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Evaluation of Standard Reference Environment for Photovoltaic Nominal Operating Cell Temperature Testing in Malaysia

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Abstract

This paper presents six months evaluation in determining Standard Reference Environment (SRE) for Photovoltaic (PV) Nominal Operating Cell Temperature (NOCT) testing of IEC61215 and IEC61646 that suits Malaysian climate. The SRE is established based on the median environmental conditions in Malaysia when solar PV is producing power. The site of the study is located at the Energy and Environment Field Lab, Universiti Teknologi MARA (UiTM) Shah Alam (3.066239ºN, 101.491685ºE). Three types of PV module technologies involved are monocrystalline, polycrystalline and copper indium diselenide (CIS) thin film. The experimental setup is a test bed that meets the IEC61215, IEC61646 and IEC61724 requirements. The measurements of module temperature (MT) and open circuit voltage (V_{OC}) are taken simultaneously for the three PV module technologies together with other ambient parameters of solar irradiance (SI), ambient temperature (AT), relative humidity (RH), wind speed (Ws) and wind direction (Wd). The data set is taken for a six months period from February 2017 to July 2017. Based on the results obtained, a new proposed SRE of NOCT testing for IEC61215 and IEC61646 has been established to suit Malaysian climate. The SI and AT values for the SRE are 300W/m^2 and 31°C respectively.

Keywords: *Standard Reference Environment, Nominal Operating Cell Temperature, Photovoltaic*

1. Introduction

Photovoltaic (PV) modules are sent to testing facilities to match international standards and obtain certifications. International certification is a proof of PV reliability in ensuring PV modules manufactured meets international standards such as IEC61215 (Crystalline Silicon Terrestrial Photovoltaic (PV) Modules-Design qualification and type approval) and IEC61646 (Thin-Film Terrestrial Photovoltaic (PV) Modules-Design qualification and type approval). Based on these standards, PV modules needed to undergo specific tests as stated in the qualification test sequence in the IEC61215 and IEC61646. All tests are conducted in the lab under controlled environment except for one test that is Nominal Operating Cell Temperature (NOCT). NOCT test is an outdoor test under real varying outdoor conditions. NOCT is defined as the equilibrium mean solar cell junction temperature within an open-rack mounted module in the following standard reference environment (SRE). The term SRE is used in IEC 61215. The purpose of determining NOCT is to guide the system designers to which a module will function in the actual environment [1]. Nowdays, NOCT values are given in the PV module data sheet provided by the manufacturer. The NOCT mathematical model is expressed by:

$$MT = AT + \frac{SI}{800W/m^2}(NOCT - 20°C) \quad (1)$$

Where,

MT = Module Temperature (°C)
AT = Ambient Temperature (°C)

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SI = Solar Irradiance (W/m^2)

However, the work of determining SRE was originated In United States. SRE was initially known as nominal terrestrial environment (NTE) and it is defined as representative of the average environmental conditions in the United States during times when solar arrays are producing power[2]. In other words, it represents the median environment based on the energy production of the PV modules. The parameters involve under the pioneer work of NTE and present work of SRE of the solar PV module are irradiance (SI), ambient temperature (AT), wind speed (Ws), electrical load and tilt angle of the solar PV modules as shown in Table 1.

There are two primary differences between NTE and SRE, which are wind speed and tilt angle. The wind speed value under NTE is less than 4.0m/s wind gust. However, the wind speed under SRE is 1.0m/s without referring to wind gusts. The best tilt angle of the PV modules based on NTE is the latitude of the site. In contrary, the tilt angle of SRE is 45º. Nevertheless, a study conducted at Solar Energy Research Institute of Singapore (SERIS) supported that the best tilt angle for PV modules is following the latitude of the location[3].

Table 1. NTE and SRE Conditions

Parameter	NTE	SRE
SI	(800 ± 400)W/m^2	800W/m^2
AT	(20 ±15)°C	20°C
Ws	< 4m/s (Gust)	1m/s (Speed)
Electrical Load	Nil (Open Circuit)	Nil (Open Circuit)
Tilt Angle	Local Latitude	(45 ± 5)º

The main issue arises when similar NOCT testing needs to be conducted in Malaysia, that lies between the latitude of 1º to 7º north. Since Malaysia is a country located in the equatorial climate region, its climate profile is expected to be different from other climate regions in the world[4]. Based on the SRE, there are three climate parameters involve namely SI, AT and Ws. However, referring to NOCT model as expressed in Equation 1, only the median values of SI and AT will be substituted in the model. The SI and AT values of the current SRE are 800W/m^2 and 20.0ºC respectively. The corresponding MT for the current SRE was found in the range of 40.0ºC to 50.0ºC but highly dependent on the PV module technologies [2], [5–7].

