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Output Characteristics of Photovoltaic Module in Medan Based on Estimated Solar Irradiance Using Hargreaves Method for Application Assessment of Transformerless Photovoltaic Inverter

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Abstract. Referring to the Department of Meteorology, Climatology and Geophysics in Medan, North Sumatera, there is missing data of solar irradiance for the year of 2014. This paper is presented to estimate the solar irradiance using Hargreaves method based on the latitude and the monthly minimum and maximum temperature of the missing data. The temperature and estimated solar irradiance were applied to observe the output characteristics of a photovoltaic (PV) module. These parameters were used to assess the potential of the transformerless photovoltaic inverter (TPVI). Simulation results show that the average monthly solar irradiation was 6.98 kWh/m^2 using Hargreaves method. This was more than twice greater the normal solar radiation (3 kWh/m^2), which indicated that the sky in Medan was clear and had very high solar irradiation intensity for the year of 2014. These findings suggest there are a big potential of solar irradiation for generating the TPVI in Medan.

INTRODUCTION

Solar radiation is a primary driver for many physics, chemical and biology processes on the earth's surface, and complete and accurate solar radiation data at a specific region are of considerable significance for such research and application fields as architecture, industry, agriculture, environment, hydrology, agrology, meteorology, limnology, oceanography, ecology and solar energy system [1, 2].Solar radiation data is the most important component to estimate output of photovoltaic systems [3, 4, 5]. Solar radiation can be classified into four categorizes [6]. They are low solar radiation (below 2.6 kWh/m^2), moderate solar radiation (between 2.6 kWh/m^2 to 3 kWh/m^2), high solar radiation (between 3 kWh/m^2 - 4 kWh/m^2) and very high solar radiation (above 4 kWh/m^2). It is important to know the sky condition and its potential towards photovoltaic (PV) application in Medan, Indonesia.

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Nomenclatures

R_S	Solar radiation
R_a	Extraterrestrial radiation
T_{max}	Maximum temperature
T_{min}	Minimum temperature
a	Empirical coefficient
V_{min}	Minimum open voltage
V_{max}	Maximum open voltage
α_{min}	Minimum solar irradiance
α_{max}	Maximum solar irradiance
T_N	Nominal temperature
I_{sc}	Short circuit current
V_{MPP}	Open circuit voltage at maximum peak point
I_{MPP}	Current at the maximum peak point
TC_i	Coefficient of temperature for the short circuit current
b	PV model fixed parameter
$I(\alpha, T, V)$	Circuit current as function of solar irradiation, temperature and voltage
$V_{oc}(\alpha, T)$	Open circuit voltage as function of solar irradiation and temperature

Abbreviations

PV	Photovoltaic
TPVI	Transformerless photovoltaic inverter
STC	Standard Test Condition

The best solar radiation data at the place of interest would be that measured at this specific site continuously and accurately over the long term. However, due to financial, maintenance, calibration requirement of the measuring equipment or institutional limitations, these data are absent, incomplete or inaccessible in most areas of the world [1, 2, 7, 8].

A transformerless photovoltaic inverter (TPVI) is operated directly by PV array [9, 10, 11]). A PV array voltage of 220 V is needed to run it. The output power of TPVI depends on the output power of the PV array and it also depends on the solar radiation and temperature. Hence, if the TPVI is to be installed in one particular area, the information of the solar radiation is vital to decide whether it is worthwhile of such installation. The solar irradiation above 3 kWh/m^2 or solar irradiance above 300 W/m^2 is considered suitable to run the TPVI [12, 13].

It is revealed that from the department of Meteorology, Climatology and Geophysics in Medan, North Sumatera, the solar radiation was not recorded in 2014. This missing data seriously hinders the progress of much research that requires solar radiation as a key driving input, especially to estimate output of photovoltaic systems. Therefore, various methods have been explored in order to estimate, with reasonable accuracy, the solar radiation from other available meteorological data. One of the models used is Hargreaves method. The estimation is based on the latitude and the monthly minimum and maximum temperature in Medan. The temperature and estimated solar irradiance can be applied to observe the output characteristics of the PV module. These parameters can be used to assess the potential of the TPVI installation.

METHODOLOGY

This document was prepared using the AIP Proceedings template for Microsoft Word. It provides a simple example of a paper and offers guidelines for preparing your article. Here we introduce the paragraph styles for Level 1, Level 2, and Level 3 headings. Please note the following:

Latitude of Medan

Medan is the capital city of the North Sumatera province in Indonesia. Located on the northern coast, Medan is the fifth largest city in Indonesia behind Jakarta, Surabaya, Bandung, Bekasi and the largest Indonesian city outside Java. Medan has latitude of 3.58^0 N and land area of 265.1 km² as shown in FIGURE 1 [14].

