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Research Article

Variation of Temperature Coefficient of Different Technology Photovoltaic Modules with respect to Irradiance

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Abstract

After the launch of JNNSM (Jawaharlal Nehru National Solar Mission) in June, 2010 by Government of India as part the action plan on climate change, both on and off grid photovoltaic (PV) installations in India have registered many folds increase. As on November, 2014 the total installed capacity of Solar PV installations in India stands at 2800 MW. The PV technologies that dominated the market in terms of installation in India are Multi crystalline silicone (mC-Si), amorphous Silicone a-Si), and cadmium telluride thin film (CdTe). Other PV technologies that are much talked about are Heterogeneous intrinsic thin film (HIT) and CIGS. The PV modules are normally rated at standard test condition defined by three parameters i.e. temperature (25^0 C), Irradiance (1000 watt/m^2) and sun spectrum (1.5 GAM). The effect of temperature on power output from a PV module is well known. The loss in power generation from the standard test condition for different technology modules is not constant rather it depends on the temperature coefficient of the particular PV technology. Hence, it is very important to study the effect of temperature on different PV technologies at various Indian climatic conditions to estimate the exact power out from different PV installations. In the present study the irradiance dependence of temperature coefficient has been measured and compared for four PV technologies (mC- S, a-Si, CdTe and HIT). It is evident from the results that temperature coefficient is dependent on irradiance. CdTe seems to have lowest temperature coefficients of power in the entire regime of irradiance in comparison to other three technologies followed by a-Si, however, the lowest is observed at 800 W/m ^{2} for CdTe and 1000 W/m^2 for a-Si. For HIT technology the lowest temperature coefficient of power is observed at 200 W/m^2. Thin film technology comes out to be a better technology in hot climates as the temperature loss of power is minimum compared to crystalline technology.

Keywords: *PV module, Temperature coefficient, NOCT, Irradiance.*

1. Introduction

Higher energy demand coupled with environmental concern catapulted the deployment of renewable sources of energy worldwide. As on November, 2014 the renewable installation portfolio of India stands at 28GW out of which 2.8 GW is from solar photovoltaic installations. Further the Jawaharlal Nehru National Solar Mission fixed an ambitious target of 20GW of solar PV installation in India by 2022.

The PV modules are rated at standard test condition (temperature 25^0C, Irradiance 1000 watt/m^2 and spectrum 1.5GAM) which normally the module does not operate at. The most probable operating condition for a PV installation is site specific. The output power of PV module depends on the actual field conditions mainly on Irradiance and temperature. The average solar insolation in India varies from 3.5 kWh/m^2/day to 6.5kWh/m^2/day with nearly 50% of area experiencing low irradiance condition and the variation in temperature is from subzero to near 50^0C in extreme conditions (Fig.1 & Fig.2).

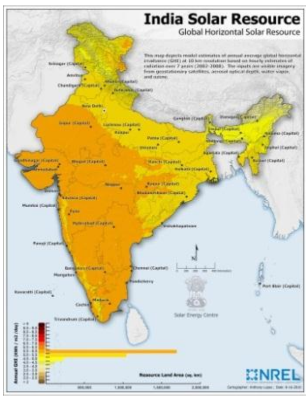

Fig.1 (Solar Resource map) **Fig.2** (Temperature map)

Hence, for understanding of generation from different PV technologies it is very important to understand the combined effect of Irradiance and temperature.

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The load current from a PV device is given by equation-1.

$$I_L = I_G - I_0\left\{\exp\left[\frac{q(V+I_L*R_S)}{A*K*T}\right]-1\right\} \quad (1)$$

Where I_0 = the dark reverse saturation current of the diode.
q = the charge of one electron.
k = the Boltzmann constant.
T= absolute temperature of the device.
A= is a constant between 1 & 2.
V = the terminal voltage.

From above (equation -1) we can derive the open circuit voltage when load current is zero (equation 2).

$$V_{OC} = \frac{AKT}{q}\ln[I_G/I_0+1] \quad (2)$$

As it is evident from the above that the performance of a PV device is dependent on temperature, three parameters that summarize the effect of temperature are as follows.

