International Journal of Innovative Research and Advanced Studies (IJIRAS)
Volume 3 Issue 7, June 2016

ISSN: 2394-4404

Improved Efficiency Of Thin-Film Solar Cells With Increase In Temperature

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Abstract: ***This work proposed a solution to the reduction in performance of copper indium gallium selenide (CIGS) PV module with increase in temperature. A practical solution to this problem is to have two modules of different technologies connected in series. This series arrangement was studied through simulation. The results show improvement in the new configuration.***

Keywords: PV module, Thin film, MATLAB, Simulation, Temperature.

I. INTRODUCTION

The entire world is facing a challenge of overcoming the hurdle of energy crisis. The reductions of nonrenewable energy resource such as fossil fuel, coil, natural gas etc have become a point of serious concerned. In 21st century the research in renewable energy has become an increasingly important topic with the problem of energy crisis becoming more aggravated, resulting in increased exploitation and search for the new energy resources such as wind, hydro, geothermal, tidal and solar energy. Solar energy is green energy which is in abundance, inexhaustible and pollution free. It becomes one of the most promising alternatives for conventional energy sources (Das & Bisht, 2013).

Photovoltaic (PV) system is the system of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon commonly studied in physics, photochemistry and electrochemistry. A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power. The process is both physical and chemical in nature, as the first step involves the photoelectric effect from which a second electrochemical process takes place involving crystallized atoms being ionized in a series, generating an electric current (Bazilian et al., 2013). Also three major families of PV cells are Monocrystalline technology, Polycrystalline technology and Thin film technologies. The monocrystalline and polycrystalline technologies are based on microelectronic manufacturing technology and their efficiency is in general between 12% and 18% for monocrystalline and between 9% and 13% for polycrystalline. For thin film cells, the efficiency is 10% for a- Si, 12% for CuInSe2 and 9% for CdTe (Islam, Rahman, & Mominuzzaman, 2014).

Thin film Photovoltaic solar cells' efficiencies are affected by their operating temperature, which is primarily a product of the ambient temperature as well as the incident solar insolation (Aish, 2015). The main candidate semiconductor materials for thin film at present are amorphous silicon, CdTe and $CuIn(Ga)Se_2$. Each of these materials has its own advantages and disadvantages so that a single choice is not possible (Schock, 1996). Hot spot and thermal runaway are serious phenomena leading to the degradation of thin film solar cells. It show that these issues are well related to temperature variation in the device structures mostly because of current following across transparent conducting oxide (TCO) layer or back contact of the thin film device structure (Perez & Gorji, 2016). Any temperature fluctuation in the local area of the film structure can increase the electrical conduction and cause shunting pathways or hot spot. The hot-spot phenomenon is a relatively frequent problem occurring in current photovoltaic generators. It entails both a risk for the photovoltaic module's lifetime and a decrease in its operational efficiency. Nevertheless, there is still a lack of widely accepted procedures for dealing with them in practice (Moretón, Lorenzo, & Narvarte, 2015). In this paper we proposed a way to alleviate the problem reported by Perez and Gorji (2016) of performance degradation of some thin film solar modules. The proposal is implemented through MATLAB simulation.

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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).

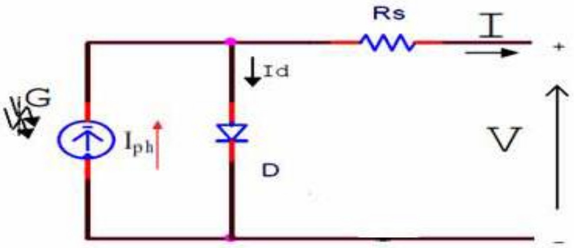

Figure 2.1: A one diode equivalent circuit PV Cell

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)

$$I = I_{ph} - I_d \tag{1}$$

And the normal diode current I_d is

$$I_d = I_S\left[exp\left(\frac{q(V+IR_S)}{KAT_C}\right) - 1\right] \tag{2}$$

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

$$I = I_{ph} - I_S\left[exp\left(\frac{q(V+IR_S)}{KAT_C}\right) - 1\right] \tag{3}$$

Where I_S is the cell saturation dark current, q (= 1.6×10^{-19}C) is an electronic charge, k (= 1.38×10^{-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)

$$I_{ph} = [I_{SC} + K_I(T_C - T_{Ref})]N \tag{4}$$

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

$$I_{SC} = I = I_{ph} - I_S\left[exp\left(\frac{q(I_{ph}R_S)}{KAT_C}\right) - 1\right] \tag{5}$$

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

$$I_S = I_{RS}\left(\frac{T_C}{T_{Ref}}\right)^3 exp\left[\frac{qE_G}{kA}\left(\frac{1}{T_{Ref}} - \frac{1}{T_C}\right)\right] \tag{6}$$

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

$$V_{OC} = \frac{AKT}{q}ln\left(1 + \frac{I_{SC}}{I_d}\right) \tag{7}$$

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 (Vajpai & Khyani, 2013) (Rizi & Abadi, 2016) .

