A Simulation of the Role of Computer Networks in Increasing the Overall Efficiency of Solar Panels by Photovoltaic and Thermoelectric System Designing

Y.V. Vorobiev*

*Professor, Computer Networks, Berlin Institute of Technology, Germany. E-Mail: yvorovnetwork@gmail.com

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Abstract--- In environments where there is an elevation in temperatures, there is likely to be a problem in photovoltaic (PV) modules' performance, especially in the outdoor. Particularly, elevations in temperature tend to cause a significant loss in the devices' efficiency of energy conversion, standing as high as 25% loss in the efficiency of conversion. In the roofs, the form of module integration dictates the degree to which there is a loss in conversion efficiency. The implication is that when the modules are cooled, the performance of PVs tends to be enhanced. This study proposed a system design in which the back of PV modules had thermoelectric (TE) converters attached to it, translating into a hybrid module that constituted a PV-TE interface. The motivation of the study was to steer improvements in the efficiency of the target solar panels that would use the integrated PV-TE hybrid system design. It is also notable that pn-junctions, with a large area, were employed toward generating thermoelectric power. Along the pn-junctions, an application of temperature gradients saw the two forms of carriers' flux to the cold zone, having originated from the hot zone. Compared to other conventional techniques proposed previously for generating thermoelectric power, the proposed PV-TE module was found to yield beneficial outcomes in terms of reduced cost and increased efficiency. At a sample temperature such as 83.00C, specific findings demonstrated that the proposed solar panel system design with PV-TE interface increases the efficiency of the cells to about 10.92%, having been recorded initially (the efficiency) at 6.80% under the same temperature (of 83.00C). Thus, simulations via computer networks are seen to play a beneficial role of informing improvements in solar panel designs, hence enhanced efficiency.

Keywords--- Pn-junctions, Solar Panel, Photovoltaic (PV) Module, Thermoelectric (TE) Conversion, PV-TE Hybrid System.

I. INTRODUCTION

CURRENTLY, environmental pollution is a major problem facing many cities and industrial communities. However, this problem comes at a time when there is a growing demand for raw materials and fuel or energy sources, yet the rate at which the latter are being exhausted is alarming (Bjørk & Nielsen 2015). In a quest to address high energy consumption, strategies have been developed to ensure that fossil energy consumption is addressed. Particularly, there has been growing attention towards the use of renewable and new sources of energy, with solar power unexceptional (Chavez-Urbiola, Vorobiev & Bulat 2012). For solar power or panels, one of the mechanisms through which electricity is generated from the sun involves the photovoltaic effect. Through this option, the direct role of the photovoltaic effect ensures that there is the conversion of solar energy into electricity (Cui, Xuan & Li 2016).

In the recent past, statistical outcomes suggest that for PV technologies, the dominant materials that have been used involve GaAs (Li, Xuan, Li & Hong 2017). Despite their growing use, Li, Zhou, Song, Zhao and Ji (2018) and Li, Witharana, Cao, Lasfargues, Huang and Ding (2014) cautioned that GaA-based solar cells are expensive compared to cells developed using crystalline silicon. Due to this drawback, polycrystalline silicon or sliced single crystal cells have been utilised in developing over 80.0 percent of solar cells around the world (Liao, Lin & Yang 2014). Even at a time when cost-effectiveness accounts for the latter dominance of the cell types, the technology's commercial breakthrough is yet to be realised due to the temperature

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effect, as well as dilemmas regarding the solar cells' long-term stability (Lorenzi, Contento, Sabatelli, Rizzo & Narducci 2017). The mixed outcomes regarding the beneficial effects and drawbacks of the various types of solar cells have also attracted growing attention among experts regarding how efficiency could be increased while ensuring that the costs are reduced (Narducci & Lorenzi 2016). With efficiency observed to be affected mostly by the operating cell temperature, some of the specific physical parameters that have proved important and worth examining include the fill factor, light absorption, open-circuit voltage, and short-circuit current.

II. Materials and Methods

In this study, a factor that was kept constant was that the TE module absorbed the heat emanated in the form of waste solar energy. For the large area pn-junctions that were developed in the proposed TE power generation technique, six main areas and parameters were on the focus. They included the cold side, the hot side, the n-layer, the p-layer, the pn-junction that was located between the n-layer and the p-layer, and the temperature gradient as a parameter that was used to predict how the proposed module was likely to reduce costs while increasing the efficiency. The figure below highlights a large area pn-junction.

