Energy Analysis on 300W SP Solar Photovoltaic (PV) Generator

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Abstract: The main objective of this paper is to gain insight into the energy achievement of 300W/12V SP photovoltaic generator with the whole year. The amount of photovoltaic energy achievement is based on output power and sunshine hours. The output power of PV is based on solar insolation. To get the maximum output power, the PV panel must be received the maximum solar insolation. When the PV panel is with the best tilt angle, it will be received the maximum insolation. The other factor concerned with PV output power is cell temperature that is connected with ambient temperature. The location on analysis is Insein (latitude = 16.876º N, longitude = 96.117º E), Yangon. Analysis results are presented here and compared with experiment.

Key Words: energy, SP photovoltaic, tilt angle, power, Insein.

1. INTRODUCTION:

Energy consumption is one of the indices in determining the levels of development of a nation. Therefore, availability of energy supply to all sectors of life in any country is crucial for its development. All kinds of energy, particularly electricity which is seriously needed for economic development.

Electricity from the sun is used in rural areas to meet basic electricity needs of a rural community. Today's electricity supply in Myanmar is generated by fuel generators and hydroelectric power plants. However, far-flung areas which are away from National Grids cannot enjoy the electricity generated by these sources. Since Myanmar is a land of plentiful sunshine, especially in central and southern regions of the country, the solar energy could hopefully become the final solution to its energy supply problem. The direct conversion of solar energy into electricity using photovoltaic system has been receiving intensive installation not only in developed countries but also in developing countries [1].

The power delivered by a PV system of one or more photovoltaic cells is dependent on the solar insolation, temperature, and the current drawn from the cells.

2. SOLAR ENERGY:

Solar irradiance is a key driving force of the earth. It is also ultimately the source of all energy supplies except for nuclear energy. Hydroelectric, wind and wave energies are linked to climate, which is also driven by the sun through uneven heating on the earth. Direct conversion of solar irradiance through solar energy systems is obviously linked to the sun as well.

Solar energy is available in abundance in most parts of the world. The amount of solar energy incident on the earth's surface is approximately1.5 x 10^{18} kWh/year [2].

2.1. Altitude Angle of The Sun at Solar Noon

The angle formed between the plane of the equator and a line drawn from the center of the sun to the center of the earth is called the solar declination, δ. It varies between the extremes of ±23.45º [3].

$$\delta = 23.45 \times \sin\left[\frac{360}{365}(n - 81)\right] \tag{1}$$

where ,

δ = solar declination (º)

n = day number

Having drawn the earth-sun system as shown in Fig. 1 also makes it easy to determine a key solar angle, namely the altitude angle β_N of the sun at solar noon. The altitude angle is the angle between the sun and the local horizon directly beneath the sun [3].

$$\beta_N = 90 - L + \delta \tag{2}$$

where,

β_N = altitude angle (º)

L = latitude of the site (º)

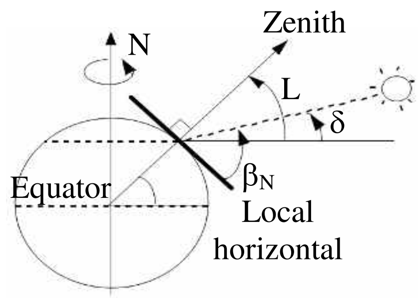

Fig. 1. The altitude angle of the sun at solar noon [3]

The tilt angle that would make the sun's rays perpendicular to the module at noon in Fig. 2 would therefore be:

Tilt = 90 – β_N

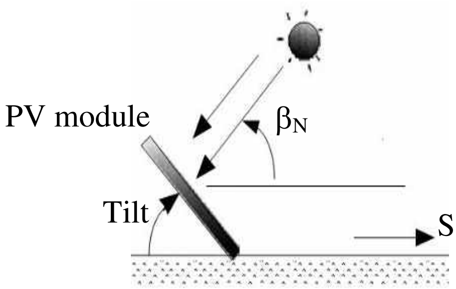

Fig. 2. The tilt angle of the module [3]

2.2. Solar Position at Any Time of Day

The location of the sun at any time of day can be described in terms of its altitude angle β and its azimuth angle φ_s as shown in Fig. 3. By convention, the azimuth angle is positive in the morning with the sun in the east and negative in the afternoon with the sun in the west. Notice that the azimuth angle shown in Fig. 3 uses true south as its reference[3].