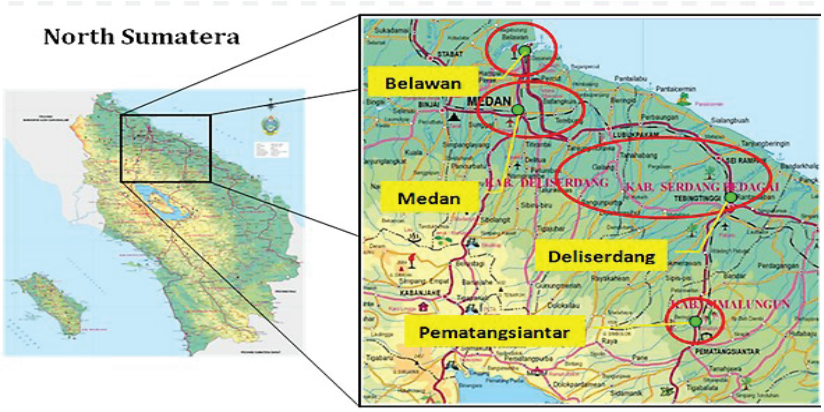

FIGURE1. Map of Medan, North Sumatera, Indonesia

Hargreaves method

Hargreaves and Samani (1985) [12] first suggested that the solar radiation (R_S) can be estimated from the difference between maximum and minimum of air temperature using a simple equation;

$$R_S = a.R_a(T_{\max} - T_{\min})^{0.5} \quad (1)$$

where R_S is in MJ.m^{-2}.d^{-1}; T_{max} and T_{min} are mean daily maximum and minimum air temperature , in ^{0}C, respectively; $R_a$is extraterrestrial radiation, in MJ.m^{-2}.d^{-1} which is a function of latitude and day of the year; and a is an empirical coefficient, the value of a to be 0.16 and 0.19 for interior and coastal regions.

The estimated solar irradiation is important to know about the sky condition and its potential towards TPVI generation in Medan, North Sumatera.

Output characteristics of photovoltaic module

The mathematical modelling of open circuit voltage and open circuit current of the performance of PV module follows what was suggested by [15] The application of this model requires the data of minimum open voltage, V_{min} and maximum open voltage, V_{max} in two operation points with low solar irradiation phase, $\alpha_{\min}$ of 200 W/m^2 and high solar irradiation phase, $\alpha_{\max}$ of 1000 W/m^2 at the same nominal temperature, T_N of 25 ^{0}C.

The type of PV module used in the simulation is Kaneka G-SA060 amorphous silicon (a-Si). The performance of PV module observed are the short circuit current I_{sc}, open circuit voltage at maximum peak point, V_{MPP} and current at the maximum peak point, I_{MPP}, all at the STC (standard test condition) as well as the coefficient of temperature for the short circuit current, TC_i and the coefficient of temperature for open circuit voltage, TC_v. The parameter of "*b*" is the PV model fixed parameter. It influences the I-V curve in the maximum power point. The circuit current $I(\alpha, T, V)$ and open circuit voltage $V_{oc}(\alpha, T)$ as function of solar irradiation, temperature and voltage are given by [15].

$$I(\alpha,T,V)=\frac{\alpha}{1000\frac{W}{m^2}}.I_{sc}.\tau_i(T).\left[\frac{1-e^{\left[\frac{V}{b.\left(1+\frac{V_{\max}-V_{\min}}{V_{\max}}.\frac{\alpha-\alpha_{\max}}{\alpha_{\max}-\alpha_{\min}}\right).(V_{\max}+\tau_v(T))}\right]^{-\frac{1}{b}}}}{1-e^{-\frac{1}{b}}}\right] \quad (2)$$

When $I(\alpha,T,V)$ = 0 A, the open circuit voltage is given by

$$V_{oc}(\alpha,T)=\left[1+\frac{V_{\max}-V_{\min}}{V_{\max}}.\frac{\alpha-\alpha_{\max}}{\alpha_{\max}-\alpha_{\min}}\right].\left[V_{\max}+\tau_v(T)\right] \quad (3)$$

$$\tau_i(T)=1+\frac{TC_i}{100\%}.(T-T_N) \quad (4)$$

$$\tau_v(T)=TC_v.(T-T_N) \quad (5)$$

RESULTS AND DISCUSSION

This document was prepared using the AIP Proceedings template for Microsoft Word. It provides a simple example of a paper and offers guidelines for preparing your article. Here we introduce the paragraph styles for Level 1, Level 2, and Level 3 headings. Please note the following:

Monthly minimum, maximum and average temperature in the year of 2014

The difference of temperature is the difference between maximum and minimum air temperature (T_{max} - T_{min}). It affects the solar irradiation (R_S). The solar irradiation is proportional to the difference of temperature, if the value of temperature difference of increases, thus the value of solar irradiation will also increase. Monthly minimum, maximum, difference and average temperature throughout the year of 2014 in Medan, North Sumatera is shown in FIGURE 2.