In the context of Malaysian climate, several studies recorded significantly different SI and AT from the current SRE. According to Malaysian Meteorological Department, AT in Malaysia is ranging from 23.0°C to 33.0°C [8]. In 2016, two studies reported the average range of SI and AT are 753W/m^2 to 979W/m^2 and 24.9°C to 35.0°C respectively[9-10]. There are also few studies conducted in Malaysia found that the average SI and AT are approximately 431 W/m^2 and 30.0°C respectively [11–15]. Consequently, the corresponding MT was found to be approximately ranging from 21.6ºC to 60.3ºC [10–12], [14].

If a testing facility of IEC61215 and IEC61646 is to be established in Malaysia, a different SRE need to be determined for the NOCT testing due to significantly different value of SI and AT. The SRE must be median environment based on the energy production of the PV modules in Malaysia. It must also represent the local climate profile and crucial to ensure an accurate determination of NOCT. Thus, the aim of this study is to establish an SRE for NOCT testing that suits in Malaysian climate.

2. Methodology

The site of this study is located at the Energy and Environment Field Lab (EEFL), Universiti Teknologi MARA (UiTM) Shah Alam (Lat:3.066239ºN, Long:101.491685ºE). The overall view of the experimental setup and the closed-up view of the PV module technologies used are as shown in Figure 2 and Figure 3 respectively. Three types of PV module technologies involved are monocrystalline, polycrystalline and copper indium diselenide (CIS) thin film. The PV modules specification are as listed in Table 2.

Table 2. PV Module Specification

Parameters	PV module technology		
	Monocrystalline Silicon	Polycrystalline Silicon	CIS Thin Film
P_{mp}_STC	100W_p	100W_p	155W_p
I_{mp}_STC	5.35A	5.72A	1.95A
I_{SC}_STC	5.70A	6.35A	2.20A
V_{OC}_STC	22.53V	22.0V	108.0V
γ V_{OC}	-0.35% / ºC	-0.36% / ºC	-0.30% / ºC
γ P_{mp}	-0.45% / ºC	-0.44% / ºC	-0.31% / ºC
NOCT	47ºC	45 ± 2ºC	47ºC

Figure 2. Overall view of the experimental setup

Figure 3. Close-up view of PV module technologies used

The complete experimental setup of the installations with monitoring equipments is shown in Figure 4. The monitoring system and sensors accuracy comply with International Standard [1], [16-17]. The monocrystalline, polycrystalline and CIS thin film PV modules are set to an open rack mounting configuration tilted at 5° facing south and in open circuit configuration. A pyranometer is mounted in the plane of array with the modules within 0.3m of the test array. An ultrasonic wind speed sensor is installed approximately 0.7m above the top of the module and 1.2m to the west. An ambient temperature sensor is installed at the same location as the wind speed sensor but at a lower level. A temperature sensor is placed at the centre back of each module. The dataset was taken for a six months period starting from February 2017 to July 2017. All data were logged every 5-minute interval using HOBOlink logger. The raw data comprises of parameters namely SI, AT, RH, Ws, Wind direction (Wd), open circuit voltage (V_{OC}) and module temperature (MT) for monocrystalline (MT_m), polycrystalline (MT_p) and CIS thin film (MT_f). The data has been analysed using SPSS and Mathcad softwares as the statistical and mathematical tools. Table 2 shows the mean, median, mode, standard deviation, skewness, standard error of skewness, minimum and maximum of each parameter.

