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# Effect of Temperature on Power Output from Different Commercially available Photovoltaic Modules

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**ABSTRACT**
Photovoltaic (PV) modules are rated at standard test condition (STC) i.e. at irradiance of 1000 W/m$^2$, temperature at 25 $^0$C and solar spectrum of Air Mass 1.5G. The actual output from the PV module in the field varies from its rated output due to change in ambient environmental conditions from the STC. The reduction in output due to temperature is determined by temperature coefficient which varies with the different types of solar module technologies. In this study, temperature coefficient of different types of commercially available solar modules is evaluated. The testing has been carried out at PV test facility of Solar Energy Centre, New Delhi. The modules are selected randomly from various manufactures. It is found that the average temperature coefficient of power for mono-crystalline, multi-crystalline and CdTe based modules are -0.446 %/°C, -0.387 %/°C and -0.172 %/°C respectively. In case of amorphous silicon module, only one sample is measured and the temperature coefficient is -0.234 %/°C. This study shows that the temperature coefficient for mono crystalline silicon module is higher than the other types of solar modules. This study provides an understanding on the variation in energy generation due to temperature correction between different cell technologies.
***Keywords* –**Solar cell, photovoltaic module, STC, Temperature Coefficient, Power Output.

## I. INTRODUCTION

PV module performance is rated under standard test conditions (STC) i.e. irradiance of 1000 W/m$^2$, solar spectrum of Air Mass 1.5 and module temperature at 25°C. Manufacturers of photovoltaic modules typically provide the ratings at only one operating condition i.e. STC. However, PV module operates over a large range of environmental conditions at the field. So the manufacturer's information is not sufficient to determine the actual performance of the module at field. The suitability of a PV module technology for a particular site depends on five major factors which includes annual solar intensity distribution, variations in the efficiency of PV module technology with intensity, annual temperature distribution and module temperature coefficient, variations in the solar spectrum distribution and rate of power degradation of the PV modules with time. The electrical efficiency of the photovoltaic module depends on ambient temperature and it reduces when the temperature increases [1]. Increases in temperature reduce the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material [2]. The parameter most affected by an increase in temperature is the open circuit voltage [2]. Temperature coefficient indicates how much will be the decrement in power output if PV module temperature varies from STC. It is also true that this temperature coefficient varies from one type of solar cell technology to another.

Various researchers have done sufficient work to understand which PV technology will be best suitable in particular climatic conditions. Ronak *et al.* study concluded that amorphous silicon performs well under Malaysia's tropical hot and humid climate, due to favourable constant high solar radiation in Malaysia and predominant diffuse nature of solar radiation [3]. Adiyabat *et al*. analysed the results of a long-term performance of two different types of PV module based on actual data measured over a period of more than six years in the Gobi Desert of Mongolia [4]. This study observed that the high output has been achieved due to the operating condition in an extreme low ambient temperature and the PV module degradation rate indicated is only -1.5 %/yr after six years of exposure test. In summary, this study showed that a PV module with a high temperature coefficient, such as crystalline silicon, is advantageous for use in the Gobi Desert area [4]. Lim *et al.* analyzed the temperature effect on the PV module output and concluded that output decreases 0.469 %/°C with the temperature variation when other factors are controlled [5]. Makrides *et al.* analysed the effect of temperature on different grid connected PV technologies installed in Cyprus. The results showed that over the evaluation period the highest average thermal losses in annual DC energy yield were 8% for mono crystalline silicon and 9% for multi crystalline silicon technologies while for thin film technologies, the average losses were 5% [6]. Skoplaki and Palyvos observed that the operating temperature plays a pivotal role in the photovoltaic conversion process. Both the electrical efficiency and hence the power output of a PV module depends linearly on the operating temperature and decreases with cell temperature [7]. George *et al.* evaluated the temperature behaviour of 13 different types of PV modules, which had been exposed to real conditions in Stuttgart, Germany and Nicosia, Cyprus. The temperature coefficient for mono crystalline, multi crystalline and amorphous silicon varied -0.353 to -0.456 %/$^0$C, -0.403 to - 0.502 %/$^0$C and -0.039 to - 0.461%/$^0$C respectively [8]. Minemoto *et al.* analysed the impact of spectral irradiance distribution and temperature on the outdoor performance of amorphous silicon and multi crystalline silicon modules and concluded that the output energy of amorphous silicon modules mainly depends on spectrum distribution and is higher under blue-rich spectrum. In contrast, the output energy of mono crystalline silicon module is sensitive to module temperature but not to spectrum distribution [9].