α = temperature coefficient of current.
β = temperature coefficient of voltage.
γ = temperature coefficient of power.

The measured current and voltage at a particular temperature and irradiance condition may be transposed to other temperature and irradiance conditions by applying the above temperature coefficient values as per the following equations laid down by IEC publication 891.

$$I_2 = I_1 + I_{SC}\left(\frac{I_{SR}}{I_{MR}}\right) - 1 + \alpha(T_2 - T_1) \quad (3)$$

$$V_2 = V_1 - R_s(I_2 - I_1) - KI_2(T_2 - T_1) + \beta(T_2 - T_1) \quad (4)$$

Where
I_1, V_1 are current and voltage at measured condition.
I_2, V_2 are current and voltage at transposed condition.
I_{SR} is the short circuit current of the reference device at standard test condition.
I_{MR} is the measured short circuit current of the reference device.
I_{SC} is the measured short circuit current of the test specimen.
T_1 is the measured temperature of test specimen.
T_2 is the other desired temperature.
α and β are the temperature coefficients of current and voltage of the test specimen.

The transposition should be carried out only within an irradiance range of ±30% of the level at which measurements are actually made.

Above discussion clearly indicates that the temperature coefficients are to be measured at different irradiance levels so as to minimize the error in transposition.

Nelson J. concluded that the low temperature operation is necessary for PV modules. As temperature is increased, there are two major effects in typical PV cell operation. The dark saturation current of the PV cell increases which leads to a decrease in open circuit voltage and the band gap of the photovoltaic material decreases which leads to an increase in photocurrent. The decrease in voltage is significant in comparison to increase in current thus there is a net decrease in the solar conversion efficiency with increasing temperature.

1.1 Literature Review

Temperature coefficient of power, open circuit voltage, short circuit current and fill factor is studied by A Virtuani for a-Si, C-Si, CdTe, CIGS (A.Virtuani et al, 2010).

Change in voltage, current and fill factor of a PV device with Irradiance and temperature is reported by Pradhan Arjyadhara (Pradhan Arjyadhara et al, 2013). The temperature dependence of performance of a-Si and CIS PV modules is studied by V. Perraki (V.Perraki et al, 2013) similarly the effect of light intensity and temperature on crystalline silicon solar module is studied by A. El-Shaer (A.El-Shaer et al, 2014)

Above studies are carried out to understand the effect of Irradiance and temperature on performance parameters of a PV device independently. However to minimize the error in estimation of actual power output from a device it is important to measure the temperature coefficient at different Irradiance levels.

In the present work four PV devices of different technologies are studied for dependence of temperature coefficient on irradiance. The results are compared to select the best technology for a particular location where the climatic parameters are known.

2. Experimental setup.

National institute of Solar energy (NISE) (erstwhile Solar Energy Centre) is the technical institute under ministry of New and renewable Energy, government of India involved in research and development in Solar Energy systems for the last three decades. The institute is well equipped with an indoor test facility to carry out characterization of solar PV cells and modules. The photovoltaic test facility of NISE is an accredited laboratory as per ISO 17025. The experimental work is carried out at photovoltaic test facility of NISE.

Fig.3 Quick sun 700A sun simulator for I~V measurement

Four PV samples are selected for the experiment with following details. The current Voltage (I~V) characterization curve is taken on the Endeas make sun simulator model no. Quick sun 700A (Fig.3) having provision of varying irradiance from 200 watt/m^2 to 1100 watt/m^2. The sun simulator is capable of measuring I~V curve up to module size of 2m x 2m and voltage range up to 150V.

Four PV technology modules one each from mC-Si, a-Si, CdTe and HIT are selected for carrying out the experiment. Sample details are given in table.1.

Table.1 Experimental sample details

Technology / Parameter	CdTe	HIT	mC-Si	a-Si
P_{max}@STC	66.7 W	206.7	157.5	86.6
V_{oc} @STC	61.4 V	67.7	25.4	96.1
I_{sc} @STC	1.647A	3.907	8.44	1.318

PV modules are heated up to 100^{0}C in the Tenny make environmental chambers (Fig.4). The hot module then mounted on the sun simulator (Fig.3). I~V curve is taken at a fixed Irradiance level and different module temperatures during natural cooling of the PV module. In the present study I~V curve is taken from PV module temperature from 70^{0}C to 25^{0}C at 5^{0}C temperature difference.