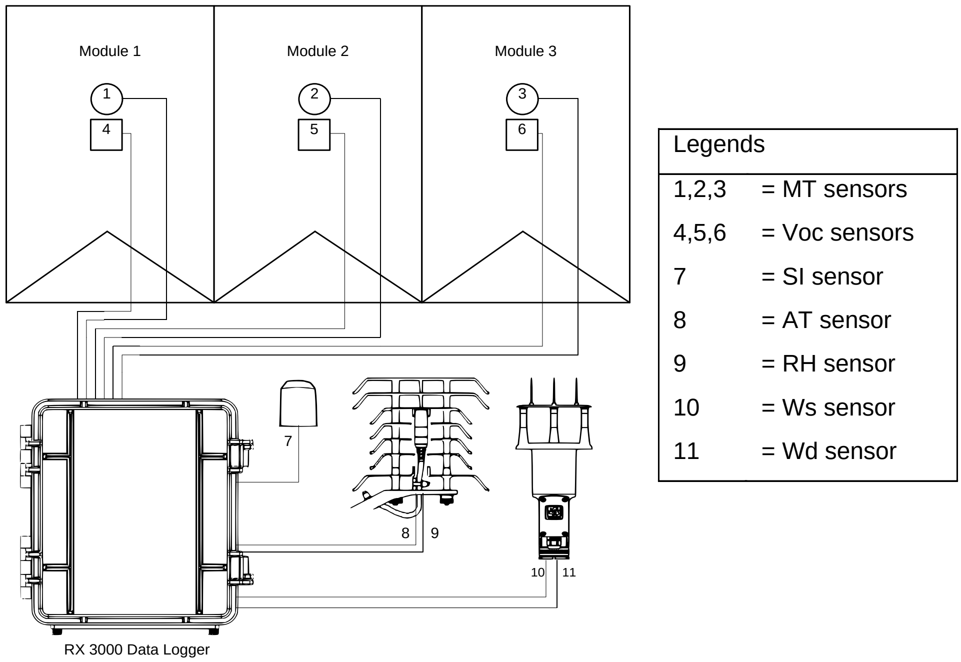


Figure 4. Experimental Set Up with Monitoring Equipments

3. Result and Discussion

The statistical analysis on overall and monthly basis of the parameters investigated are depicted as in Table 2 and Table 3. Based on the result obtained, the overall median environment recorded are (294 ± 10)W/m^2 for SI, (31.36 ± 0.21)°C for AT, (69.6 ± 2.5)% for RH, (0.899 ± 0.11)m/s for Ws, (175.57 ± 2)° for Wd and 41.94 ºC, 42.45 ºC, 44.04ºC for corresponding MT_m, MT_p and MT_f. This preliminary reading of SRE already shown distinctive difference with the current SRE of IEC 61215.

a) Solar Irradiance

For a six months period, the maximum reading of SI recorded is 1226W/m^2. The minimum and highest frequency of SI is 41W/m^2. This is likely due to filtration technique used as the data is filtered at 40W/m^2 based on thermal equilibrium point [12]. The highest median achieved is 317W/m^2 in April while the lowest is 264W/m^2 in May. From Figure 5), it's clearly shown that the distribution of SI is skewed to the right, which the median is lower than the mean.

b) Ambient Temperature

AT maintains constant median at approximately 31.00°C for the six months period. It is the only parameter that expresses the nearly constant median values and skewed to the left based on Figure 5b). From the figure, it is shown that the range of AT is within 23.00°C. The highest temperature recorded is 40.03°C and the lowest is 23.33°C. This clearly suggests that AT in current SRE, which is at 20.00ºC is not achievable in Malaysian climate.

c) Relative Humidity

Median RH is recorded high, ranging from 65.0% to 73.0%. The lowest median is at 65.4% in February and the highest is at 73.7% in May. These values are somehow reciprocally related to SI value as they may be regarded by the cloud formation. For instance, in May it is recorded the highest median of RH but the lowest median of SI. From Figure 5c), the RH data range is normally distributed with approximately 56.0% range and the data distribution is somewhat skewed to the right.

d) Wind Speed

During the six months period, Ws showed nearly constant median of nearly 1.0m/s, with the highest median at 0.958m/s and lowest median at 0.855m/s. Based on Figure 5d), the data range is 5.8m/s and the data distribution is skewed to the right. Based on this result, it indicates that wind condition in Malaysian climate is favorable and easily achievable to suit the wind speed requirement of 1.0m/s for SRE as stated in IEC61215 andIEC61646.

e) Wind Direction

Wd median is at 175.57°. This means that most of the wind comes from southeast to south direction, which at 167.38° and 185.08° respectively. From Figure 5e), the overall distribution of Wd data, shows wide variation. This also proven that there is no obstuctions near the experimental setup area. Wd is not directly stated in SRE conditions. Nevertheless, it is one of the parameters used for data filtration in determining NOCT.

f) Module Temperature

From Table 3, 4 and Figure 5f), g) and h), all three module temperatures shown nearly similar pattern during the period. The median values of MT_m and MT_p vary within only 1.0°C. However, the median MT_f is higher by 1.0°C to 2.0°C although it is under the same environment. This may be ascribable to its size, since the size of the PV module is bigger than the other two PV modules, which may influence the heat capacity [5], [18]. In other words, it is due to their different thermal mass and response to changes in environment.

