ADVANCED ELECTRICAL AND ELECTRONICS ENGINEERING AND SCIENTIFIC JOURNAL
VOLUME1-NO 1- JANUARY 2017. WWW.AEEESJ.COM
ISSN: 2520-7539

Meteorological Parameters in Malaysia: An Investigation Between Real Measurements and NASA Database

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Abstract This article investigates the meteorological parameters database for six locations in Peninsula Malaysia (Kuala Lumpur (KL), Johor Bahru (JB), Malacca, Ipoh, Kuantan, and Bayan Lepas) comparing to NASA database. Hourly measurements of global solar radiation, ambient temperature and wind speed were obtained from Malaysia Meteorological Department (MMD) between years 2005-2009. The conducted investigation shows that there is a clear discrepancy between real measurements and satellite-based data provided by NASA. The historical data obtained from MMD can be modeled for predicting weather parameters for other locations in Malaysia and worldwide. The investigation concludes that utilizing real meteorological measurements is more convenient and accurate for predicting the energy output of photovoltaic (PV) systems in the pre-installation phase in terms of feasibility and performance analysis of the system.

***Index Terms*—Malaysia meteorology, NASA meteorological database, PV energy output, solar radiation, .**

I. INTRODUCTION

THE solar PV planning in Malaysia aimed for significant uptake, from merely 65 MW in 2015 to 18,700 MW in 2050, surpassing all other renewable energy uptakes combined [1]. Grid-connected PV in Malaysia will be the main market from 2015 onwards. Malaysia targets 1250MW and 3100MW (25% of renewable energy mix) solar power capacity to be connected to the grid by 2020 and 2030 respectively [2].

The bibliography comprises plenty of works that correlate historic meteorological records with solar energy and related studies. Many researchers have proposed several mathematical models to estimate the global solar radiation from ground-based measurements. The sunshine duration is one of the parameters often used to correlate to the global solar radiation [3-6]. In [7], using five different models; linear, quadratic, linear-logarithmic, logarithmic, and power equations, the monthly clearness index and normalized monthly sunshine duration were correlated in order to search the regression coefficients. Based on the meteorological data collected from 25 stations throughout Thailand over ten years, a prediction model for solar radiation has been proposed.

Recently, several studies have been proposed for predicting the global solar radiation and PV module temperature utilizing the artificial neural network (ANN) where they consider various related climatological parameters such as ambient temperature and wind speed as input variables [8-11] . Based on measured 1-year hourly global solar radiation, ambient temperature, relative humidity, wind speed and PV module temperature, the author in [12] developed an empirical regression model to calculating the hourly PV module temperature from meteorological parameters.

This paper was first submitted on June 1, 2016 and sent for second review on August 16, 2016.

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II. METEOROLOGICAL PARAMETERS DATABASE FROM NASA

Malaysia consists of the Peninsula, which is part of mainland Southeast Asia, and the states of Sabah and Sarawak on the Northern edges of Borneo. It is located close to the equator, between 1 and 7 degrees north and between 100 and 120 degrees east, thus having a high level of irradiance. The annual solar irradiation in Malaysia is 1643 kWh/m^2 [13]. As at September 2012, there were 13 observation stations recording solar radiations throughout the country. It was recorded that the monthly average radiation ranged from 12.9 MJ/m^2 (Kuching) to 19.20 MJ/m^2 (Bayan Lepas) [14].

Solar radiation is the prime force of the energy delivered from PV systems. When solar radiation comes directly from the sun it is known as direct radiation whereas when it is scattered by the atmosphere and sent back to the Earth it is referred to as diffuse. Clear, cloudy, and overcast are the three types of irradiance conditions. On a clear sunny day, the power density of irradiance is approximately 1 kW/m^2 [15]; that is called full sun at which the solar PV array is rated.

