ICSE
2009

PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON SCIENCE AND ENGINEERING

Volume - 1

Electronics
Electrical Power
Information Technology
Engineering Physics

Sedona Hotel, Yangon, Myanmar
December 4-5, 2009

PROCEEDINGS OF THE FIRST INTERNATIONAL CONFERENCE ON SCIENCE AND ENGINEERING

Volume - 1

Electronics
Electrical Power
Information Technology
Engineering Physics

Organized by
Ministry of Science and Technology

DECEMBER 4-5, 2009
SEDONA HOTEL, YANGON, MYANMAR

ELECTRICAL POWER ENGINEERING

Analysis of Photovoltaic Arrays

Aung Ze Ya
Electrical Power Engineering Department, Yangon Technological University
Ministry of Science and Technology, Myanmar
dr.aungzeya010@gmail.com

Abstract **— Solar energy can be the ultimate energy solution for global warming crisis. Solar energy in Myanmar is about 51973.8 TWH per year. Overview of PV (photovoltaic) is presented .Monthly temperatures of 10 selected meteorological stations of Central Myanmar are studied. Considerable attention is performed to analyze the commercial PV arrays by utilizing single-diode (circuit-based) model and MATLAB environment. The main goal is to predict the parameters of the nonlinear I-V characteristic with simple and accurate simulation. Final validation of the developed model is done by matching the result-curve with the experimental data at three main points.**

Keywords**—Solar energy, Temperatures, PV, I-V, simulation.**

I. INTRODUCTION

There can never be a true "energy shortage," as Einstein demonstrated, everything in the universe is energy, light, heat, matter—everything except space itself—is just energy in one form or another[1]. The sun is radiating energy at a rate of 400,000,000 EW into space. Less than one billionth of that energy actually strikes the earth, a third of which is promptly reflected back out into space [6]. The Sun is a light source whose radiation spectrum may be compared to the spectrum of a black body near 6000°K. A black body absorbs and emits electromagnetic radiation in all wavelengths. The AM1.5 standards are defined for a PV device whose surface is tilted at 37∘ and faces the Sun rays. In the extraterrestrial space, at the average distance between the Sun and the Earth, the irradiated solar energy is about 1.353kW/m^2. On the Earth's surface, the irradiation is approximately 1 kW/m^2 [8]. Solar cell was the common term used during its early stages of development. Thus, the term, photovoltaic is more precise. It indicates the cell's function. PV cells use particles of light energy called photons. Voltaic means to produce electricity [11].

PV cells are made of semiconductor materials. The major types are crystalline and thin films, which vary from each other in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production. Mono-crystalline silicon, poly-crystalline silicon and Gallium Arsenide (GaAs) are crystalline materials. Cadmium Telluride (CdTe) and Copper Indium Selenide (CIS) are thin films materials. Mono-crystalline silicon has a uniform molecular structure. Its conversion efficiency is between 15-20%. Poly-crystalline silicon cells are less expensive to produce than single-crystalline cells because their manufacturing process does not require many careful hours of cooling and rotating silicon material. The energy conversion efficiency for poly-crystalline silicon ranges between 10 to 14%. A compound semiconductor, GaAs has a crystal structure similar to that of silicon. It has high level of light absorptive and much higher energy conversion efficiency about 25 to 30%. GaAs is also popular in space applications where strong resistance radiation damage and high cell efficiency are required. The biggest drawback of GaAs is the high cost. CdTe has a high light absorptive level. The conversion efficiency for a CdTe is about 7%.The instability of cell and module performance is one of the major drawbacks of using CdTe. Another disadvantage is that cadmium is a toxic substance. Although very little cadmium is used in CdTe modules, extra precautions have to be taken in manufacturing process. CIS has been one of the major research areas in the thin film industry has the conversion efficiency of 18%. Its complexity makes it difficult to manufacture. Also, safety issues might be another concern in the manufacturing process as it involves hydrogen selenide, an extremely toxic gas.