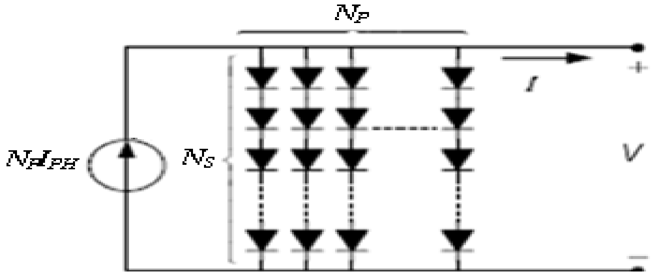

Figure 2.2: Ideal model of PV module

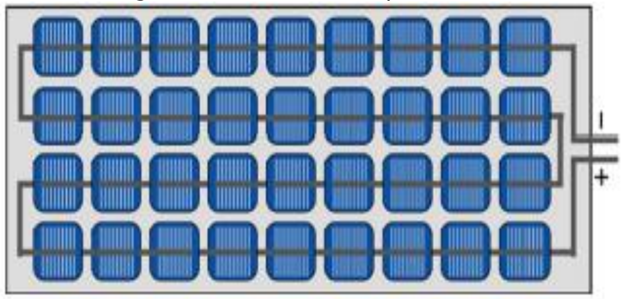

Figure 2.3: A typical PV module with cells connected in series

The terminal equation for the current and voltage of the array becomes as follows

$$I = N_P I_{ph} - N_P I_S\left[exp\frac{q}{kAT_c}\left(\frac{V+IR_S}{N_S}\right) - 1\right] \tag{8}$$

The output power can be obtained by:

$$P = V\left[N_P I_{ph} - N_P I_S\left[exp\frac{q}{kAT_c}\left(\frac{V+IR_S}{N_S}\right) - 1\right]\right] \tag{9}$$

The efficiency of the PV module is the ratio of the maximum output power to the incident light power collected by the module and is given as:

$$\eta = \frac{P_{out}}{P_{in}} * 100\% \tag{10}$$

Where P_{out} , is the output power and P_{in} is the input power (is taken as the product of solar irradiation of the incident light measured in W/m^2, with the surface area of the solar panel in m^2).

III. METHODOLOGY

PV modules of power 220W made from the three photovoltaic cell technologies shown in (Table3.1) were used. MATLAB scripts that simulate equations (8) and (9) for single module and their equivalents, for two serially connected modules were developed and used. The simulation was carried out at constant solar insolation of 1000W/m^2 at temperatures of 10^{0}C, 25^{0}C, 35^{0}C, 45^{0}C, 55^{0}C, 65^{0}C, 75^{0}C respectively. The

ISSN: 2394-4404

efficiency of each module was evaluated at these different temperatures.

Technology	Module	P_{max} (W)	I_{mp} (A)	V_{mp} (V)	I_{sc} (A)	V_{oc} (V)	N_S	Temp Coeff I_{sc} (%/^{0}C	Area (m^2)
Monocrystalline	SR-M654 220	220	8.15	27.00	8.80	33.21	54	0.05	1.47
Polycrystalline	CS6P-220	220	7.52	29.30	8.09	36.30	60	0.06	1.61
CIGS. Thin film	FLEX-01220	220	9.86	22.60	11.13	28.20	60	-0.003	1.71

Table 3.1: Major specifications for the PV Modules

Technology	Ideality Factor
Monocrystalline	1.2
Polycrystalline	1.3
a-Si:H (amorphous silicon)	1.8
a-Si:H tadem	3.3
a-Si:H triple	5
CIGS (Copper indium gallium Selenide)	1.5
CdTe (Cadmium Telluride)	1.5
AsGa (gallium arsenide)	1.3

Table 3.2: Ideality Factor (A) for PV Technologies

IV. RESULTS AND DISCUSSION

We found that the series arrangement of thin film solar module with a monocrystalline or polycrystalline module improved the performance of the thin film module despite increase in temperature which normally decreases the thin film cells performance. Individual performances of the three PV technologies with increase in temperature are given in Fig.4.1 through Fig.4.3.

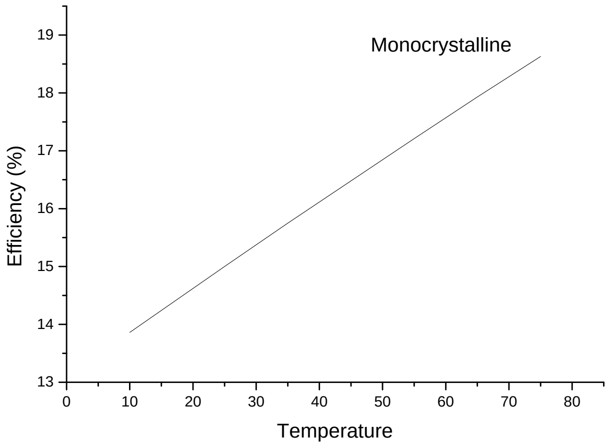

Figure 4.1: Variation of efficiency with temperature at Fixed Irradiance (1000W/m^2) rated at 220W

