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Investigating The Effects Of Irradiance And Temperature On The Performances Of PV Modules Technologies

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Abstract: This paper presents the effects of irradiance and temperature on the performances of PV module technologies. Since the efficiency of photovoltaic cells vary with the operating condition, there is need to access the rate of these variations for the different photovoltaic solar cells technologies. Simulations of parameters of the PV modules to evaluate their performances under changing environmental conditions are carried out using MATLAB. The results show that, thin film solar cell technologies; amorphous silicon (a-Si) and copper indium gallium disillined (CIGS), response to variation in both irradiance and temperature more rapidly. However, CIGS's efficiency, uniquely, decreases with increase in temperature. This fact is in agreement with the experimental results reported.

I. INTRODUCTION

The demand of energy is increased due to speedy rise in population and advancement in the technology day-to-day in the entire process of development, growth and continued existence of all living beings. Therefore, countries should have high awareness to utilize alternative sources of energy (Tiwari, Katiyar, Katiyar, & Pandey, 2015). The entire world is facing a challenge of energy crisis due to the diminishing deposits of non-renewable energy resources such as coal, natural gas, fossil fuels etc and increasing concerns of its effects on global warming, damage to environment and ecosystem. In order to overcome the growing global energy demand alongside the limitation of the fossil fuels reserves and their negative effects on the environment have results in a great tendency toward renewable energy sources development (Sabzpooshani & Mohammadi, 2014). Renewable energy sources like wind, geothermal, tidal and solar energy are environmentally friendly, since they have a much lower environmental impact than conventional sources like fossil fuel. Among different kinds of renewable energy sources solar energy is considered as immense source because of its abundance, sustainability and completely free of cost.

Solar energy is a renewable that is inexhaustible and if used in a proper way, it has a capacity to fulfill numerous energy needs of the world (Kachhiya, Patel, & Lokhande, 2011). Solar energy is widely accepted as a key energy source for the future around the world with respect to the environmental issues associated with fossil fuels. The information concerning available solar radiation is essential for solar energy devices, such information is also vital for meteorological experts, architects, agriculturalists, air conditioning engineers and energy-conscious designers of buildings (Li, Bu, Long, Zhao, & Ma, 2012). Solar radiant energy is important factors that characterize the energy through the PV (photovoltaic) effect among the renewable energy resources. PVs offer several advantages such as: high reliability, low maintenance cost, no environmental pollution, and absence of noise, photovoltaic cells convert sunlight directly to electricity.

The design and analysis of photovoltaic modules require a tool that can predict the behavior of photovoltaic generators under various weather conditions. Manufacturers usually provide electrical specifications of the PV panels at standard test conditions, namely solar radiation of 1000 W/m^2 and cell temperature of 25 ^{0}C. To characterize the performance of a photovoltaic module under varying weather conditions, simulation models of PV modules have been developed (Vengatesh & Rajan, 2011). The market for PV systems is growing worldwide. In fact, nowadays, solar PV provides

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around 4800 GW. Between 2004 and 2009, grid connected PV capacity reached 21 GW and was increasing at an annual average rate of 60%. In order to get benefit from the application of PV systems, research activities are being conducted in an attempt to gain further improvement in their cost, efficiency and reliability (Salmi, Bouzguenda, Gastli, & Masmoudi, 2012). Photovoltaic solar energy is a clean renewable energy with a long service life and high reliability. Both because of its high cost and low efficiency its energy contribution is less than other energy sources (Ramos-Hernanz et al., 2012). However solar energy is the most ubiquitous and redundant and this makes its study necessary in order to harness it to the fullest human endeavor.

Low efficiency of photovoltaic technologies is central to their user. This problem is approached from different perspectives; battery efficiency and panel efficiency. Some external factors such as temperature of the cell and the amount of the incident radiation also contribute to the performance of a given solar panel. Many mathematical models have been developed (Jitendra Bikaneria A.R. Joshi, 2013), (Taherbaneh, 2011), (Tamrakar & Gupta, 2015). However manufacturer produces PV modules at standard test condition (STC), there is need to investigate it nonlinear behavior at different environmental condition in order to analyze the performance of the PV cell.