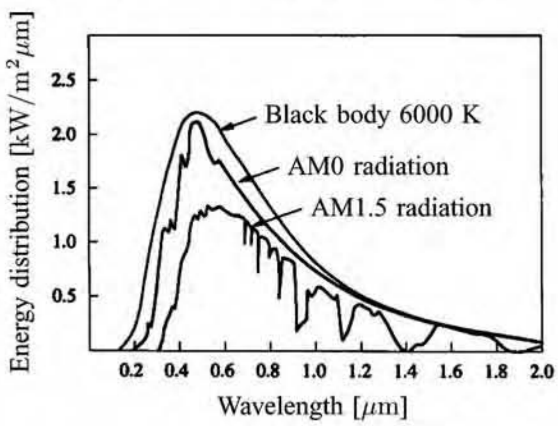

Fig. 1 Spectral distribution of the black body radiation and Sun radiation in the extraterrestrial space (Air Mass 0) and on Earth's surface (Air Mass 1.5)

PV cells can be thought of as a direct current (DC) generator powered by the sun. When light photons of sufficient energy strike a solar cell, they knock electrons free in the silicon crystal structure forcing them through an external circuit and then returning them to the other side of the solar cell to start the process all over again as shown in Fig. 2 [14]. PV cells are interconnected to form modules, modules to form arrays as illustrated in Fig. 3. A single cell is not of much practical use, producing less than a volt. Several cells have to be connected in a series of cells to produce a useable voltage. A number of cells linked and mounted together are known as a solar panel [15].

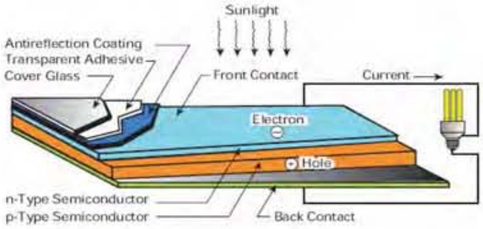

Fig. 2 Process of generating DC from PV cell

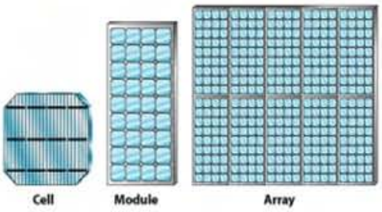

Fig. 3 PV cell, module and array

II. TEMPERATURE ANALYSIS IN MYANMAR

Seasons of Myanmar are (1) Northeast Monsoon Season or winter (December to February); (2) Hot Season (March to May); (3) Southwest Monsoon Season (May to September) and (4) Retreating Monson Season (October and November). Day-to-day temperature variations are far from spectacular in Myanmar. The most important features of temperatures in Myanmar are summarized as:(1) diurnal change from night to day, about 8°C to 12°C at most stations;(2) annual range which is greater in Central and North Myanmar , being about 10°C to 15°C and less in the south and coastal areas, about 2°C to 5°C. The highest temperatures usually occur in April just before the onset of the monsoon and the lowest are in December or January at the time of lowest solar elevation; (3) hottest area is the rain shadow area of Central Myanmar during April and (4) north of this hot area temperatures decrease with both latitude and elevation. Table III and IV illustrate the record of mean monthly maximum and minimum temperatures of 10 selected meteorological stations in Central Myanmar for the decade year 1990 to 2000. Based upon these data, it can be observed that the overall maximum and minimum temperatures are respectively about 33.56°C and 21.1167°C in that period.

III. DEVELOPMENT OF PV MODEL

A. Ideal PV Cell Model

The simplest equivalent circuit of an ideal PV cell is a current source in parallel with diode. The equation that describes the I–V characteristic of the ideal PV cell is:

$$I = I_{phc} - I_{sd} \tag{1}$$

where I_{phc} is the light-generated current of ideal PV cell and I_{sd} is the current of Shockley diode.

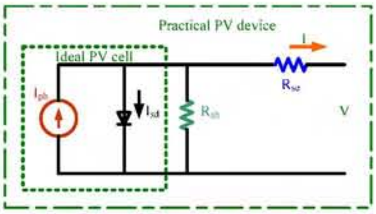

Fig. 4 Single-diode model of ideal PV cell and practical PV array

Then, Shockley diode current equation is substituted:

$$I = I_{ph} - I_{0d}\left[e^{\left(\frac{QV}{DkT}\right)} - 1\right] \tag{2}$$

where I_{0d} is the dark saturation or leakage current of the diode, Q is the charge of electron (1.60217646 x 10^{-19}C), k is the Boltzmann constant (1.3806503 x 10 $^{-23}$ J/°K), T is the temperature of the p-n junction, and D is the diode ideal factor. This is dependent on PV material [4] and is listed in Table I. PV materials are briefly discussed in section I.