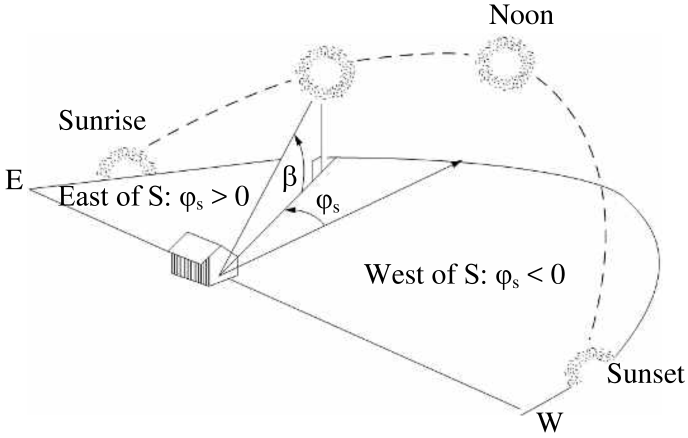

Fig. 3. The sun's position described by its altitude angle and its azimuth angle [3]

The azimuth and altitude angles of the sun depend on the latitude, day number and most importantly, the time of day. The following two equations allow us to compute the altitude and azimuth angles of the sun [3].

$$\sin\beta = \cos L \times \cos\delta \times \cos H + \sin L \times \sin\delta \quad (3)$$

$$\sin\phi_s = \frac{\cos\delta \times \sin H}{\cos\beta} \quad (4)$$

The difference between the local meridian (line of longitude) and the sun's meridian is the hour angle, with positive values occurring in the morning before the sun crosses the local meridian. In the afternoon, the hour angle is negative. Considering the earth to rotate 360º in 24 h, or 15º/h, the hour angle can be described as follows:

$$H = \left(\frac{15°}{\text{hour}}\right) \times \text{(hours before solar noon)} \quad (5)$$

where,

β = altitude angle of the sun (º)

φ_s = azimuth angle of the sun (º)

There is a slight complication associated with finding the azimuth angle of the sun from Equation 4. During spring and summer in the early morning and late afternoon, the magnitude of the sun's azimuth is liable to be more than 90º away from south. Since the inverse of a sine is ambiguous, sin x = sin (180 – x), there is a test to determine whether to conclude the azimuth is greater than or less than 90º away from south. Such a test is

$$\text{if } \cos H = \frac{\tan\delta}{\tan L}, \text{ then } |\varphi_s| \le 90° \text{; otherwise } |\varphi_s| > 90°$$

2.3. Direct-Beam Radiation

The direct-beam radiation passes in a straight line through the atmosphere to the receiver.

The length of the path h_2 divided by the minimum possible path length h_1 is called the air mass ratio, m. As shown in Fig. 4, under the simple assumption of a flat earth the air mass ratio can be expressed as

$$m = \frac{h_2}{h_1} = \frac{1}{\sin\beta} \quad (6)$$

where,

m = air mass ratio

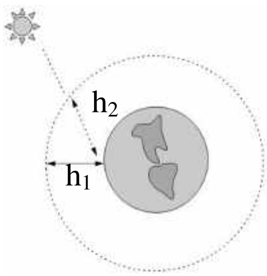

Fig. 4. The length of the path taken by the sun's rays [3]

The value of optical depth k and apparent extraterrestrial flux A are as follows:

$$A = 1160 + 75 \times \sin\left[\frac{360}{365}(n - 275)\right] \quad (7)$$

$$k = 0.174 + 0.035 \times \sin\left[\frac{360}{365}(n - 100)\right] \quad (8)$$

where,

A = apparent extraterrestrial flux (W/m^2)

k = optical depth

The direct-beam radiation I_B can be calculated by using the equation shown below.