The above process is repeated to measure the temperature coefficients at five irradiance levels i.e. 200, 400, 600, 800, and 1000 watt/m^2.

Then the normalized short circuit current, normalized open circuit voltage and normalized maximum power for all four PV technologies are calculated for different temperatures taking the corresponding values at 25^{0}C as the base.

The slope of the curve plotted taking normalized parameter (Current, Voltage and power) in Y- axis and Temperature in X- axis is evaluated, which is the indicator of Temperature coefficient of corresponding parameter.

Finally the slope for Current, voltage and Power is plotted against irradiance for all four technologies and compared.

Fig.4 (Environmental chamber)

3. Results and discussions

Fig. 5 to Fig.7 shows the variation of normalized short circuit current, open circuit voltage and maximum power with temperature at 200 watt/m^2 irradiance respectively.

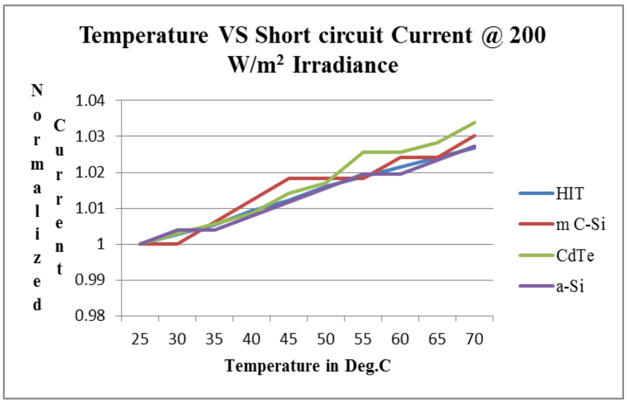

Fig.5 Normalized short circuit current with temperature @ 200 W/m^2 Irradiance

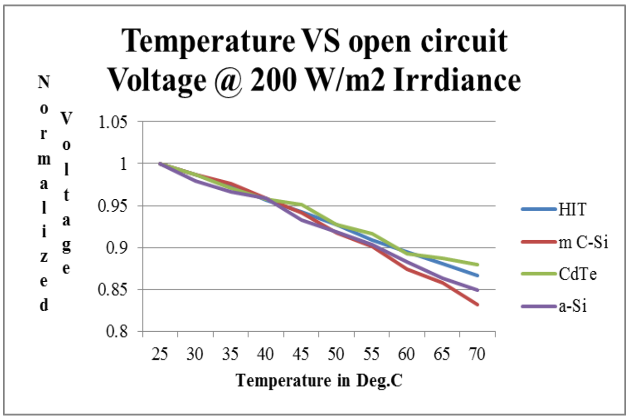

Fig.6 Normalized open circuit voltage with temperature @ 200 W/m^2 Irradiance

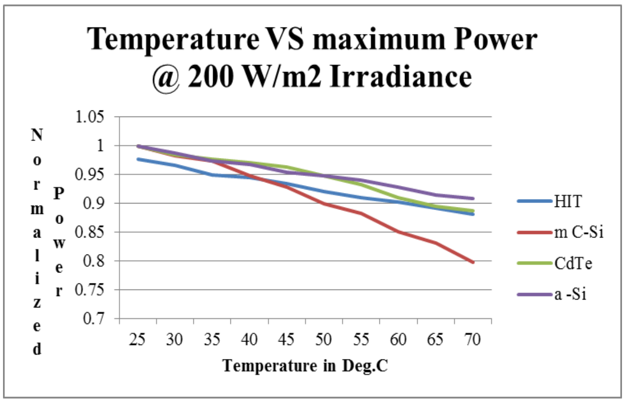

Fig.7 Normalized maximum power with temperature @ 200 W/m^2 Irradiance.

From the figure it is evident that, at 200W/m^2 irradiance level the temperature loss for power is maximum in case of mC-Si and minimum in case of a-Si.