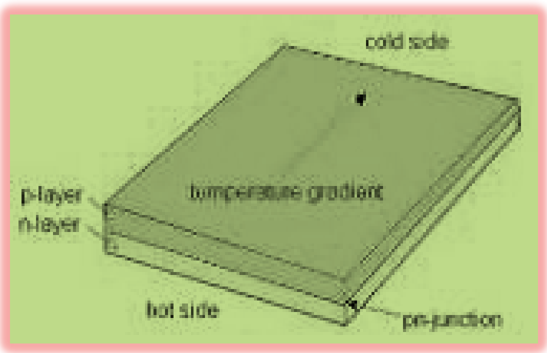

Figure 1 - An Illustration of Temperature Gradient Interaction in a Large Area Pn-junction
Source: Tyagi, Kaushik and Tyagi (2012)

Of importance to note is that the p-n junction electrons deviate from conventional TE devices whereby it is through thermal coupling that the generation of hole-pairs is achieved. In this study, the proposed model strived to ensure that even at higher temperatures, the arrangement or module would outperform conventional TE devices in such a way that there would be a considerable improvement in efficiency, arising from an arrangement in which there is an increase in the generation of electron-hole pairs. Particularly, the improvement was poised to arise from the attribute of the temperature gradient. From the previous literature, the pn-junctions' potential gradient, which is in-built, separates electron-hole pairs, with the latter having been generated thermally.

In the later phases of the experiment, the pn-junctions had the temperature application along them used to generate fluxes of the two types of carriers, emanating from the cold zone and the hot zone. With layers of p and n-type exposed to selective contact, the outcome was a series of circular currents that were directed to power sources and external loads in the form of TE elements. The figure below summarises this experimental setup.

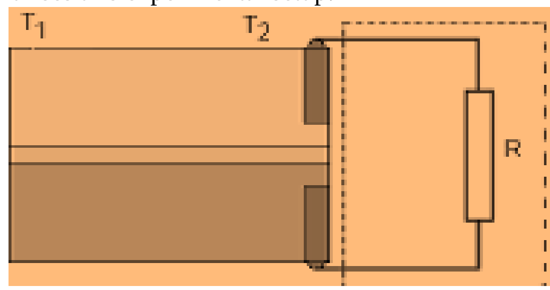

Figure 2 - Summary of the Experimental Setup for the Proposed PV-TE Interface (System Design)

In the arrangement above, which was adopted in the proposed model, one material type was used to make the TE element. Given this provision, the proposed model avoided possible mechanical tension that could have, otherwise, been experienced between two parts. An additional beneficial effect that was poised to accrue from this arrangement was that the proposed model was likely to counter fatigue that could have also arisen from thermal cycling.

III. Results and Discussion

For the simulation results, the findings were reported for the PV module and the TE module before establishing the generated power and the efficiency of the proposed PV-TE model.

Table 1 - Input Parameters and their Associated Experimental Values

Input parameter	Experimental value(s)
τp	$1.0x10^{-6}$
τn	$1.0x10^{-6}$
Nn	$1.0x10^{18}$
np	$1.0x10^{17}$
Wn	$3.0x10^{-1}$
Wp	$1.0x10^{2}$

Having identified the parameters of concern in the experimental setup (and their associated experimental values under simulation), the next step of the initial phase was to determine the relationship between temperature increase and the behavior of the parameters on the solar cell, with the PV simulation process on the focus. The following figures summarise the results that were obtained regarding the relationship between temperature increase and solar cell parameter behaviors.