$$I_B = A \times e^{-km} \quad (9)$$

where,

I_B = direct-beam radiation (W/m^2)

The translation of direct-beam radiation I_B (normal to the rays) into beam insolation striking a collector face I_{BC} is a simple function of the angle of incidence θ between a line drawn normal to the collector face and the incoming beam radiation shown in Fig. 5. It is given by

$$\cos\theta = \cos\beta \times \cos(\phi_S - \phi_C) \times \sin\Sigma + \sin\beta \times \cos\Sigma \quad (10)$$

$$I_{BC} = I_B \times \cos\theta \quad (11)$$

where,

I_{BC} = beam insolation striking on collector (W/m^2)

θ = incidence angle

φ_c = collector azimuth angle

Σ = tilt angle

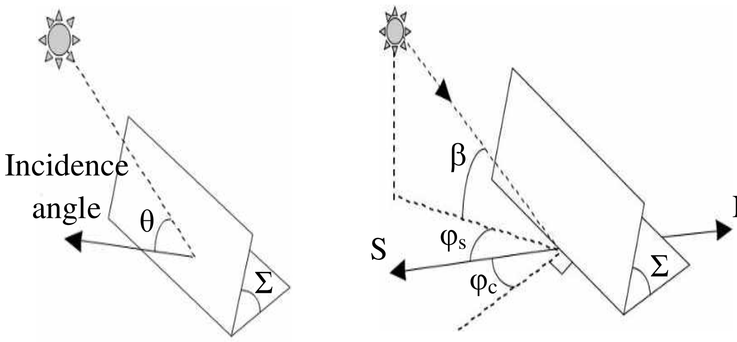

Fig. 5. The collector and its associated angles [3]

2.4. Diffuse Radiation

Diffuse radiation has been scattered by molecules and aerosols in the atmosphere. The component of the radiation coming from all direction in the sky is diffused.

$$I_{DH} = C \times I_B \quad (12)$$

where,

I_{DH} = diffuse radiation on horizontal surface (W/m^2)

C = sky diffuse factor

$$C = 0.095 + 0.04 \times \sin\left[\frac{360}{365}(n - 100)\right] \quad (13)$$

The following expression is used to find the value of diffuse radiation on the collector,

$$I_{DC} = I_{DH} \times \left(\frac{1+\cos\Sigma}{2}\right) = C \times I_B \times \left(\frac{1+\cos\Sigma}{2}\right) \quad (14)$$

where,

I_{DC} = diffuse radiation on the collector (W/m^2)

It is common to consider separately the direct (or beam) radiation coming from solar disk and the diffuse radiation from elsewhere in the sky with their sum known as ‘global’ radiation [2].

3. PHOTOVOLTAIC (PV) GENERATOR:

An assessment of the operation of solar cells and the design of power systems based on solar cells must be based on the electrical characteristics, that is, the voltage-current relationships of the cells under various levels of radiation and at various cell temperatures [4].

Fig. 6 is an equivalent circuit that can be used for an individual cell, a module consisting of several cells, or an array consisting of several modules. This circuit requires that five parameters be known: the light current I_L, the diode reverse saturation current I_o, the series resistance R_s, the shunt resistance R_{sh}, and a curve fitting parameter *a*. At a fixed temperature and solar radiation, the I-V characteristic of this model is given by

$$I = I_L - I_D - I_{sh}$$

$$I = I_L - I_o \left\{ \exp\left[{(V + IR_s)}/{a} \right] - 1 \right\} - \frac{V + IR_s}{R_{sh}} \quad (15)$$