Based on the minimum temperature bar chart of FIGURE 2, its lowest and average values are 15.80 ^{o}C and 20.04 ^{o}C respectively in August. Based on the maximum temperature bar chart, its highest and average values are 36.8 ^{o}C and 35.23 ^{o}C respectively in June. Based on the difference of temperature bar chart, its lowest, highest and average values were 12.80 ^{o}C in December , 20.20 ^{o}C in August and 15.19 ^{o}C, respectively.

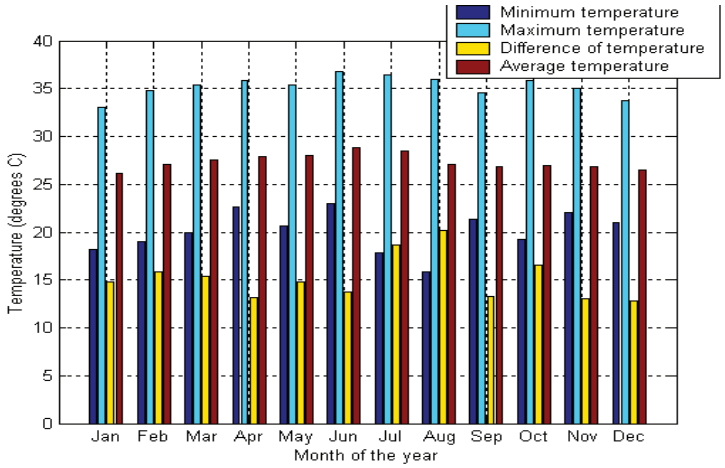

FIGURE 2. Monthly temperature throughout the year of 2014 in Medan

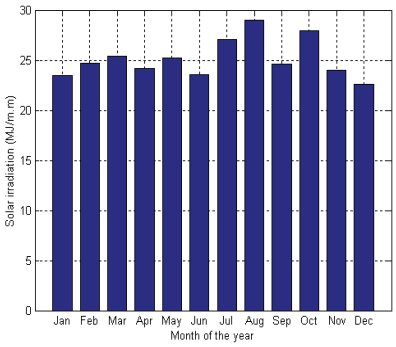

FIGURE 3. Monthly estimated solar irradiation in MJ/m^2

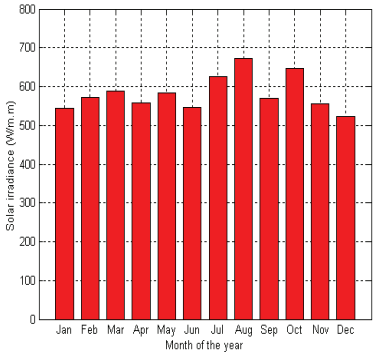

FIGURE 4. Monthly estimated solar irradiance in W/m^2

Monthly solar irradiance in the year of 2014

The monthly estimated solar radiation was based on the minimum and maximum temperature recorded by the Department of Meteorology, Climatology and Geophysics in Medan, North Sumatera is shown in Figs. 3 and 4. The minimum and maximum estimated solar radiation using Hargreaves method were 22.56 MJ/m^2 or 522.19 W/m^2 in December and 29.02 MJ/m^2 or 671.69 W/m^2 in August, respectively.

Output characteristics of PV module for potential assessment of TPVI

The monthly output characteristics of the PV module Kaneka G-SA060 amorphous silicon (a-Si) are shown in Figs. 5, 6, and 7. The output characteristics of the PV module were based on the average monthly temperature and the estimated monthly solar irradiance. The temperature and solar irradiance affected the output characteristics of the PV module. If the temperature was increased and solar irradiation was constant, the open circuit voltage and maximum power of PV module would decrease.

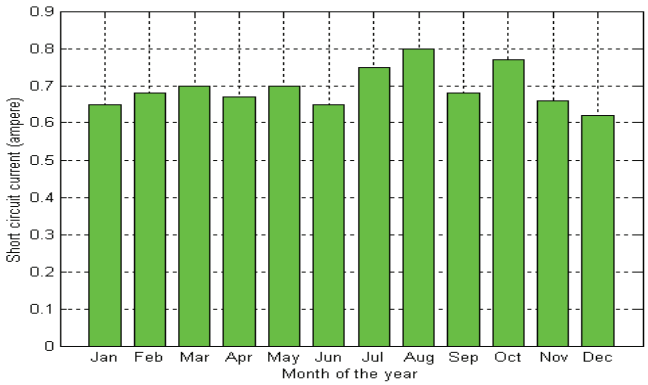

FIGURE 5. Monthly short circuit current of PV module

FIGURE 5 shows the monthly short circuit current of the PV module Kaneka G-SA060 amorphous silicon (a-Si) throughout the year of 2014 in Medan. The minimum and maximum short circuit current were 0.62 A in December and 0.80 A in August.