Meanwhile, most of commercial software for estimating the PV energy output and studying the performance of PV system such as PVWatts, PVSyst, RETscreen, and HOMER import the solar radiation data from NASA [16]. Even GreenTech Malaysia [17], the government's think-tank on energy-related issues which has been the advocate and catalyst for building integrated photovoltaic (BIPV) development within the national framework, adopts solar irradiation data from NASA and Meteonorm.

As reported by NASA [18], that there are about 1000 on-ground meteorological stations spread out over the globe mostly in Central America, Europe and far east as shown in Fig. 1. Yet each station is valid for 30 km^2 area around which covers only 2% of the world's area. For this reason NASA uses satellite based model to estimate the global solar irradiation for other locations worldwide. The images collected from satellites are processed and some parameters like cloud cover and albedo are extracted. Then by using Pinker and Laszlo model which utilizes interpolation and extrapolation, the global solar radiation at any location worldwide is estimated starting from 1° latitude to 180° and from 1° longitude to 360°.

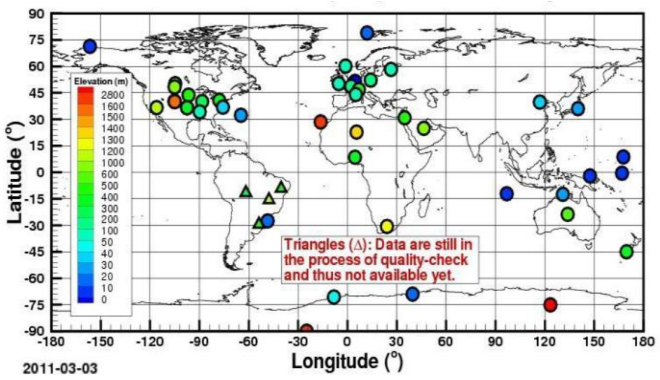

Fig.1 Location of ground stations for NASA meteorological database [18]

Table I shows the meteorological data obtained from NASA for Kuala Lumpur (KL) at latitude 3.139 degree north and longitude 101.69 degree east.

As can be seen from Table I, the data provided by NASA for solar radiation (G) is monthly day-average based which does not give a real indication on the variation of the solar radiation over the day. The ambient temperature (T_a), relative humidity (RH), and wind speed (W_s) are also in monthly basis i.e., 24 hour average. These data may be significant for some applications but not for solar energy that requires data during daytime only.

TABLE I
METEOROLOGICAL DATA OBTAINED FROM NASA FOR KL

Month	T_a (°C)	G (kWh/m^2/day)	RH (%)	W_s (m/s)
January	25.1	4.79	77.5	3.1
February	25.7	5.37	74	2.6
March	25.9	5.42	77.6	2.3
April	25.9	5.27	82.2	1.6
May	26	5.11	83	1.5
June	25.6	4.98	82.8	2.2
July	25.3	4.92	83.1	2.2
August	25.4	4.87	83	2.4
September	25.5	4.88	82.6	1.9
October	25.6	4.77	82.1	1.7
November	25.4	4.36	83.1	2.3
December	25	4.17	81.7	3.1
Year Average	25.53	4.90	81.05	2.24

This article undertakes the mission of investigation about weather database used in solar energy applications. 5-years hourly records of solar radiation, ambient temperature and wind speed for six sites in Malaysia were obtained from MMD [19] and compared with NASA database.

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III. METEOROLOGICAL PARAMETERS DATABASE FROM MMD

The total daily solar insolation unit given in kWh/m^2 per day is sometimes referred to as "Peak Sun Hours" or PSHs. The PSHs refer to the solar irradiation which a particular location would receive if the sun were shining at its maximum value for a certain number of hours. Since the peak solar radiation is 1 kW/m^2, the number of PSHs is numerically identical to the total average daily solar insolation. For example, a location that receives 5kWh/m^2 per day can be said to have received 5 hours of sun per day at 1 kW/m^2. Being able to calculate the PSHs is useful because PV modules are often rated at an input rating of 1 kW/m^2.