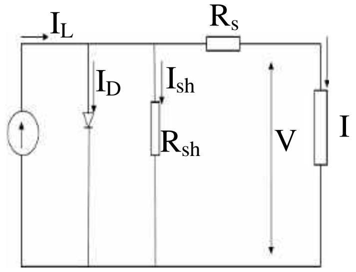

Fig 6. A equivalent circuit for PV generator

The power is given by

$$P = I \times V \quad (16)$$

When the voltage, V is zero, short circuit conditions exist. The current at this point is called short circuit current, I_{sc}. When the current, I is zero; the voltage is at its maximum. This voltage is called open circuit voltage, V_{oc}. The voltage at the point where the power supplied reaches its maximum is denoted as V_{mp} and the current at this point as I_{mp}. The manufacturers of PV modules usually provide measured values of V_{oc}, I_{sc}, V_{mp} and I_{mp} at reference conditions. The reference conditions usually are at an incident solar radiation of $1000 W/m^2$ and an ambient temperature of 25ºC. With these measured values, the four parameters I_L, I_o, R_s and *a* can be evaluated. R_{sh} is assumed to be infinite and therefore the last term in Equation 15 is neglected [5].

At short-circuit conditions, the diode current is very small and the light current is equal to the short circuit current :

$$I_L = I_{sc} \quad (17)$$

At open circuit conditions, the load current, I, is zero and the 1 in Equation 15 is small compared to the exponential term so that

$$I_o = I_L \exp\left[-{V_{oc}}/{a} \right] \quad (18)$$

The series resistance can be calculated from :

$$R_s = \frac{a \ln\left(1 - \frac{I_{mp}}{I_L}\right) - V_{mp} + V_{oc}}{I_{mp}} \quad (19)$$

The PV modules manufacturers also provide the temperature coefficients for the short circuit current, $\mu_{I,sc}$ and the open circuit voltage, $\mu_{V,oc}$. With these coefficients known, we can now decipher the values of the curve fitting parameter at reference conditions. The relationship is shown as:

$$a_{ref} = \frac{\mu_{V,oc} T_{c,ref} - V_{oc,ref} + \varepsilon N_s}{\frac{\mu_{I,sc} T_{c,ref}}{I_{L,ref}} - 3} \quad (20)$$

where; ε is the band gap energy (1.12 eV for silicon and 1.35 eV for gallium arsenide), N_s is the number of cells in the PV array, a_{ref} is the curve fitting parameter at reference conditions, $T_{c,ref}$ is the cell temperature at reference conditions, $I_{L,ref}$ is the light current at reference conditions, μ_{Isc} is the temperature coefficients for the short circuit current, μ_{Voc} is the temperature coefficients for the open circuit voltage [5].

An increasing temperature leads to decreased open circuit voltage and slightly increased short circuit current. In order for the model to reproduce these effects, it is necessary to know how the model parameters I_o, I_L and *a* vary with temperature. The series resistance R_s is assumed independent of temperature in this model. Townsend (1989) showed that the following equations are good approximations for many PV modules [4]:

$$\frac{a}{a_{ref}} = \frac{T_c}{T_{c,ref}} \quad (21)$$

$$I_L = \frac{G_T}{G_{T,ref}}\left[I_{L,ref} + \mu_{I,sc}(T_c - T_{c,ref})\right] \quad (22)$$

$$\frac{I_o}{I_{o,ref}} = \left(\frac{T_c}{T_{c,ref}}\right)^3 \exp\left[\frac{\varepsilon N_s}{a_{ref}}\left(1 - \frac{T_{c,ref}}{T_c}\right)\right] \quad (23)$$

where; G_T is the solar insolation (W/m^2), G_{Tref} is the solar insolation at reference conditions (W/m^2), T_c is the PV cell temperature (ºC), I_{oref} is the diode reverse saturation current at reference conditions (A).

An energy balance on a unit area of module which is cooled by losses to the surroundings can be written as

$$\eta G_T A_s = G_T A_s \alpha\tau - U A_s (T_c - T_a) \quad (24)$$

From Equation 24,

$$T_c = T_a + \left(\frac{G_T \alpha\tau}{U}\right)\left(1 - \frac{\eta}{\alpha\tau}\right) \quad (25)$$

From NOCT (nominal operation cell temperature) condition $\frac{\alpha\tau}{U} = 0.0325$ K- m^2/W, $\alpha\tau = 0.9$ (Used by all solar panel manufacturers).