Fig. 8 to Fig.10 shows the variation of normalized short circuit current, open circuit voltage and maximum power with temperature at 400 watt/m² irradiance respectively.

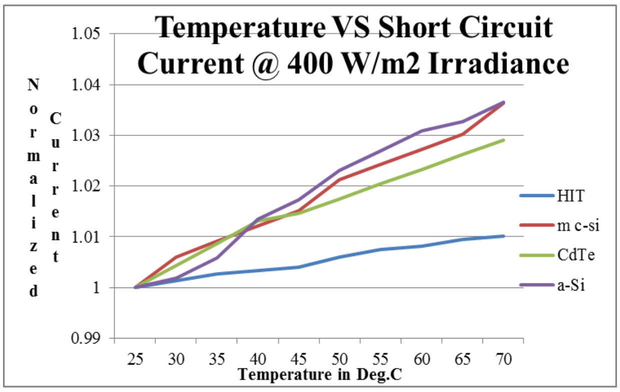

Fig.8 Normalized short circuit current with temperature @ 400 W/m² Irradiance.

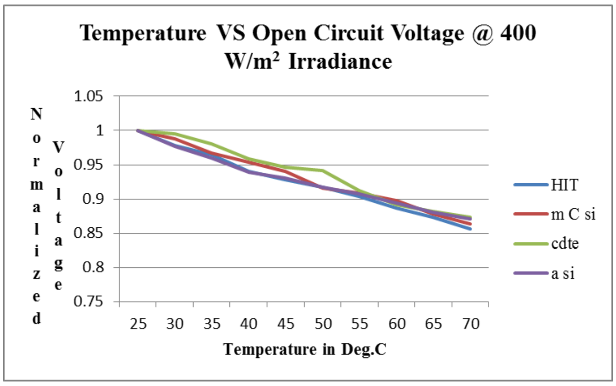

Fig.9 Normalized open circuit voltage with temperature @ 400 W/m² Irradiance.

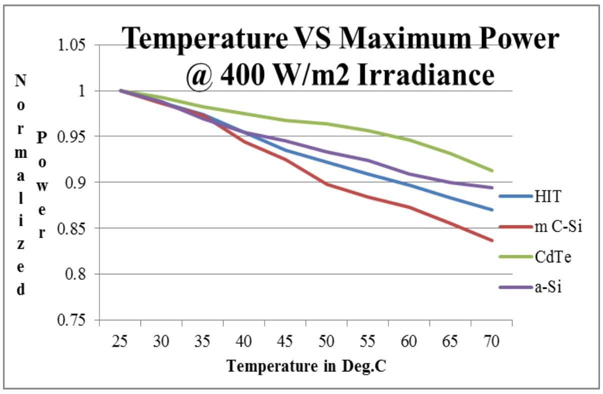

Fig.10 Normalized maximum power with temperature @ 400 W/m² Irradiance.

At irradiance 400 W/m² the highest loss of power with temperature is observed for mC-Si however the lowest is observed for CdTe. For locations with hot climate and irradiance level of 400W/m² CdTe seems to be a better technology.

Fig. 11 to Fig.13 shows the variation of normalized short circuit current, open circuit voltage and maximum power with temperature at 600 watt/m² irradiance respectively.

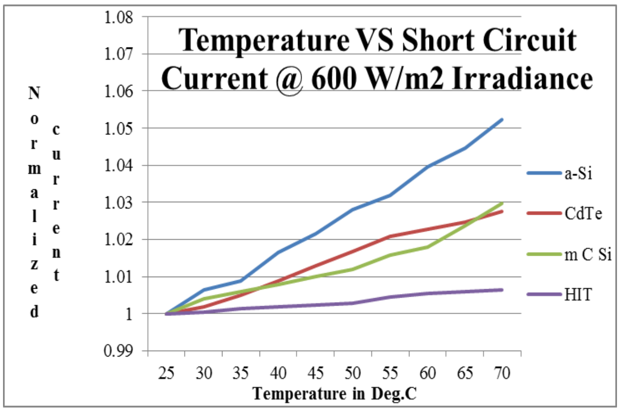

Fig.11 Normalized short circuit current with temperature @ 600 W/m² Irradiance.