In this paper, an investigation has been conducted on the data obtained from NASA and the ones obtained from real measurements for 6 cities around Peninsular Malaysia (KL, Johor Bahru (JB), Malacca, Ipoh, Kuantan, and Bayan Lepas). Table II tabulates a typical 1-day (January 1st, between years 2005-2009) hourly solar radiation data for KL and the last column represents the average of the 5 years data at every specific hour. Hence, the average full-year data is the adopted solar radiation database for KL which is called Average Reference Year (ARY). This ARY is used to calculate the solar energy potential for KL. It is finally used to predict the output of any system installed at KL. Table III lists a 1-day sample of hourly ARY data of T_a, G, and W_s for KL.

TABLE II
TYPICAL 1-DAY DATA FOR GLOBAL SOLAR RADIATION (Wh/m^2) FROM MMD FOR KL

Hour	2005	2006	2007	2008	2009	Average (adopted)
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	11.11	11.11	5.55	0	5.55
8	41.66	44.44	86.11	200	8.33	76.11
9	130.55	166.66	197.22	475	122.22	218.33
10	372.22	333.33	555.56	763.89	286.11	462.22
11	488.88	530.55	652.78	930.56	494.44	619.44
12	350	650	616.67	969.44	747.22	666.67
13	341.66	736.11	605.56	513.89	594.44	558.33
14	205.55	772.22	711.11	633.33	438.89	552.22
15	244.44	363.89	438.89	244.44	533.33	365
16	97.22	497.22	72.22	102.78	405.56	235
17	105.55	0	52.78	127.78	366.67	130.56
18	50	0	38.89	83.33	119.44	58.33
19	0	0	0	0	52.78	10.56
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0

TABLE III
1-DAY REAL DATA FROM THE ADOPTED AVERAGED YEAR FOR G, T_a, AND W_s FOR KL

Hour	T_a (^{o}C)	G (kWh/m^2)	W_s (m/s)
6	24.7	0	1.1
7	24.7	0.0055	0.5
8	25.6	0.0761	1.0
9	26.9	0.2183	1.5
10	28.4	0.4622	1.8
11	29.7	0.6194	2.0
12	30.4	0.6667	1.9
13	30.4	0.5583	2.3
14	30.4	0.5522	2.3
15	29.5	0.3650	3.3
16	28.0	0.2350	2.5
17	27.0	0.1305	1.5
18	26.7	0.0583	1.6
19	25.9	0.0105	1.9

On the other hand, an adopted full-year 8:00 -18:00 hourly data for T_a, G and Ws for six locations around Malaysia are shown in Figures 2-4. Fig.2 clearly shows that the day's ambient temperature ranges between 23 ^{o}C and 35 ^{o}C at all selected sites while the average daily ambient temperature is 29 ^{o}C. As can be observed from Fig. 3, solar radiation in Malaysia ranges from 0 W/m^2 in overcast weather and exceeds 1000 W/m^2 in sunny day. From the historical data, it was recorded that on the March 18th,2008, the maximum solar radiation measured was at 1661.11 W/m^2 in KL. It is worth mentioning that for all selected sites, the global solar radiation can easily reach 1100 W/m^2 during the clear sky. Maximum sun hours of a day were also recorded in the Subang-KL area with 8.13 hours of full sun. That was on March 27th, 2007. Adopted full-year daytime hourly wind velocity is depicted in Fig. 4. The wind speed for Malaysia ranges from 0 m/s and could

ADVANCED ELECTRICAL AND ELECTRONICS ENGINEERING AND SCIENTIFIC JOURNAL
VOLUME1-NO 1- JANUARY 2017. WWW.AEEESJ.COM
ISSN: 2520-7539

reach up to 7 m/s while the average is 3 m/s.

Table IV shows the trend and deviation of the real data comparing with NASA data in terms of the total annual sun hours. The yearly sun hours adopted is the summation of the kWh/m^2 of total hours for the particular year. By comparing the two databases, the significant difference between NASA and the real measurements is identified. The discrepancy here is that the data from NASA is satellite based and the records are estimated depending on the latitude and longitude thus the measurements are not imported from ground sensors. Consequently, the adopted hourly meteorological data set is important for studying the performance of the PV system installed and the accuracy of its prediction of energy output.