Substituting these values into Equation 25;

$$T_c = T_a + (0.0325 G_T)\left(1 - \frac{\eta}{0.9}\right) \quad (26)$$

Equation 26 shows a relationship between the cell temperature, T_c, the ambient temperature, T_a, the insolation level, G_T and the efficiency of the solar panel, η.

4. SPECIFICATION DATA:

The specification data for 300 W/12V SP photovoltaic generator and the mean maximum average temperature data for Insein, Yangon from Kaba Aye station of Department of Meteorology and Hydrology are shown in Table I and II.

Table I

300W/12V SP Photovoltaic Specification

Max: power at STC	300 W / 12 V
Max: power voltage , V_m	18.2 V
Max: power current, I_m	16.52 A
Open circuit voltage , V_{oc}	22.8 V
Short circuit current , I_{sc}	17.3 A
Module efficiency (%)	15.46 %
No. solar cell	36
NOCT temp:	46 ºC
Temp: coeff: of I_{sc}	6.574×10^{-3} A/K
Temp: coeff: of V_{oc}	-0.07752 V/K

Table II

Mean Maximum Temperature Data for Insein, Yangon

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2015	32.7	35.0	37.8	38.1	35.9	32.3	31.7	31.2	32.2	32.4	34.1	33.3
2016	31.6	34.4	36.7	38.5	37.1	31.7	31.8	30.2	-	-	-	-

5. METHODOLOGY:

The ways to find the tilt angle, solar insolation, voltage-current curve, output power and energy of photovoltaic generator are shown in the following flowchart.

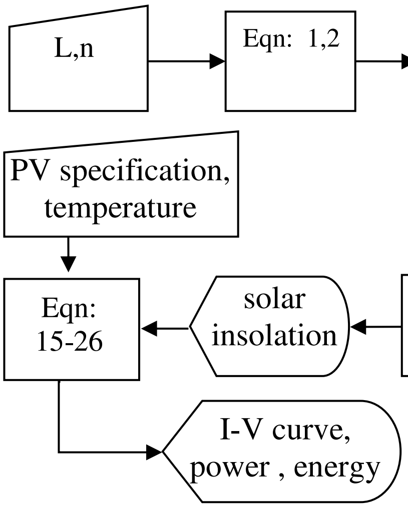

Fig 7 . The flowchart of analysis

6. RESULT AND DISCUSSION:

The solar insolation received from collector is changed with the tilt angle of the collector. The tilt angle is varied with day number, i.e. with month. The various tilt angle with day number is shown in Fig. 8.

In Fig.8, the tilt angle varied with month. Thus, the tilt angle for January is the best tilt angle for this month. It may be the best for other month, i.e. a year or may not be.