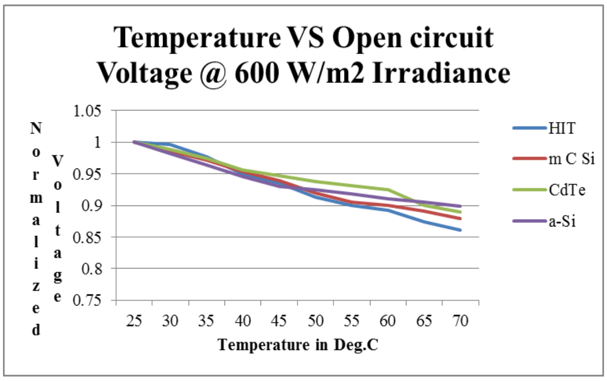

Fig.12 Normalized open circuit voltage with temperature @ 600 W/m² Irradiance.

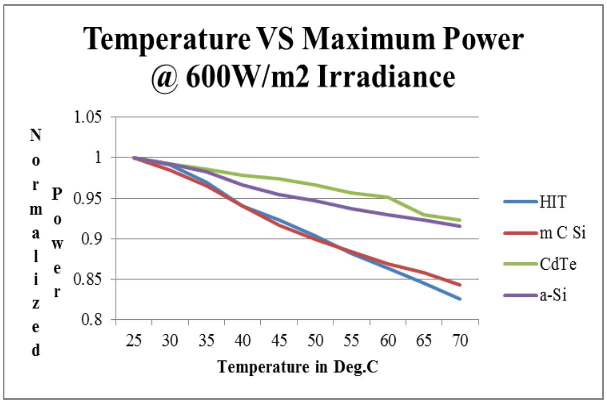

Fig.13 Normalized maximum power with temperature @ 600 W/m² Irradiance.

At irradiance level of 600 W/m² the temperature loss trend is similar for CdTe and a-Si similarly the magnitude of loss for HIT and mC-Si is same. However CdTe looks a better choice.

Fig. 14 to Fig.16 shows the variation of normalized short circuit current, open circuit voltage and maximum power with temperature at 800 watt/m² irradiance respectively.

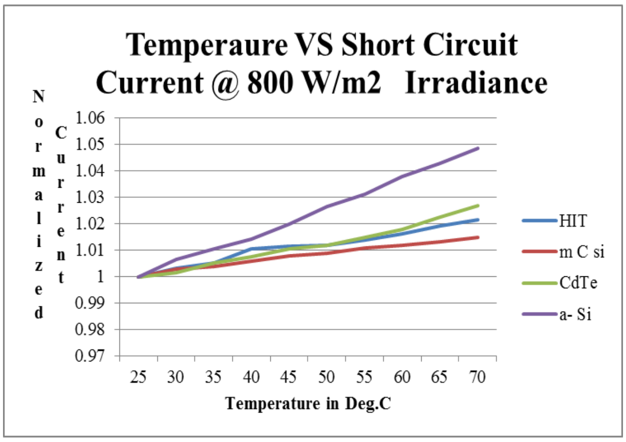

Fig.14 Normalized short circuit current with temperature @ 800 W/m² Irradiance.

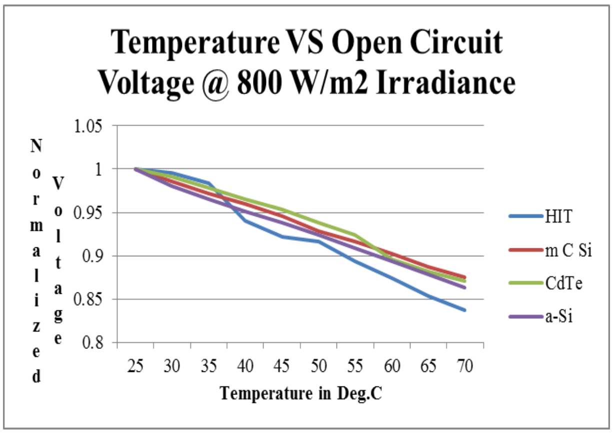

Fig.15 Normalized open circuit Voltage with temperature @ 800 W/m² Irradiance.