FIGURE 6 shows the monthly open circuit voltage of the PV module Kaneka G-SA060 amorphous silicon (a-Si) throughout the year of 2014 in Medan. The minimum and maximum open circuit voltages were 76.99 V in December and 80.22 V in August.

FIGURE 7 shows the monthly maximum power of the PV module Kaneka G-SA060 amorphous silicon (a-Si) throughout the year of 2014 in Medan. The minimum and maximum power were 26.17 W in December and 35.63 W in August.

The monthly average temperature and solar irradiance throughout the year of 2014 were 27.37 ^{0}C and 582.01 W/m^2, respectively. The values were applied into Eq. (2) to (5) to obtain the output characteristics of PV module. These parameters were implemented in the I-V and P-V curve as shown in Figs. 8 and 9, respectively. These parameters show that the short circuit current, open circuit voltage and maximum power of the PV module Kaneka G-SA060 amorphous silicon (a-Si) were 0.69 A, 78.84 V and 29.80 W, respectively.

A transformerless photovoltaic inverter (TPVI) operated directly by PV array voltage of 220 V, it means three PV modules (one string) Kaneka G-SA060 amorphous silicon (a-Si) should be connected in series. One string produced the short circuit current of 0.69 A, open circuit voltage of 236.52 V and maximum power of 89.40 W. If the TPVI needed a higher power, thus some strings should be connected in parallel.

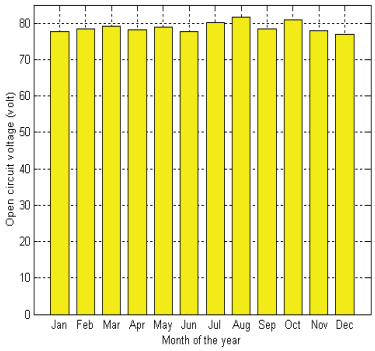

FIGURE 6. Monthly open circuit voltage of PV module

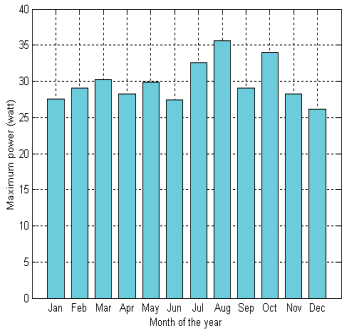

FIGURE 7. Monthly maximum power of PV module

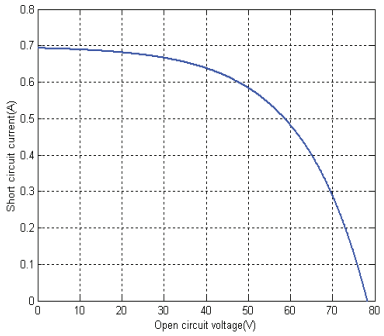

FIGURE 8. I-V curve PV module at the temperature of 27.37 ^{0}C and Solar irradiance of 582.01 W/m^2

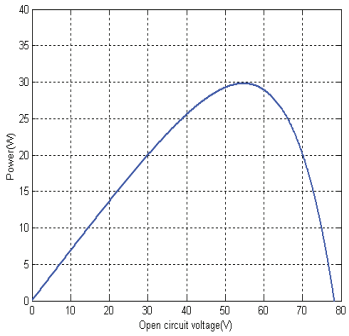

FIGURE 9. P-V curve PV module at the temperature of 27.37 ^{0}C and Solar irradiance of 582.01 W/m^2

CONCLUSIONS

There is missing data of solar irradiance for the year of 2014 in Medan, North Sumatera. The missing data can be estimated using Hargreaves method which is based on the latitude and the monthly minimum and maximum temperature in Medan. the average monthly solar irradiation was 6.98 kWh/m^2 using Hargreaves method. This was more than twice greater the normal solar radiation (3 kWh/m^2), which indicated that the sky in Medan was clear and had very high solar irradiation intensity for the year of 2014. These findings suggest there are a big potential of solar irradiation for generating the TPVI in Medan.

A TPVI operated directly by PV array voltage of 220 V, it means three PV modules (one string) Kaneka G-SA060 amorphous silicon (a-Si) should be connected in series.

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