In this work, we investigated the effect of irradiance and the ambient temperature on the performance of photovoltaic modules technologies; monocrystalline, polycrystalline and thin film solar cells; amorphous silicon (s.Si) and copper indium gallium disillinide (CIGS) using MATLAB.

II. PHOTOVOLTAIC (PV) CELL MODEL & CHARACTERISTIC EQUATIONS

A general mathematical description of I-V output characteristics for a PV cell has been studied for over the past four decades. Such an equivalent circuit-based model is mainly used for the MPPT technologies (EL-BASIT, 2013).

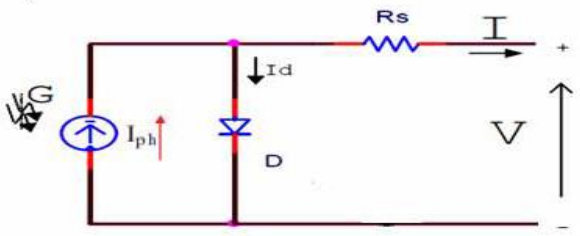

Figure 1: A one diode equivalent circuit PV Cell

Where I_{ph}, is the photocurrent generator, D is a single parallel-connected diode, Rs is a series resistor, I_d is the normal diode current and I is the output current. From Figure 1, it can be seen that (Vengatesh & Rajan, 2011)

$$I = I_{ph} - I_d \qquad (2.1)$$

And the normal diode current I_d is

$$I_d = I_S\left[exp\left(\frac{q(V+IR_S)}{KAT_C}\right) - 1\right] \qquad (2.2)$$

Substituting Eq. (2.2) into Eq. (2.1) yields

$$I = I_{ph} - I_S\left[exp\left(\frac{q(V+IR_S)}{KAT_C}\right) - 1\right] \qquad (2.3)$$

Where I_S is the cell saturation dark current, q (= 1.6×10^{-19}C) is an electronic charge, k (= 1.38 $\times10^{-23}$J/K) is a Boltzmann's constant, T_C is the cell's working temperature, A is the ideality factor. The photocurrent I_{ph} mainly depends on the solar insolation and cell's working temperature, which is described as (Islam et al., 2014)

$$I_{ph} = \left[I_{SC} + K_I\left(T_C - T_{Ref}\right)\right]N \qquad (2.4)$$

Where I_{SC} is the cell's short-circuit current at 25^0C and 1000W/m^2, K_I is the short-circuit temperature coefficient, T_{Ref} is the cell's reference temperature, N is the solar insolation in W/m^2. Since normally $I_{ph} \gg I_S$ and ignoring the small diode current I_d and ground-leakage currents under zero-terminal voltage, the short-circuit current is approximately equal to the photocurrent I_{ph}(Kachhiya et al., 2011)

$$I_{ph} = I_{SC} \qquad (2.5)$$

Therefor the short-circuit current I_{SC} can be obtained as:

$$I_{SC} = I = I_{ph} - I_S\left[exp\left(\frac{q(I_{ph}R_S)}{KAT_C}\right) - 1\right] \qquad (2.6)$$

On the order hand the cell's or diode saturation current varies with the cell temperature, which is described as:

$$I_S = I_{RS}\left(\frac{T_C}{T_{Ref}}\right)^3 exp\left[\frac{qE_G}{kA}\left(\frac{1}{T_{Ref}} - \frac{1}{T_C}\right)\right] \qquad (2.7)$$

WhereI_{RS}, is the cell's reverse saturation current at a reference temperature of a solar radiation, E_G is the bang-gap energy of the semiconductor used in the cell. The reverse saturation current at reference temperature can be approximately obtained as (Vajpai & Khyani, 2013)

$$I_{RS} = \frac{I_{SC}}{\left[exp\left(\frac{qV_{OC}}{N_S T_C KA}\right) - 1\right]} \qquad (2.8)$$