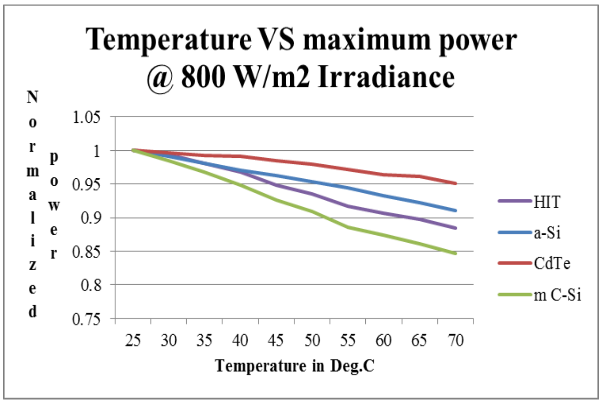

Fig.16 Normalized maximum power with temperature @ 800 W/m² Irradiance.

CdTe clearly a better choice among the four considering the temperature loss of power, if the maximum occurrence of irradiantion is at 800 W/m² level for a location.

Fig. 17 to Fig.19 shows the variation of normalized short circuit current, open circuit voltage and maximum power with temperature at 1000 watt/m² irradiance respectively.

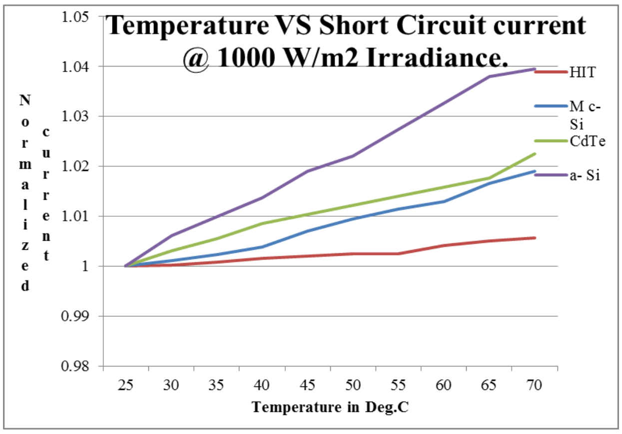

Fig.17 Normalized short circuit current with temperature @ 1000 W/m² Irradiance.

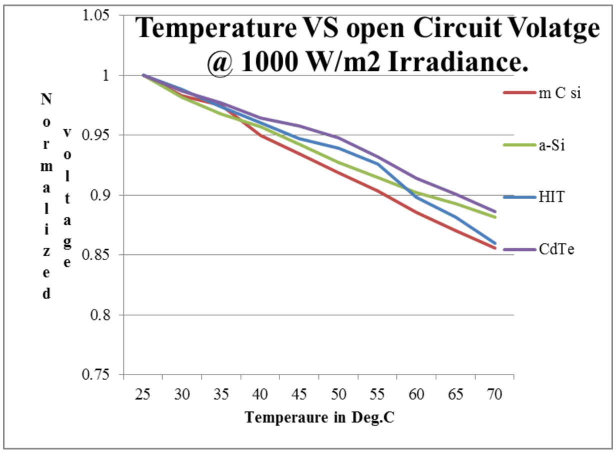

Fig.18 Normalized open circuit voltage with temperature @ 1000 W/m² Irradiance.

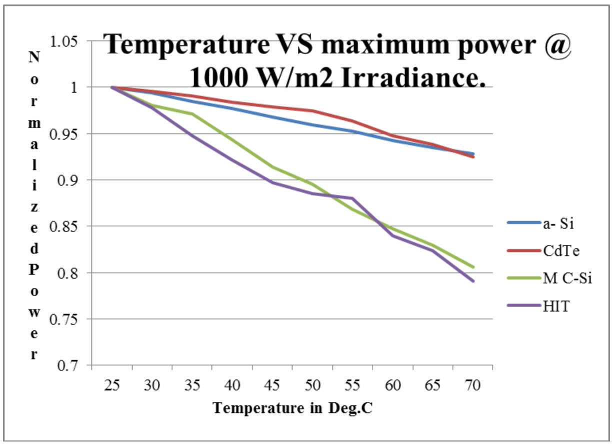

Fig.19 Normalized maximum power with temperature @ 1000 W/m² Irradiance.