Tables V and VI show the yearly day-average data for ambient temperature and wind speed. It can be seen that the yearly differences of day-average real data for T_a and W_s are very small. Comparing the real 24-hours average data with NASA's data which are also day-average, it can clearly be seen that the ambient temperature database retrieved from NASA are underestimated while for wind speed are overestimated. Since the solar radiation is not available at night, the daytime data from 8:00 am until 18:00 pm should only be considered in solar energy applications. Therefore, 11 hours daytime data for T_a and W_s were adopted. These are the two important factors that have great impacts on solar energy particularly in predicting the PV module temperature (T_m).

IV. CALCULATION OF HOURLY PV SYSTEM AC ENERGY OUTPUT

The use of appropriate performance model facilitates the evaluation and comparison of PV systems that may differ with respect to technology, design or geographic location. The energy output of PV system can be calculated hourly utilizing the recorded climatological parameters such as solar radiation and ambient temperature.

Generally, the calculation of energy output of any PV system involves four important factors; the capacity of the installed PV system (kWp), the solar radiation data of a selected site (kWh/m2), calculation of the PV module temperature (^{o}C), and other system losses in per unit. The equation for estimating the PV system energy output can be expressed as [20-22] :

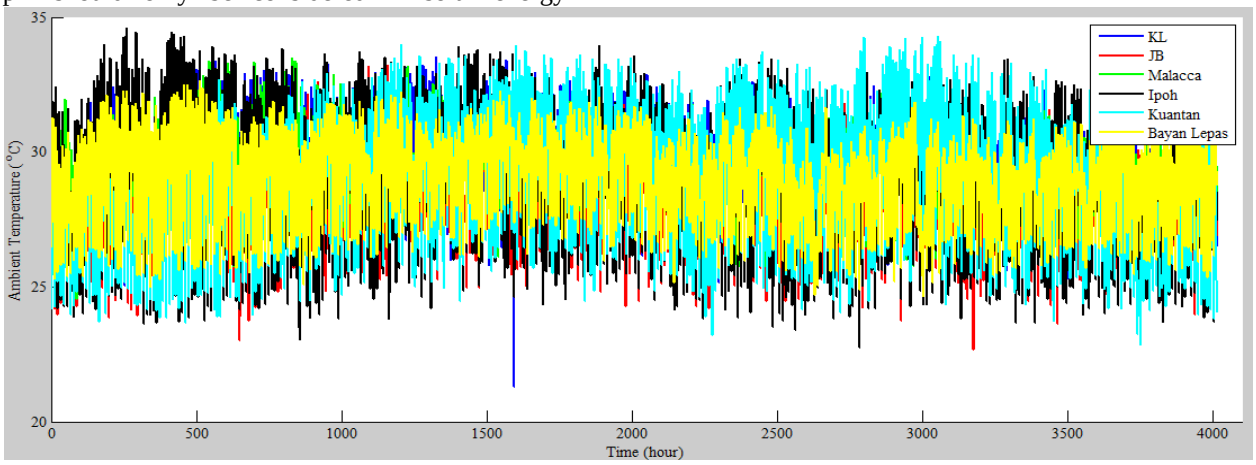

Fig. 2 Adopted full-year hourly ambient temperature data at six locations in Malaysia