TABLE I
DIODE IDEAL FACTOR

PV Material	D
Si-mono	1.2
Si-poly	1.3
CdTe	1.5
CIS	1.5
GaAs	1.3

B. PV Array Model

The basic equation of the ideal PV cell does not represent the I–V characteristic of a practical PV array. Practical arrays are composed of several connected PV cells. The observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters to the basic equation as:

$$I = I_{ph} - I_0\left[e^{\left(\frac{V + R_{se}I}{V_t D}\right)} - 1\right] - \frac{V + R_{se}I}{R_{sh}} \tag{3}$$

where I_{ph} is the current of PV array, I_0 is the saturation current of PV array , $V_t = (N_{se}kT)/Q$ is the thermal voltage of the PV array with N_{se} cells connected in series, R_{se} is the equivalent series resistance and R_{sh} is the equivalent parallel resistance of the PV array. This equation originates the I–V curve in Fig. 5, where three remarkable points are highlighted: short circuit point (0, I_{SC}), Maximum Power Point (V_{mp}, I_{mp}), and open circuit point (V_{OC}, 0) [8].

Current source region borders on voltage source region as mentioned in Fig. 5. A series resistance (R_{se}) influences stronger when the PV device operates in the voltage source region and a parallel resistance R_{sh} with stronger influence in the current source region of operation. R_{se} is the sum of several structural resistances of the device and basically depends on the contact resistance of the metal base with the p semiconductor layer, the resistances of the p and n bodies, the contact resistance of the n layer with the top metal grid, and the resistance of the grid [12]. The R_{sh} resistance exists mainly due to the leakage current of the p–n junction and depends on the fabrication method of the PV cell. The value of R_{sh} is generally high and it is neglected in order to simplify the model as in [5]. The value of R_{se} is very low, and sometimes this parameter is neglected too as in [9].

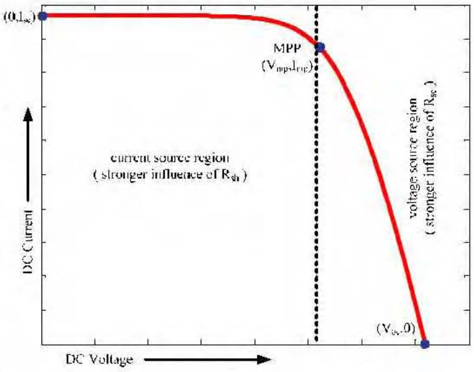

Fig. 5 I-V characteristic showing the three points given on a specification sheet

C. Determination of Model Parameters

The most important parameters widely used for describing the cell electrical performance is the open-circuit voltage and the short-circuit current [2]. The small diode and ground-leakage currents under zero-terminal voltage are neglected and light-generated current (I_{ph}) of the elementary cells is normally greater than the short circuit current (I_{sc}). Therefore, the following assumption is generally taken as:

$$I_{ph} \approx I_{sc} \tag{4}$$

The light-generated current of the PV cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation as in [13]–[15]:

$$I_{ph} = \left(I_{phs} + K_I \Delta T\right)\frac{G}{G_S} \tag{5}$$

where I_{phs} is the light-generated current at STC, K_I = the short-circuit current/temperature coefficient(A/°K), $\Delta T = T - T_S$ (T and T_S are the ambient and standard temperatures [°K]), G is the irradiation on the device surface (W/m^2), and G_S is the standard irradiation. Consequently, the diode saturation current I_0 and its dependence on the temperature can be expressed as in [13]:

$$I_0 = I_{0r}\left(\frac{T_s}{T}\right)^3 e^{\left[\frac{QE_g}{Dk}\left(\frac{1}{T_S}-\frac{1}{T}\right)\right]} \tag{6}$$