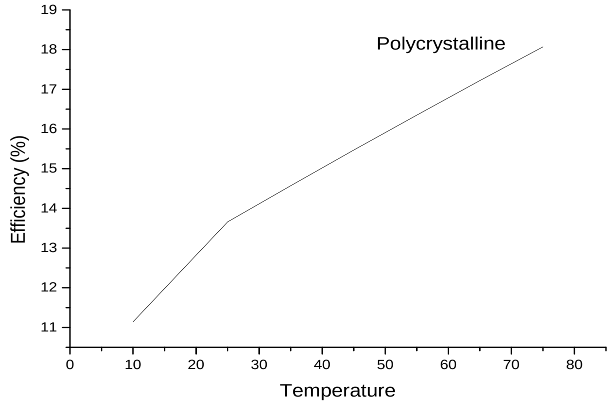

Figure 4.2: Variation of efficiency with temperature at fixed irradiance (1000W/m^2) rated at 220W.

It can be observed that the performances (efficiency) of monocrystalline and polycrystalline modules simulated are increase with increase in temperature.

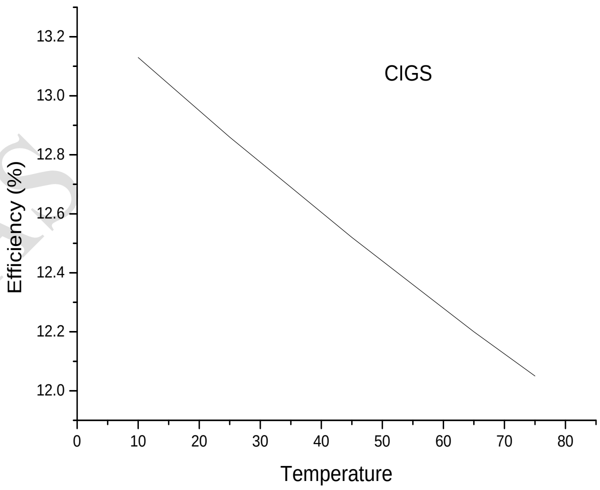

Figure 4.3: Variation of efficiency with temperature at Fixed irradiance (1000W/m^2) rated at 220W

It can be seen that from Fig.4.3 the increase in temperature decrease the performance of thin film; CIGS (Copper indium gallium selenide) solar module. As the temperature increases the efficiency of the solar cell module decreases which is in agreement with the experimental work reported (Aish, 2015). This decrease in performance of the CIGS with increase in temperature is due to the hot spot and inhomogeneity in is structure as it operates under different temperature which cannot be optimized simultaneously (Vasko, Vijh, & Karpov, 2014).

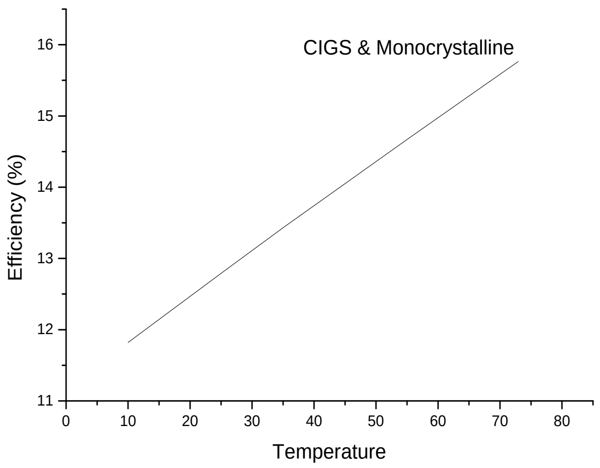

Figure 4.4: Variation of efficiency with temperature at fixed irradiance (1000W/m^2) rated at 220W

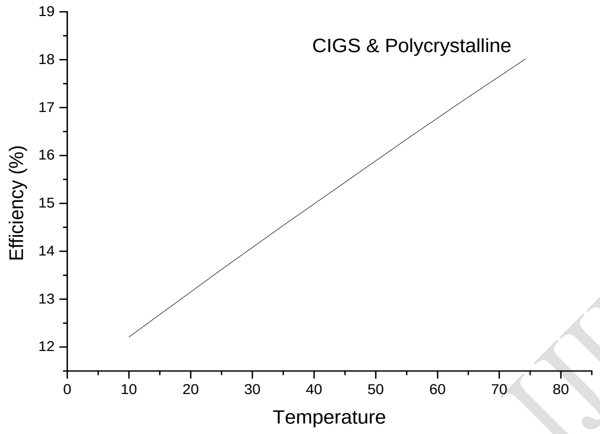

Figure 4.5: Variation of efficiency with temperature at fixed irradiance (1000W/m^2) rated at 220W

It can observed from Fig.4.4 and Fig.4.5 that by combining monocrystalline with CIGS or Polycrystalline with CIGS in series there overall efficiency increases with rise in temperature as found in the other two PV technologies.

V. CONCLUSION

We found that series connection of CIGS with polycrystalline or monocrystalline eliminated the decrease in performance of CIGS module when temperature increases. This solution will further make thin film photovoltaic modules more affordable, since CIGS technology are easier to produce and cheaper than the other two; monocrystalline and polycrystalline.

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