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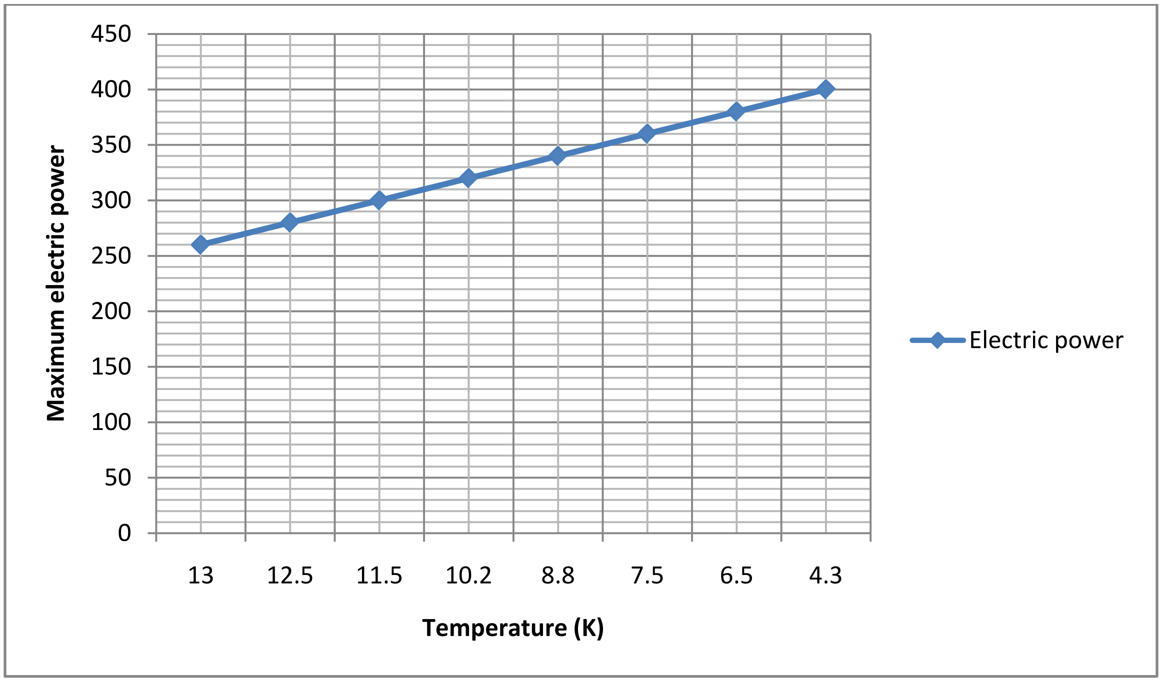

Figure 3 - An Illustration of the Relationship between Temperature and the Silicon p-n cell's Maximum Electric Power

Based on the figure above, this study established that for the p-n silicon solar cell, there was an about 25-percent reduction in performance efficiency with an increase in temperature. Even in situations where the same irradiance values were considered, but different temperature values applied, the resultant trend was a decrease in the efficiency values. The next step in the simulation involved an examination of the relationship between temperature adjustment for the silicon p-n cell and the open-circuit voltage and maximum voltage.

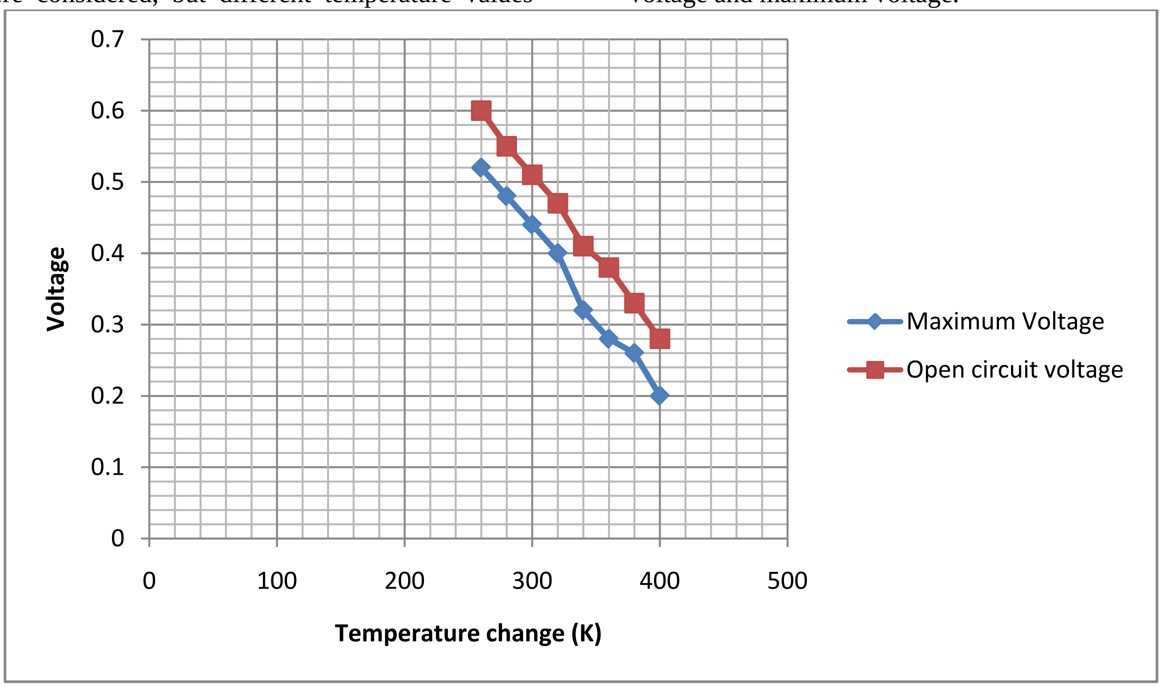

Figure 4 - The Relationship between Open-circuit Voltage (and Maximum Voltage) and Temperature Variation