g) Open Circuit Voltage

The only electrical output of the PV module discussed in this study is the open circuit voltage which aligned with the IEC61215 and IEC61646 requirements. From Figure 6, monocrystalline, polycrystalline and CIS thin film PV module technologies shown similar V_{OC} patterns with their corresponding MT. However, CIS thin film shows wide spread of V_{OC} data from the other PV modules. The corresponding median MT for MT_m, MT_p, and MT_f based on the SRE determined in this study are 41.94°C, 42.45°C and 44.04°C respectively. It is noted that variation of V_{OC} is in the range of approximately 4V of corresponding MT for both monocrystalline and polycrystalline PV module technologies. Yet, for thin film technology, the variance is approximately 23V. Further research needs to be carried out to rectify this issue

Table 3. Overall Statistical Analysis

	SI (W/m^2)	AT (°C)	RH (%)	Ws (m/s)	Wd (°)	MT_m (°C)	MT_p (°C)	MT_f (°C)
Mean	363.12	31.0289	71.3414	1.00955	167.73131	41.9103	42.4712	43.9823
Median	294.00	31.3600	69.6000	.89900	175.57000	41.9400	42.4500	44.0400
Mode	41	32.59	64.40	.125	1.530	56.03	51.03	47.45
Std. Deviation	258.501	2.57505	11.72798	.627700	105.622518	9.17031	9.51630	10.43493
Skewness	.717	-.381	.339	1.187	.002	.054	.062	.037
Std. Error of Skewness	.018	.018	.018	.018	.018	.018	.018	.018
Minimum	41	23.33	44.10	.009	.030	23.59	23.62	23.57
Maximum	1226	40.03	100.00	5.872	358.930	64.79	65.97	71.42

Table 4. Monthly Median Statistical Analysis

Month	SI (W/m^2)	AT (°C)	RH (%)	Ws (m/s)	Wd (°)	MT_m (°C)	MT_p (°C)	MT_f (°C)
Feb	314.00	31.2000	65.4000	.95800	171.83000	41.3000	42.7100	43.6500
March	282.00	31.3300	69.5000	.95800	167.38000	40.9500	42.0300	43.3100
April	317.00	31.4800	69.5000	.90800	185.08000	41.9100	42.1800	43.4300
May	264.00	31.3600	73.700	.85500	175.2400	41.4700	41.5900	42.8000
June	303.00	31.4800	69.700	.87400	178.0550	42.8150	43.0850	45.5150
July	303.00	31.1800	69.400	.87400	173.8500	42.6500	42.7400	45.0600