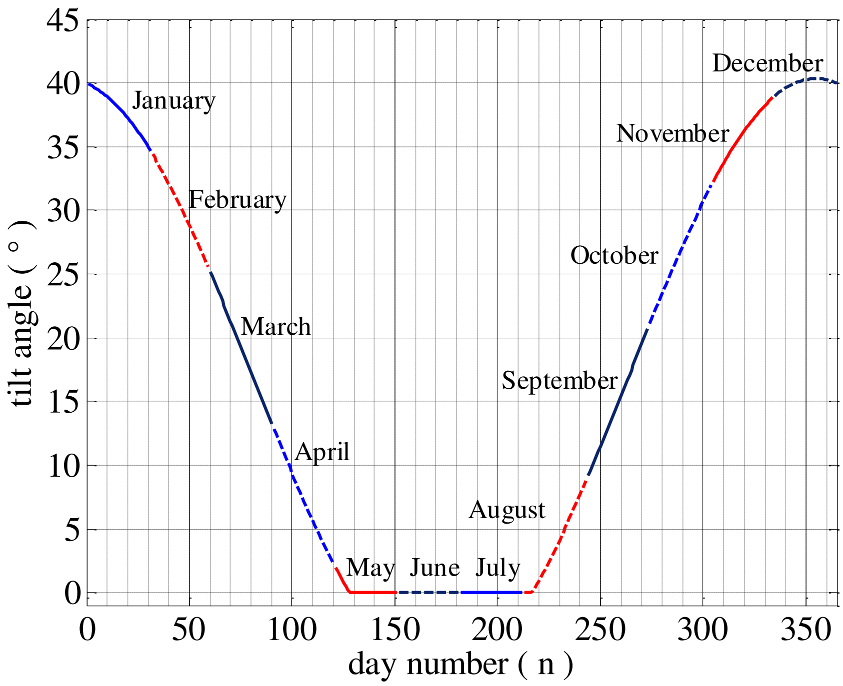

Fig 8 . The tilt angle of the collector with day number at solar noon

For fixed axis solar system, the best tilt angle is very important. At this angle, the maximum insolation is achieved in a whole year. In Fig. 9, the total average insolation is changed with the tilt angle. According to the Fig. 9, the best tilt angle is 17º.

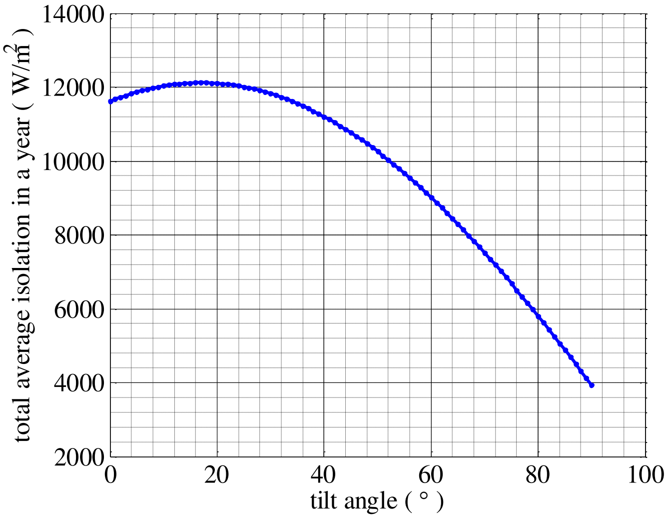

Fig 9. The tilt angle with total average insolation in a year at solar noon

The solar insolation is varied with day number, i.e., with month. The solar insolation variation with month is shown in Fig. 10.

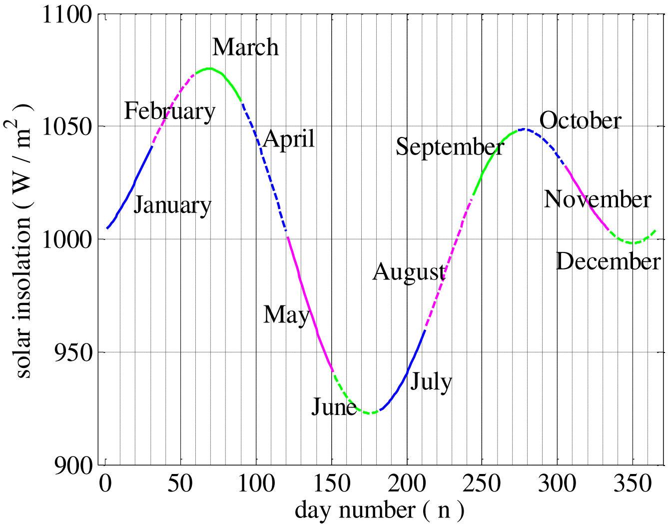

Fig 10. The solar insolation with day number for tilt angle 17° at solar noon

The current-voltage characteristics of a photovoltaic module is changing with ambient temperature and solar insolation. The following Fig. 11 and 12 show the current-voltage characteristics for one month and a year at solar noon.