The results shows that at 1000 W/m² the temperature coefficient of power for CdTe and a-Si is same and the lowest in comparison to other two technologies.

Fig. 20 to fig.22 summarizes the variation of current, voltage and maximum power with respect to irradiance for four technologies respectively.

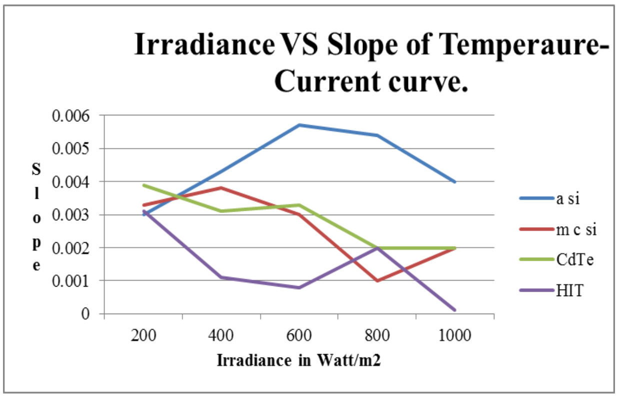

Fig.20 Temperature coefficient of current with irradiance.

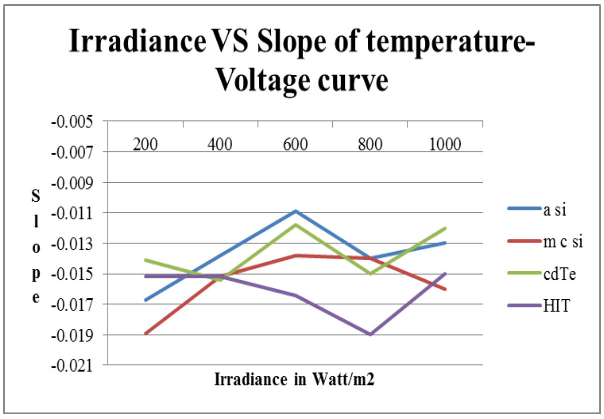

Fig.21 Temperature coefficient of Voltage with irradiance

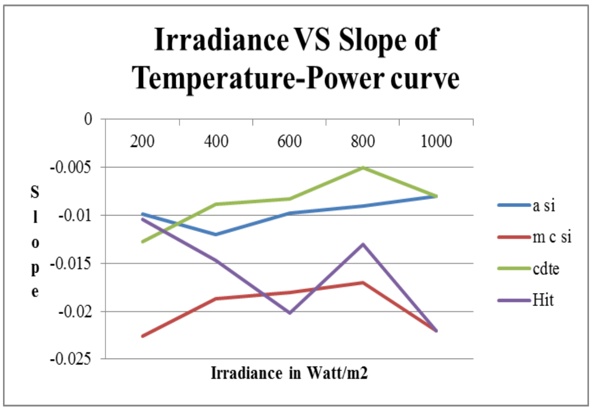

Fig.22 Temperature coefficient of power with irradiance

It is evident from the graphs that the temperature coefficient is not constant for a technology rather it changes with irradiance. CdTe seems to have lowest temperature coefficient in the entire irradiance range in comparison to other three technologies.

Conclusions

The above study summarizes the effect of temperature for four PV technologies viz. a-Si, CdTe, mC-Si and HIT at various irradiance levels. The study will help the project developers of PV power plant to estimate the power out of a PV power plant at a particular location. Further the comparison of different PV technology will be helpful in selecting a particular technology for a specific installation site. The results are concluded as follows.

1) The temperature coefficient of power, current and voltage is not constant for a given technology rather it depends on the irradiance level.
2) Power loss due to elevation of PV module temperature is minimum for CdTe technology in the entire range of irradiance in comparison to other three technologies.
3) Temperature behaviors of mC-Si and HIT are quite similar.
4) a-Si PV technology is also very promising for hot climates.

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