Where V_{OC} is an open circuit voltage obtained when the diode is not conducting. V_{OC} is found to be given as (Rodrigues, Melício, Mendes, & Catalão, 2011)

$$V_{OC} = \frac{AKT}{q} ln\left(1 + \frac{I_{SC}}{I_d}\right) \qquad (2.9)$$

Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series and parallel configurations on a given module to produce enough high power (Seifi et al., 2013). A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The terminal equation for the current and voltage of the array becomes as follows

$$I = N_P I_{ph} - N_P I_S\left[exp\frac{q}{kAT_c}\left(\frac{V+IR_S}{N_S}\right) - 1\right] \qquad (2.10)$$

The output power can be obtained by:

$$P = V\left[N_P I_{ph} - N_P I_S\left[exp\frac{q}{kAT_c}\left(\frac{V+IR_S}{N_S}\right) - 1\right]\right] \qquad (2.11)$$

The efficiency of the PV module is given as:

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$$\eta = \frac{P_{out}}{P_{in}} * 100\% \qquad (2.12)$$

Where P_{out} , is the output power and P_{in} is the input power (solar irradiance for the area of the panel).

III. METHODOLOGY

The method adopted in this work is the simulation using MATLAB program. We consider PV modules rated at 200W and 220W from the three photovoltaic modules technologies as shown in (Table3.1). We wrote MATLAB scripts that can simulate equations (2.10) and (2.11). First we set the module at constant ambient temperature of 25^0C and vary the irradiance as 100W/m^2, 200W/m^2, 300W/m^2, 400W/m^2, 500W/m^2, 600W/m^2……1200W/m^2. Secondly the irradiance is maintained constant at value of 1000W/m^2 and varies the temperature as 10^0C, 25^0C, 35^0C, 45^0C, 55^0C, 65^0C, 75^0C. From the scripts, we evaluated the performances (efficiency) of the modules from equation (2.12).

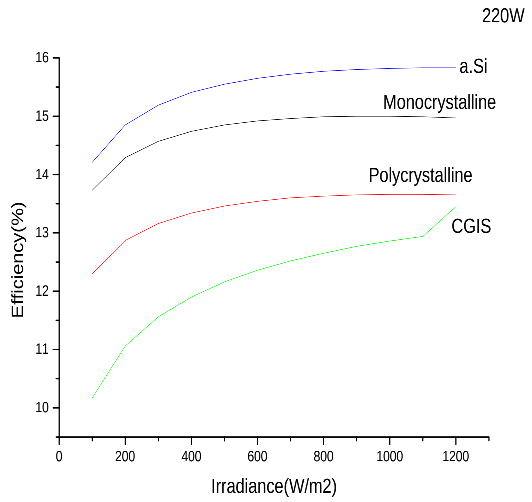
The essential input parameters such as Voc, Isc, Ns, K_I, Tc and G are taken from the manufacturers datasheet for the typical 220W and 200W modules selected under test at standard test condition (STC) as shown in Table:3.1.

Technology	Module	P_{max} (W)	I_{mp} (A)	I_{sc} (A)	V_{mp} (V)	V_{oc} (V)	Temp Coeff I_{sc} (%/^{0}C)	Area (M^2)
Monocrystalline	SR-M654220	220	8.15	8.80	27.00	33.21	0.05	1.47
Monocrystalline	CS5A-200	200	5.35	5.71	37.40	45.30	0.06	1.28
Polycrystalline	CS6P-220	220	7.52	8.09	29.30	36.30	0.06	1.61
Polycrystalline	SR-P654200	200	7.34	7.90	27.25	33.79	0.046	1.47
CIGS. Thin film	FLEX-01 220	220	9.86	11.13	22.60	28.20	-0.003	1.71
CIGS. Thin film	BIPV-200	200	5.50	6.40	32.20	46.40	-0.03	1.92
a.Si. Thin film	HIP-220HDE1	220	6.57	7.07	33.50	41.40	0.0299	1.39
a.Si. The film	HIP-200BA3	200	3.59	3.83	55.80	68.70	0.0229	1.18

Table 3.1: Major specifications for the PV Modules

IV. RESULTS AND DISCUSSION

By simulating the equations (2.10) and (2.11), we are able to develop the following graphs indicating the variation of the performances of each module technology with solar intensity and ambient temperature.