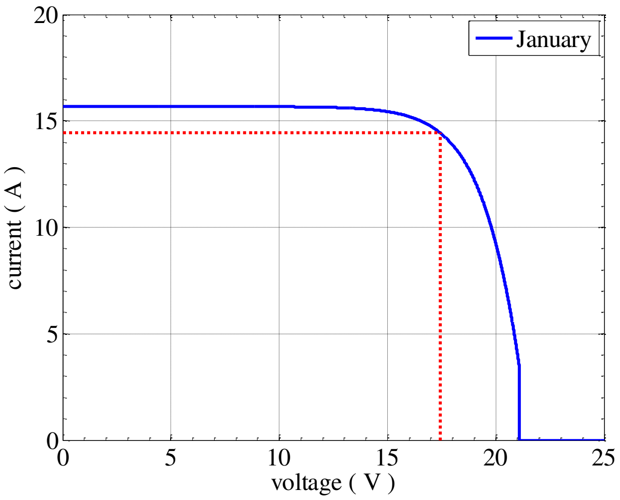

Fig 11. The current and voltage characteristics of PV for January

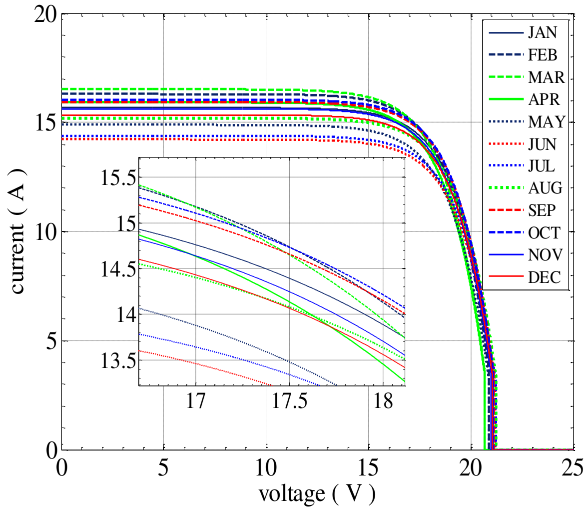

Fig 12. The current and voltage characteristics of PV for a year

The operating current and voltage can be get from current-voltage characteristics in Fig. 11. The power is achieved from this operating current and voltage. The output power for 300W/12V photovoltaic generator is shown in Fig. 13.

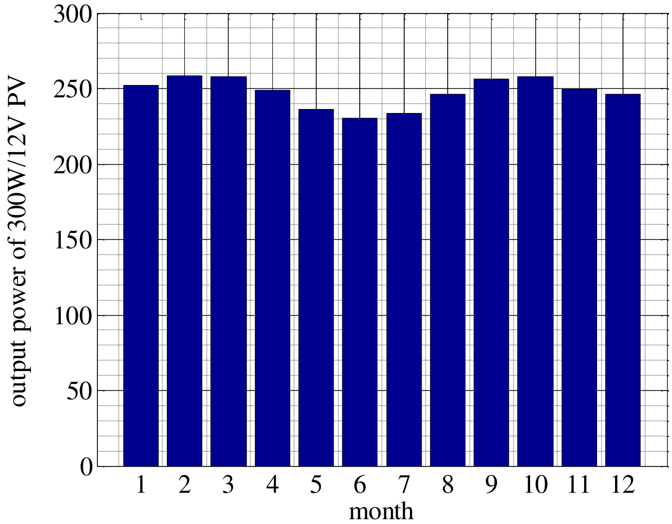

Fig 13. The output power of 300W/12V PV with month

The energy achievement from PV is depended on sunshine hours. The Fig. 14 shows the energy achievement with sunshine hours.