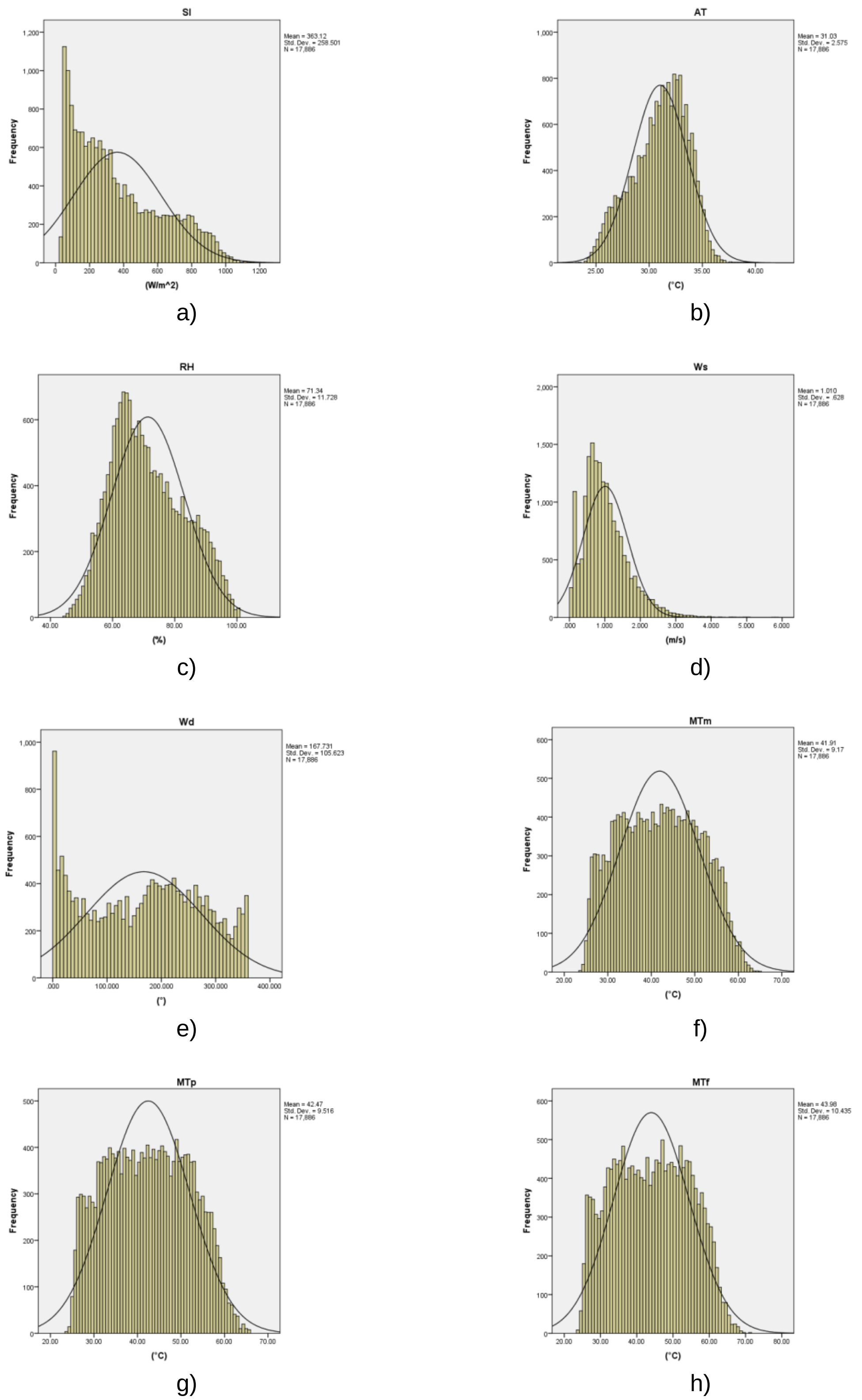
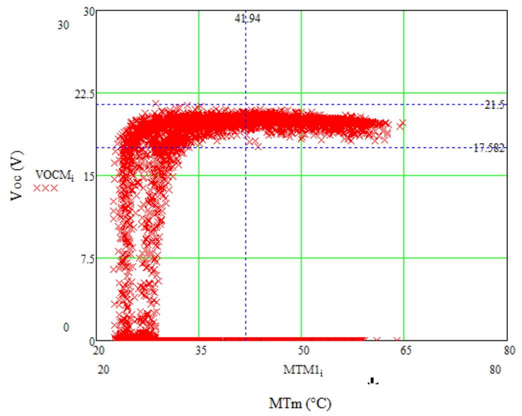
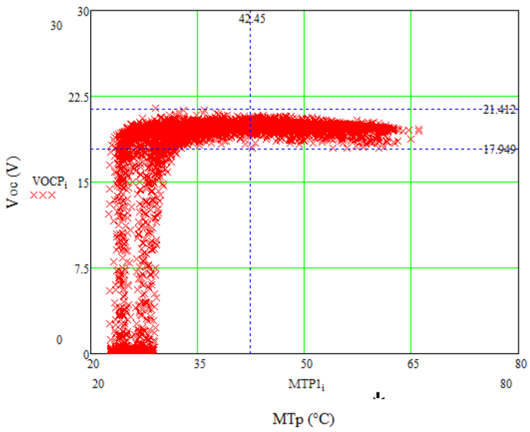


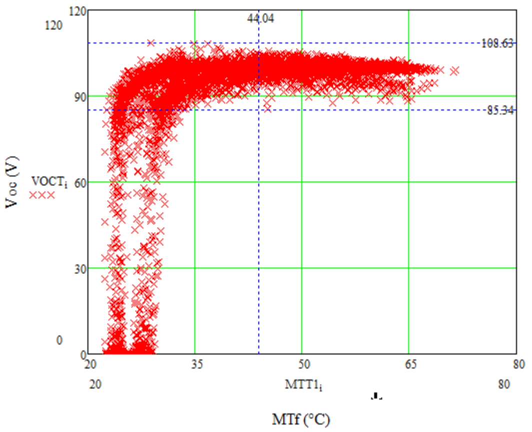
Figure 5. Frequency Distribution of a)SI, b)AT, c)RH, d)Ws, e)Wd, f)MT_m, g)MT_p, and h)MT_f



a)



b)



c)

Figure 6. V_{OC} with corresponding MT a)monocrystalline, b)polycrystalline and c) CIS thin film

4. Conclusion

A new proposed SRE for NOCT testing of IEC61215 and IEC61646 has been established to suit the Malaysian climate. The SI and AT values of the SRE are 300W/m^2 and 31°C respectively based on the median values obtained. The corresponding median MT of the new proposed SRE of monocrystalline, polycrystalline and CIS thin film technologies are 41.94°C, 42.45°C and 44.04°C respectively.

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