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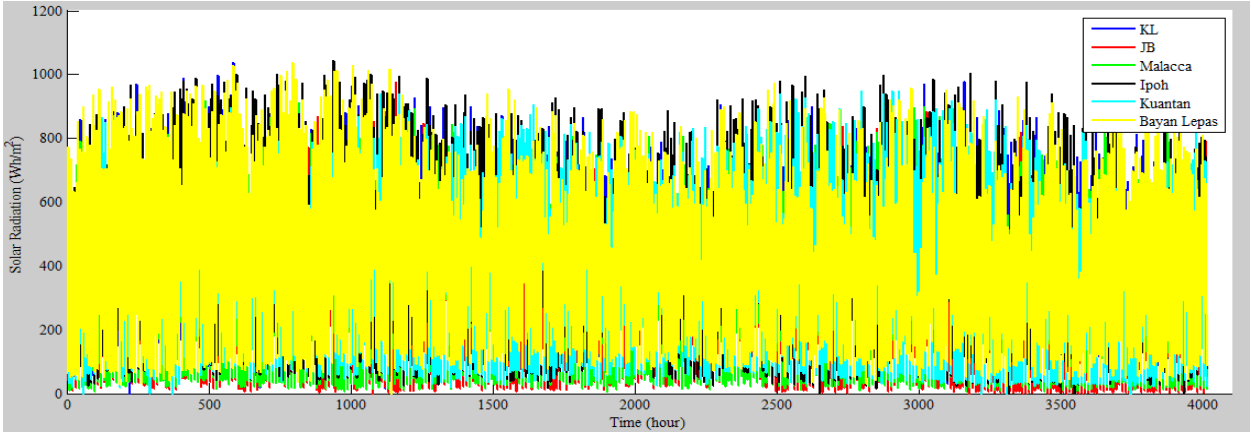

Fig. 3 Adopted full-year hourly solar radiation data at six locations in Malaysia

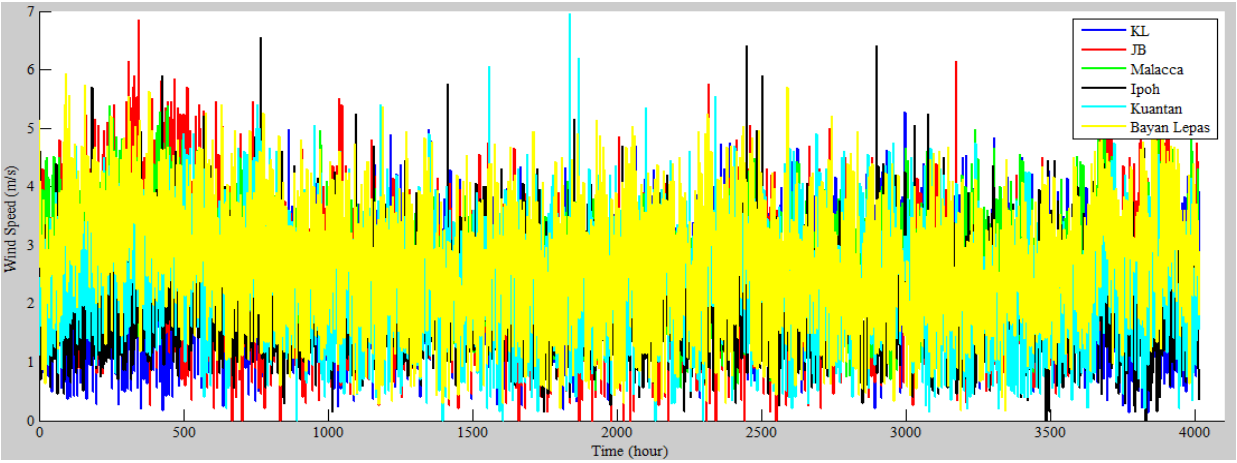

Fig. 4 Adopted full-year hourly wind speed data at six locations in Malaysia

TABLE IV
TOTAL ANNUAL GLOBAL SOLAR RADIATION (kWh/m²/year): A COMPARISON BETWEEN REAL DATA AND NASA'S DATA

City	2005	2006	2007	2008	2009	Average	NASA
KL	1605.62	1608.15	1833.36	1827.72	1857.59	**1746.44**	**1791.85**
JB	1530.19	1327.39	1286.66	1279.25	-	**1365.36**	**1667.20**
Malacca	1764.45	1657.43	1664.22	1613.36	-	**1674.87**	**1710.60**
Ipoh	-	-	1785.07	1810.53	-	**1797.80**	**1735.20**
Kuantan	-	-	1672.25	1665.43	-	**1668.84**	**1747.90**
Bayan Lepas	-	-	1822.97	1827.02	1818.91	**1822.97**	**1895.70**