Kalogirou and Tripanagnostopoulos showed that for mono crystalline and poly crystalline silicon solar cells, the efficiency decreases by about 0.45% for every degree rise in temperature, while for amorphous silicon cells, the effect is less, with a decrease of about 0.25% per degree rise in temperature [10]. Vokas *et al.* showed the electrical efficiency of the photovoltaic panel depends on its temperature and it reduces when the temperature increases [1]. Nelson concluded that the low temperature operation is necessary for PV modules. As temperature is increased, the dark saturation current of the PV cell increases which leads to a decrease in open circuit voltage. Also, the band gap of the photovoltaic material decreases which leads to an increase in photocurrent. The first effect is more dominant than the second effect and thus there is a net decrease in the solar conversion efficiency with increasing temperature [2]. Nishioka *et al.* analysed field test data from a 50 kW PV system installed at Japan. It is found that the PV system operated in a wide temperature range and was strongly affected by the temperature coefficient on conversion efficiency when the module temperature became high. The results showed that annual output energy of the PV system increased about 1% by an improvement of 0.1%/°C in the temperature coefficient [11].

Jawaharlal Nehru National Solar Mission is a major initiative of the Government of India to promote solar energy while addressing India's energy security challenges [12]. The mission has set an ambitious target of deploying 20 GW of grid connected solar power by 2022 in the country. The installed capacity of grid interactive PV based electricity is 1648 MW as on 31$^{st}$ March 2013[12]. Hence it is important to understand the performance of modules at different ambient temperature of the country. In this study temperature coefficient of different types of commercially available solar modules are evaluated. The testing has been carried out at PV test facility of Solar Energy Centre, New Delhi. The modules are selected randomly from various manufactures.

## II. EXPERIMENTS

Temperature coefficients for different type of PV technologies are evaluated at the test facility established at Solar Energy Centre (SEC), New Delhi for testing of modules under indoor laboratory conditions. Figure1and 2 represents the large area (2m × 2m) single pulse sun simulator (Model: QuickSun 700A, Endeas, Finland) and environmental test chamber (Model: BSC-ETC 1000, Make: Tenny incorporation USA). The temperature of the module is increased at environmental test chamber. Once the module has reached the desired temperature, short circuit current, open circuit voltage and power output are measured. The module temperature has varied in steps of approximately 5°C over a range of interest and kept for 30 °C before the measurements. Different types of module from various manufacturers are tested which are selected randomly. The module rated capacity varies from 3 Wp to 300 Wp. Four different solar cell technologies i.e. single crystalline silicon, multi crystalline silicon; amorphous silicon and CdTe are used for evaluation of temperature coefficient. The temperature coefficient is determined according to IEC 61215 and 61646 standards at an irradiance of 1000 W/m2 [13,14]. The experimental measurements of short circuit current with respect to various temperature are plotted and the least square fit curve is obtained. The slope of this least square fit curve divided by the short circuit current at 25°C is the temperature coefficient for current for this particular module. Similar kinds of experiments are conducted for open circuit voltage and power for evaluation of temperature coefficients for open circuit voltage and power respectively.

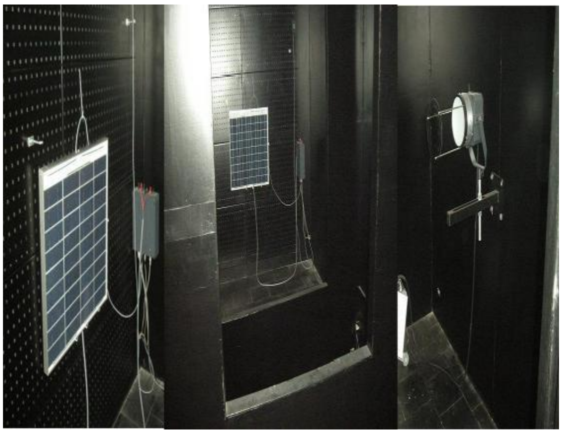

Figure 1 QuickSun 700A large area solar simulator

Figure 2 Environmental test chambers.

## III. Results and Discussion

The temperature coefficient for short circuit current, open circuit voltage and power are evaluated for mono crystalline silicon, multi crystalline silicon, amorphous silicon and CdTe based solar modules. Figure 3-5 represent the variations in current, voltage and power with respect to temperature for a mono crystalline silicon module of 10 Wp rated capacity. Similar kinds of profiles are obtained for different rated capacity modules and also for different types of module technologies. It can be observed from these Figures that a linear best fitted straight line has been drawn based on the experimental measurements. The temperature coefficient is the slope of this best fitted straight line divided by the value of that parameter at 25°C. In similar fashion, the temperature coefficients are evaluated for different module technologies. Table 1 represents the average temperature coefficients of power for mono crystalline silicon, multi crystalline silicon, amorphous silicon and CdTe respectively. The temperature coefficient of power in mono crystalline silicon varies from -0.394%/°C to -0.483%/°C with an average of -0.446%/°C. In case of multi crystalline silicon, it varies from-0.329%/°C to -0.506%/°C with an average of -0.387 %/°C. In case of CdTe, only two samples are measured with values -0.168%/°C and 0.176%/°C and an average of -0.172%/°C. In case of amorphous silicon module, only one sample is measured and the temperature coefficient is -0.234%/°C. It is found from the study that the average temperature coefficient of power for CdTe technology is minimum (-0.17%/°C) and maximum for mono crystalline silicon module (-0.446%/°C). It also can be concluded that CdTe module will perform better in high ambient temperature region in compare to other types of modules.