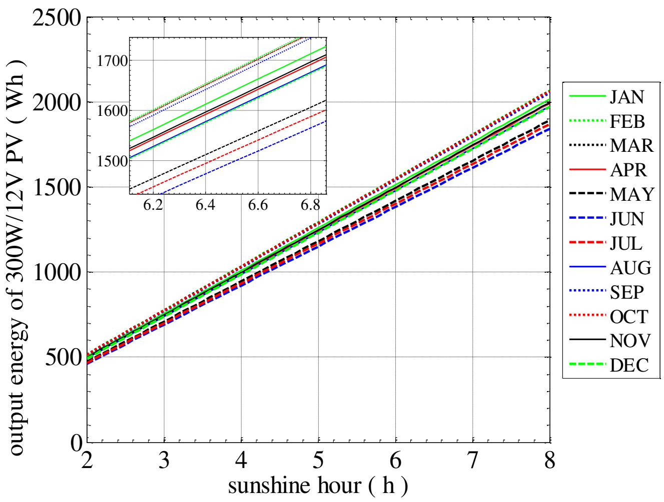

Fig 14. The output energy of 300W/12V PV with sunshine hour

7. Experiment Work

The experiment is carried out in 28 July 2016 within 9 A.M to 3 P.M. The PV is connected with resistant box (1.5 Ω) and then the current and voltage can be read with multi-meter. In this way, the data are collected. This data are depended on resistance of the resistant box. From this data, the power can be calculated. The experiment setup (Σ=17,φ_C = 0) is shown in Fig. 15.

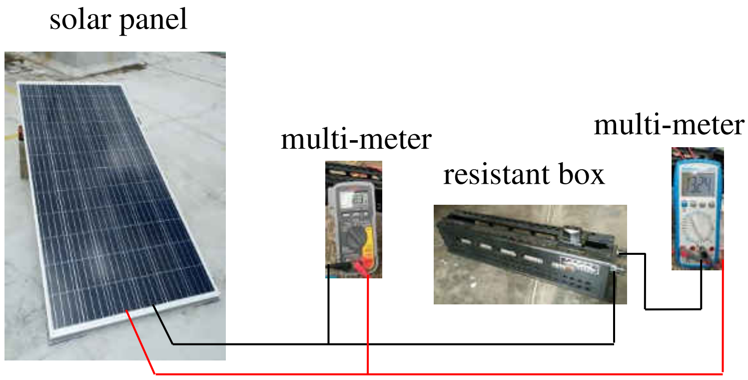

Fig 15. The schematic diagram of experiment setup

The Fig.16 describes the power output of 300W/12V PV on theory and experiment work.

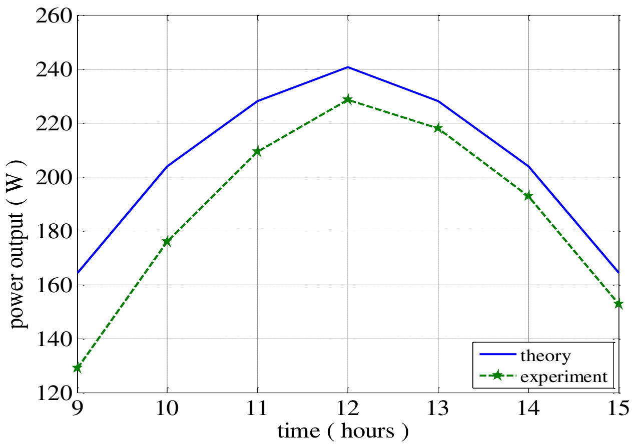

Fig 16. The output power of 300W/12V PV with hour

8. CONCLUSIONS:

It is very important to find the best tilt angle to get the maximum output power of PV in a fixed axis system.

According to the results, the best tilt angle for PV generator is 17º for Insein, Yangon. In this location, the solar insolation is changing around 925 W/m^2 to 1075 W/m^2 . The minimum output power is 230.2 W found in June and the maximum power is 258.3 W found in February.

In the experiment work, the output power of PV is 228.42 W at solar noon and 240.67 W in theory.

Everywhere away from National Grids can enjoy the electricity generated by solar energy

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