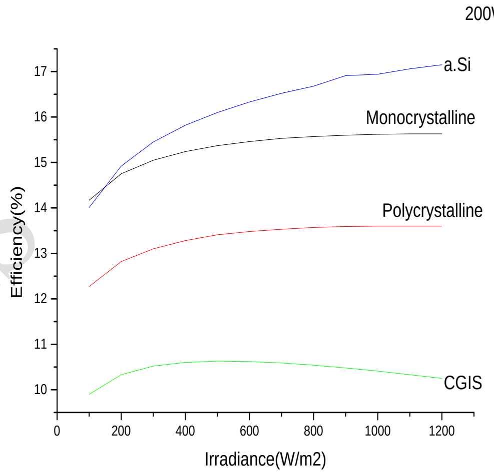
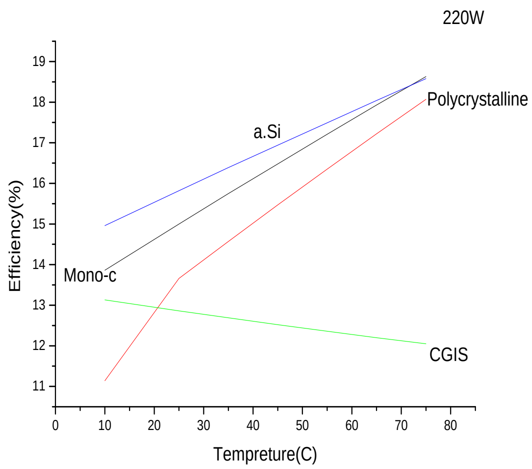


Figure 2: Variation of efficiency with irradiance at fixed Temperature (25^0C) for the three PV module technologies rated at 220W and 200W

It observed that efficiency is raising up with increase in irradiance for both mono-crystalline, poly-crystalline, amorphous silicon(a.Si) and CIGS technology which is in agreement with other work reported (Islam et al., 2014).



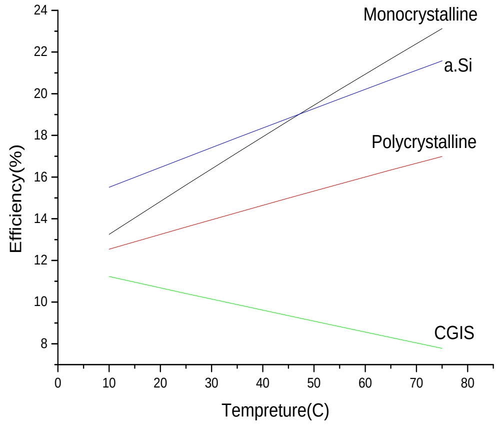
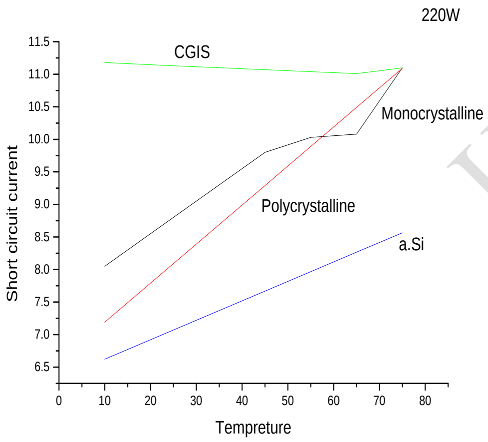


Figure 3: Variation of efficiency with temperature at fixed irradiance (1000W/m^2) for three the PV module technologies rated at 220W and 200W

It can be seen that temperature has effect on the performance of monocrystalline, polycrystalline, amorphous silicon (a.Si) and CIGS. The efficiency increases with increase in temperature in mono-crystalline, poly-crystalline and amorphous silicon (a.Si) technology while the efficiency decreases with increase in temperature in cupper indium gallium diselenide (CIGS) technology which is in agreement with other work reported (Aish, 2015).