where E_g is the band-gap energy of the semiconductor and its value is taken as 1.12 eV for the polycrystalline Si at 25 °C as in[13].The nominal saturation current can be expressed as:

$$I_{0r} = \frac{I_{scr}}{e^{\left(\frac{V_{ocr}}{DV_{ts}}\right)} - 1} \tag{7}$$

where V_{ts} is the thermal voltage of N_s series-connected cells at T_s, I_{scr} is the short circuit current at rated condition and V_{ocr} is the open circuit voltage at rated condition. The rated saturation current I_{0r} is indirectly obtained from the experimental data through (7), which is obtained by evaluating (3) at the rated open-circuit condition, with $V = V_{ocr}$, $I = 0$, and $I_{ph} \approx I_{scr}$ as in [7]. Then, the saturation current can be modified as:

$$I_0 = \frac{I_{scr} + K_I \Delta T}{e^{\left(\frac{V_{ocr} + K_V \Delta T}{DV_T}\right)} - 1} \tag{8}$$

where K_V is the open circuit voltage/ temperature coefficient(A/°K).

The relation between R_{se} and R_{sh} may be found by making $P_{mm} = P_{ms}$ and solving the resulting equation for R_{se}, as shown in the following:

$$P_{mm} = V_{mp}\left\{ I_{ph} - I_0\left[e^{\left(\frac{Q(V_{mp}+R_{se}I_{mp})}{kTDN_{se}}\right)} - 1\right] - \frac{V_{mp}+I_{mp}}{R_{sh}} \right\} = P_{ms} \tag{9}$$

$$R_{sh} = V_{mp}\left(V_{mp} + I_{mp}R_{se}\right) / \left\{ V_{mp}I_{ph} - V_{mp}I_0\left[e^{\left(\frac{Q(V_{mp}+R_{se}I_{mp})}{kTDN_{se}}\right)}\right] + V_{mp}I_0 - P_{ms} \right\} \tag{10}$$

where P_{mm} is the maximum power evaluated by I-V model of (3) and P_{ms} is the maximum power taken from manufacturer's specifications sheet. The goal is to find the values of R_{se} and R_{sh} that makes the peak of the mathematical P–V curve coincide with the peak power of data sheet at the (V_{mp}, I_{mp}) point. This requires several iterations until $P_{mm} = P_{ms}$. R_{se} must be slowly incremented starting from $R_s = 0$. The initial value of R_{sh} may be predicted as in [8] by the following:

$$R_{sh,min} = \frac{V_{mp}}{I_{scr} - I_{mp}} - \frac{V_{ocr} - V_{mp}}{I_{mp}} \tag{11}$$

R_{se} and R_{sh} are updated with each step of the iteration process to access the best model solution. The following equation can be introduced for improving the model:

$$I_{phr} = \left(\frac{R_{sh} + R_{se}}{R_{sh}}\right) I_{scr} \tag{12}$$

III. SIMULATION AND RESULTS

BP 3125 solar panel is chosen for simulation process. Then, the required parameters are taken from the specifications sheet of BP 3125 solar panel. These are listed in the following table. Then, simulation is performed under STC. Moreover, average maximum temperature (33.56°C) and minimum temperature(21.1167°C) which are determined in section II are also inserted into MATLAB program with standard irradiation (1000 W/m^2). It is observed that the results curves are exactly matched with the manufacturer's specifications at three remarkable points as shown in Fig. 6 and Fig. 7.

TABLE II
INPUT PARAMETERS

V_{mp}	17.6V
I_{mp}	7.1A
I_{scr}	7.54A
V_{ocr}	22.1V
K_I	(0.0065±0.0015)%/°K
K_V	-(80±10)mV/°K
N_s	36

