| mV/°C     | -49.5  | -77.93 | -117.9 | -123.9 | -71.6  | -89.4  |
| ( %/°C )           |           | -0.02298| -0.03592| -0.04949| -0.05185| -0.02763| -0.03448|
| Power coefficient  | W/°C      | 0.0104 | 0.0031 | -0.0048| -0.0077| 0.0046 | -0.0027|
| ( %/°C )           |           | 0.00048| 0.00015| -0.00023| -0.00038| 0.00027| -0.00016|

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