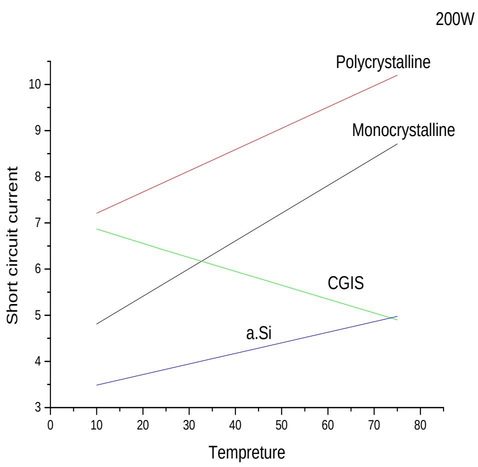
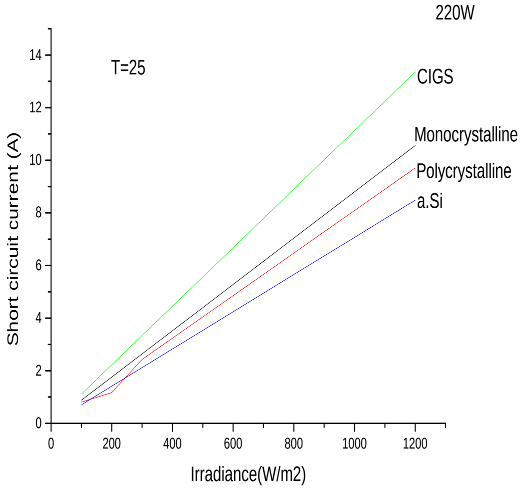


Figure 4: Variation of Short circuit current with temperature at fixed irradiance (1000W/m^2) for the three PV module technologies rated at 220W and 200W



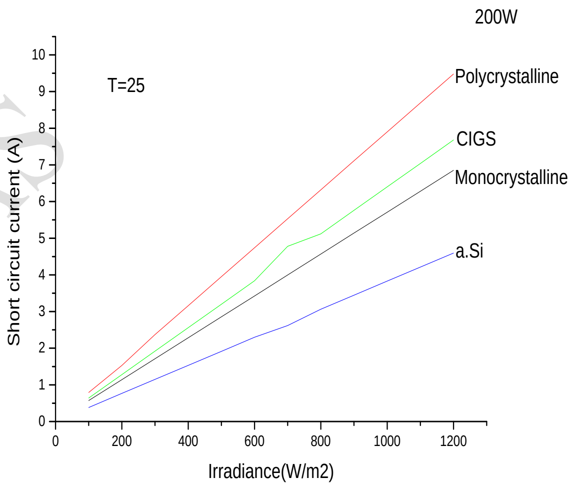


Figure 5: Variation of Short circuit current with irradiance at fixed Temperature (25^{0}C) for the three PV module technologies rated at 220W and 200W

It can be seen that variation of the short circuit current with irradiance for all the technologies is pure linear with positive slope.

V. CONCLUSION

We found that the response of thin film solar cells to variations of solar irradiance and ambient temperature is faster than those of monocrystalline and polycrystalline solar cells. We also found that the performance of one of the thin film solar cells, CIGS, decreases with increase in temperature. Since thin film has fast response to variations in operating conditions, this makes it very advantageous. However the decrease in efficiency of some thin film solar cells with increase in temperature is a drawback. As such it is recommendable to make use of a combination of thin film and monocrystalline or polycrystalline solar cells where there is need for more than one PV cells. This would improve the overall performance of the entire system and thus maximizes the utilization of the solar energy.

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