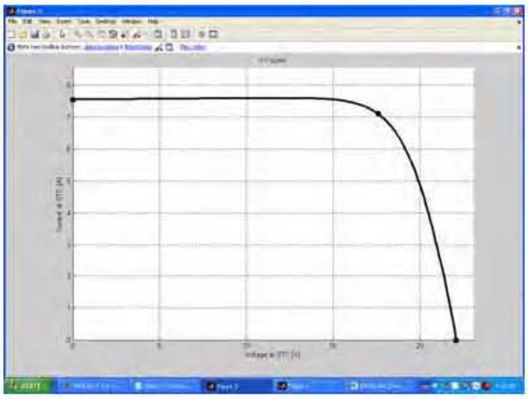

Fig. 6 Simulation result of I-V characteristics at STC

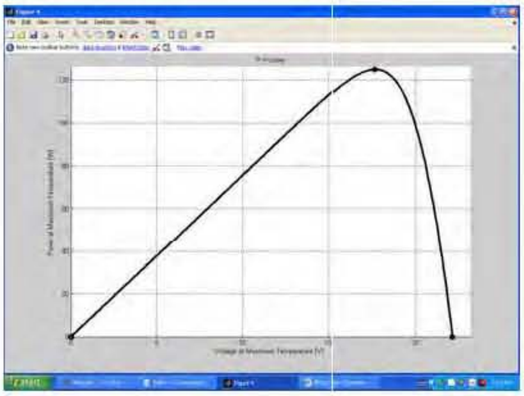

Fig. 7 Simulation result of P-V characteristics at T_{max}

V. CONCLUSION

In modeling, a single diode model is considered to achieve the simplicity and accuracy. Diode ideal factor should be selected based on PV material. Maximum power voltage, maximum power current, open circuit voltage, short circuit current, number of cells and temperature coefficients are taken from specification sheet. Evaluating R_{se} and R_{sh} is important in modeling of PV arrays. These parameters influence on the I-V characteristic and should be considered together in order to get the accurate and reliable PV model. Ambient temperature is probably the single most important climate variable to be considered in the design of solar energy system. Therefore, monthly temperatures of Myanmar are studied in this paper. But, further work will deal with considering the other aspects such as cloud cover, humidity and wind effects of the actual PV site.

ACKNOWLEDGEMENT

The author would like to express his deep gratitude to H.E, U Thaung, Minister, the Ministry of Science and Technology, for the celebration of this conference at Yangon, Myanmar. The author also offers his appreciation to his parents for their supports, encouragement and valuable guidance.

REFERENCES

[1] H.M.Anderson, *Introduction to Solar Energy*, New York, USA: Addison-Wesley Publishing Company, 1982.

[2] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, "Development of generalized photovoltaic model using MATLAB/SIMULINK" in *Proceedings of the WCECS 2008*, October 22 - 24, 2008, San Francisco, USA, ISBN: 978-988-98671-0-2.

[3] AMETEK, Inc, *Solar Energy Handbook*, 2nd ed., Radnor, Pennsylvania, USA: Chilton Book Company, 1984.

[4] C. C. Hua and C. M. Shen, "Study of maximum power tracking techniques and control of dc-dc converters for photovoltaic power system," in *Proc.29th annual IEEE Power Electronics Specialists Conference*, vol. 1, 1998, pp. 86-93.

[5] W. Xiao, W. G. Dunford, and A. Capel, "A novel modeling method for photovoltaic cells," in *Proc. IEEE 35th Annu. Power Electron Spec. Conf.(PESC)*, 2004, vol. 3, pp. 1950–1956.

[6] John Elkington, Sun Traps, New York, USA: Penguin Books, 1984.

[7] M. G. Villalva, J. R. Gazoli and E. Ruppert F, "Modeling and circuit-based simulation of photovoltaic arrays," *Brazilian Journal of Power Electronics*, vol.14, pp 3545, May,2009.

[8] M. G. Villalva, J. R. Gazoli and E. Ruppert F, "Comprehensive Approach to modeling simulation of photovoltaic arrays," *IEEE Transactions on Power Electronics*, vol.24, no.5,pp1198– 1208 , May. 2009.

[9] Y. T. Tan, D. S. Kirschen, and N. Jenkins, "A model of PV generation suitable for stability analysis," *IEEE Trans. Energy Convers.*, vol. 19,no. 4, pp. 748–755, Dec. 2004.