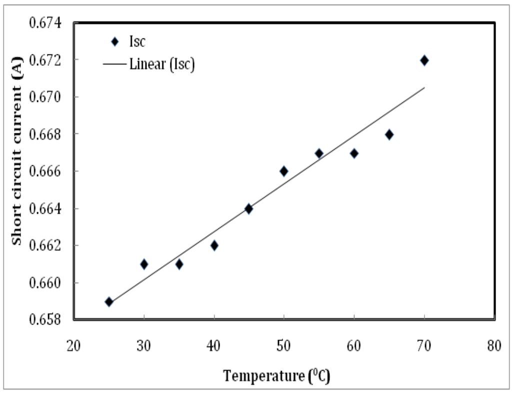


Figure 3 Temperature coefficient of short circuit current (mono C-Si sample : 10Wp)

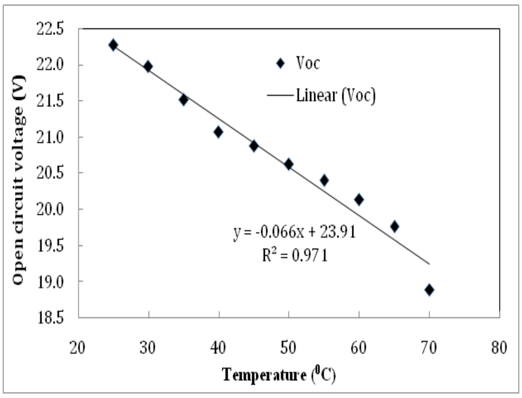


Figure 4 Temperature coefficient of open circuit voltage (mono C-Si sample : 10Wp)

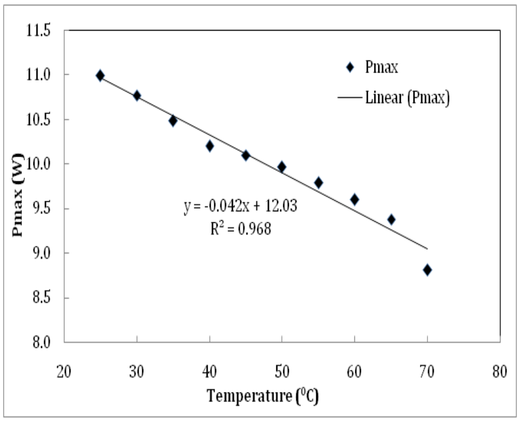


Figure 5 Temperature coefficient of power (mono C-Si sample: 10Wp)

Table 1 Temperature coefficient for different PV module technologies

| Type of PV module | Module peak output (Wp) | Temperature coefficient (%/°C) | | | Average temperature coefficient of power (%/°C) |
|---|---|---|---|---|---|
| | | current | voltage | Power | |
| Mono C-Si | 10 | 0.044 | -0.337 | -0.440 | -0.446 |
| | 74 | 0.025 | -0.336 | -0.479 | |
| | 40 | 0.034 | -0.336 | -0.455 | |
| | 75 | 0.037 | -0.323 | -0.428 | |
| | 12 | 0.029 | -0.359 | -0.483 | |
| | 12 | 0.027 | -0.295 | -0.394 | |
| Multi C-Si | 75 | 0.031 | -0.267 | -0.356 | -0.387 |
| | 75 | 0.059 | -0.369 | -0.506 | |
| | 12 | 0.036 | -0.291 | -0.373 | |
| | 50 | 0.046 | -0.264 | -0.346 | |
| | 50 | 0.033 | -0.291 | -0.396 | |
| | 300 | 0.054 | -0.306 | -0.428 | |
| | 75 | 0.001 | -0.058 | -0.329 | |
| | 75 | 0.002 | -0.075 | -0.364 | |
| a-Si | 3 | 0.098 | -0.294 | -0.234 | -0.234 |
| CdTe | 80 | 0.071 | -0.28 | -0.176 | -0.172 |
| | 80 | 0.034 | -0.197 | -0.168 | |

## IV. Conclusion

This work helps in understanding the variation in output from a particular PV technology due to variation in operating temperature only. It is found from the analysis that CdTe photovoltaic modules seems to be better option in hot climates considering the temperature loss to be minimum due to low temperature coefficient. This study is planned to extend for generating data with more number of modules to predict the trend of temperature coefficient of power with respect to different rated module of a particular technology in the different climatic zones of India. It is important to have a technology mapping based on energy yield for each PV technology for different climatic zones so as to get maximum possible return from the project investment.

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