TABLE V
YEARLY DAY-AVERAGE AMBIENT TEMPERATURE BETWEEN HISTORIC REAL DATA AND NASA'S DATA

Location	Average for	2005	2006	2007	2008	2009	Average	NASA

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KL	24 hr	27.8	27.2	27.3	27.1	27.7	27.4	25.53
	11 hr	30.0	29.4	29.4	29.3	29.5	29.5	
JB	24 hr	-	26.50	26.05	25.92	-	26.16	25.65
	11 hr	-	28.82	28.20	28.07	-	28.36	
Malacca	24 hr	27.76	27.38	27.33	27.33	-	27.45	25.74
	11 hr	29.90	29.51	29.40	29.35	-	29.54	
Ipoh	24 hr	-	-	26.86	26.59	-	26.73	24.91
	11 hr	-	-	29.38	29.11	-	29.24	
Kuantan	24 hr	26.80	26.86	26.86	26.81	-	26.84	26.37
	11 hr	-	-	29.08	29.20	-	29.14	
Bayan Lepas	24 hr	-	-	27.62	27.55	27.75	27.64	25.98
	11 hr	-	-	29.36	29.32	29.27	29.32	

TABLE VI
YEARLY DAY-AVERAGE WIND SPEED (M/S) BETWEEN HISTORIC REAL DATA AND NASA'S DATA

Location	Average for	2005	2006	2007	2008	2009	Average	NASA
KL	24 hr	1.47	1.30	1.56	1.55	1.49	1.47	2.24
	11 hr	2.38	2.15	2.42	2.43	2.26	2.33	
JB	24 hr	-	-	1.49	1.53	-	1.51	2.54
	11 hr	-	-	2.40	2.44	-	2.42	
Malacca	24 hr	1.88	1.84	1.92	1.94	-	1.89	1.93
	11 hr	2.66	2.54	2.64	2.69	-	2.63	
Ipoh	24 hr	-	-	1.66	1.61	-	1.63	2.4
	11 hr	-	-	2.02	1.97	-	1.99	
Kuantan	24 hr	1.52	1.66	1.58	1.54	-	1.56	2.73
	11 hr	-	-	2.35	2.36	-	2.35	
Bayan Lepas	24 hr	-	-	1.98	1.91	1.90	1.93	2.21
	11 hr	-	-	2.83	2.82	2.69	2.78	

E_{out}= PV system capacity × Sun Hour × Derate factor of PV module temperature × Derate factor of system losses

Where sun hour is the measured solar radiation in (kWh/m^2), derate factor of PV module temperature is an efficiency factor due to module temperature increase. Derate factor of system losses is an efficiency factor which includes inverter losses, soiling, wiring losses and PV module mismatch. As mentioned earlier, most of the available commercial software such as PVWatts and RETScreen import the solar radiation data from NASA which are given in monthly day-average sun hours. In the proposed procedure, ARY of real hourly solar radiation data is utilized instead. The total predicted yearly energy output is actually the summation of hourly energy yield rather than monthly based energy yield.

V. CONCLUSION

The discrepancy between real records of three important meteorological parameters and the data provided by NASA was identified. Hourly measurements of global solar radiation, ambient temperature and wind speed were obtained for six locations in Malaysia from Malaysia Meteorological Department between years 2005-2009. The difference identified between the two databases is interpreted as the data from NASA is satellite based and the records are estimated depending on the latitude and longitude thus the measurements are not imported from ground sensors. The historical data obtained from MMD can be modeled for predicting weather parameters particularly solar radiation for other locations in Malaysia and similar climate countries. The real database obtained can also be useful for predicting the energy output of PV systems in the pre-installation phase in terms of feasibility and performance analysis of the PV system.

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ISSN: 2520-7539

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