[10] K. Nishioka, N. Sakitani,Y. Uraoka, and T. Fuyuki, "Analysis of multicrystalline silicon solar cells by modified 3diode equivalent circuit model taking leakage current through periphery into consideration," *Solar Energy Mater. Solar Cells*, vol. 91, no. 13, pp. 1222–1227, 2007.

[11] R.C.Bohn and A.J.MacDonald, *Power and Energy Technology*, 3rd ed, Mission Hills, California, USA: McGraw-Hill, 1991.

[12] F. Lasnier and T. G. Ang,*Photovoltaic Engineering Handbook*. NewYork, USA: Adam Hilger, 1990.

[13] W. De Soto, S. A. Klein, and W. A. Beckman, "Improvement and validation of a model for photovoltaic array performance," *Solar Energy*, vol. 80,no. 1, pp. 78–88, Jan. 2006.

[14] (2009) Wholesale Solar, Inc website. [Online]. Available : http://www.wholesalesolar.com/

[15] (2009) Solar Panels website. [Online]. Available: http:// /www.solarnavigator.net/solar_panels/

[16] (2009) bp solar website. [Online]. Available: http:// /www.bpsolar.com

TABLE III

MONTHLY MAXIMUM TEMPERATURE OF 10 SELECTED METEOROLOGICAL STATIONS IN MYANMAR (1991-2000)

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Shwebo	28.5	30.8	35.3	38.1	36.1	34.5	34.1	33.1	32.3	31.7	30.3	28.3
Monya	28.9	32.0	36.5	39.3	38.1	35.7	36.1	35.0	33.7	32.7	30.4	27.3
Mandalay	29.9	32.4	36.4	38.8	36.9	35.5	35.3	34.1	33.8	33.4	31.3	29.1
Meiktila	30.3	32.9	36.8	38.7	36.4	33.6	32.9	32.4	33.0	32.8	30.4	29.0
Myingyan	29.2	32.4	37.1	40.0	38.2	36.4	36.0	34.9	34.1	33.3	31.1	28.8
Nyaungoo	29.3	32.1	36.5	38.1	37.5	35.4	34.7	34.1	33.3	32.6	30.8	28.9
Yamathin	30.5	33.0	36.4	38.0	35.7	32.8	32.0	31.4	32.3	32.5	30.6	29.1
Pyinmana	31.3	33.7	37.0	38.3	35.7	32.5	31.4	31.1	32.4	33.1	31.5	30.3
Minbu	29.7	33.7	38.3	40.5	37.5	34.2	32.8	32.7	32.8	32.8	30.9	29.1
Magway	30.6	34.0	38.4	40.7	38.1	34.6	33.4	33.0	33.4	33.5	30.9	29.3

TABLE IV

MONTHLY MINIMUM TEMPERATURE OF 10 SELECTED METEOROLOGICAL STATIONS IN MYANMAR (1991-2000)

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Shwebo	13.1	15.2	19.7	24.0	25.7	25.5	25.5	25.3	24.7	23.2	19.0	14.3
Monya	13.1	15.0	18.5	22.6	24.9	24.9	25.4	25.0	24.3	22.8	18.9	14.4
Mandalay	13.5	15.7	20.4	24.3	25.8	25.8	26.1	25.8	25.2	24.0	20.0	15.0
Meiktila	14.3	16.6	21.0	24.7	25.1	24.5	24.3	24.1	24.0	23.3	20.1	15.9
Myingyan	12.2	14.5	19.6	24.7	26.7	26.7	26.9	26.3	25.6	24.3	19.7	13.9
Nyaungoo	13.3	15.6	20.3	24.7	26.6	26.5	26.5	26.1	25.2	23.8	19.8	14.7
Yamathin	13.0	15.3	20.2	24.3	24.6	24.0	23.9	23.7	23.6	23.2	19.6	14.6
Pyinmana	13.9	15.6	19.8	23.9	24.6	24.4	24.3	24.0	24.1	23.5	20.2	15.7
Minbu	13.2	15.3	19.7	24.2	25.4	25.2	24.9	24.6	24.3	23.0	19.7	14.9
Magway	10.5	12.9	17.4	21.3	23.2	22.6	22.5	22.4	22.1	21.2	17.8	13.0