Based on the results presented in the figure above, it was established that as the coefficient (*C*) increased, the efficiency of the cell decreased. For different values of C in the PV module, the ambient temperature was kept constant and set specifically at 25^{0}C. The table below qualifies this inference regarding the study's realisation of an inverse relationship between efficiency and the coefficient parameter – for the PV module simulation.

Table 2 - A Summary of the Study's Established Inverse Correlation between Efficiency and the Coefficients

Value of C (coefficient)	Temperature value in K	Percentage efficiency
0.0200	318.00	9.20
0.0270	325.00	8.60
0.0360	334.00	8.30
0.0580	356.00	6.80

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It is also worth noting that the study proceeded to examine how the silicon p-n cell's current density in the PV simulation was likely to be affected by the parameter of temperature. The figure below highlights the trend that was obtained regarding the interaction between the cell's current density and the impact of temperature variation.

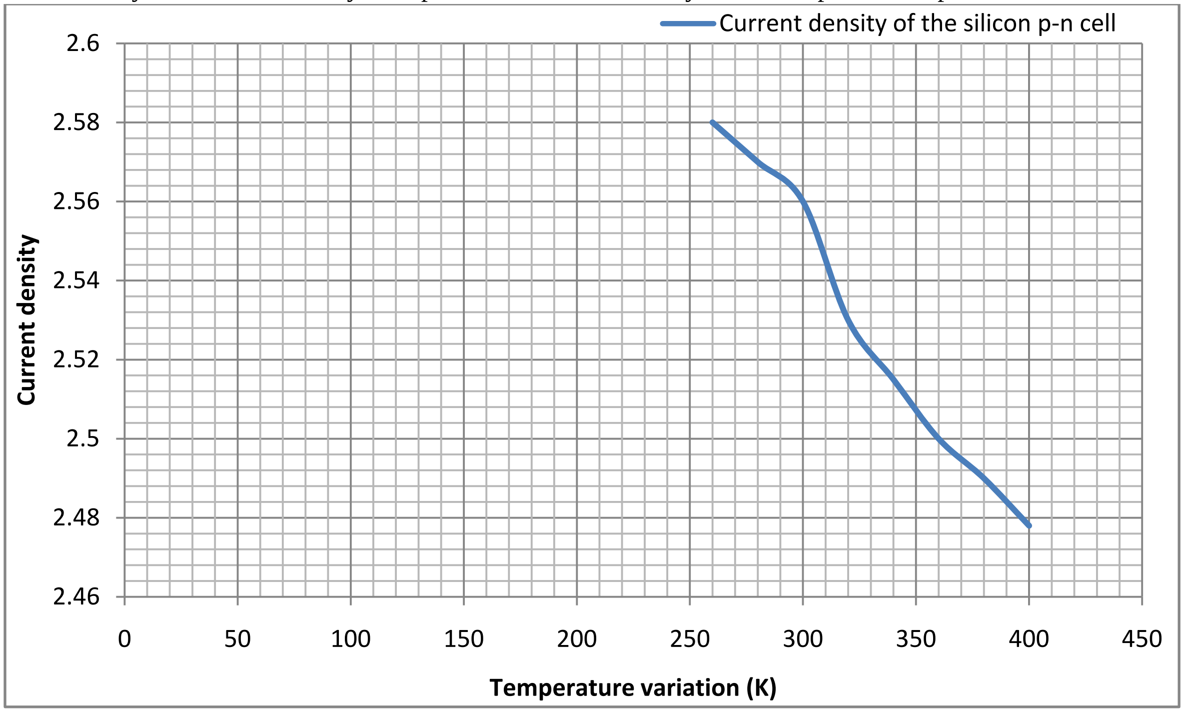

Figure 5 - A Summary of the Relationship between the Silicon p-n cell's Current Density and Temperature Variation

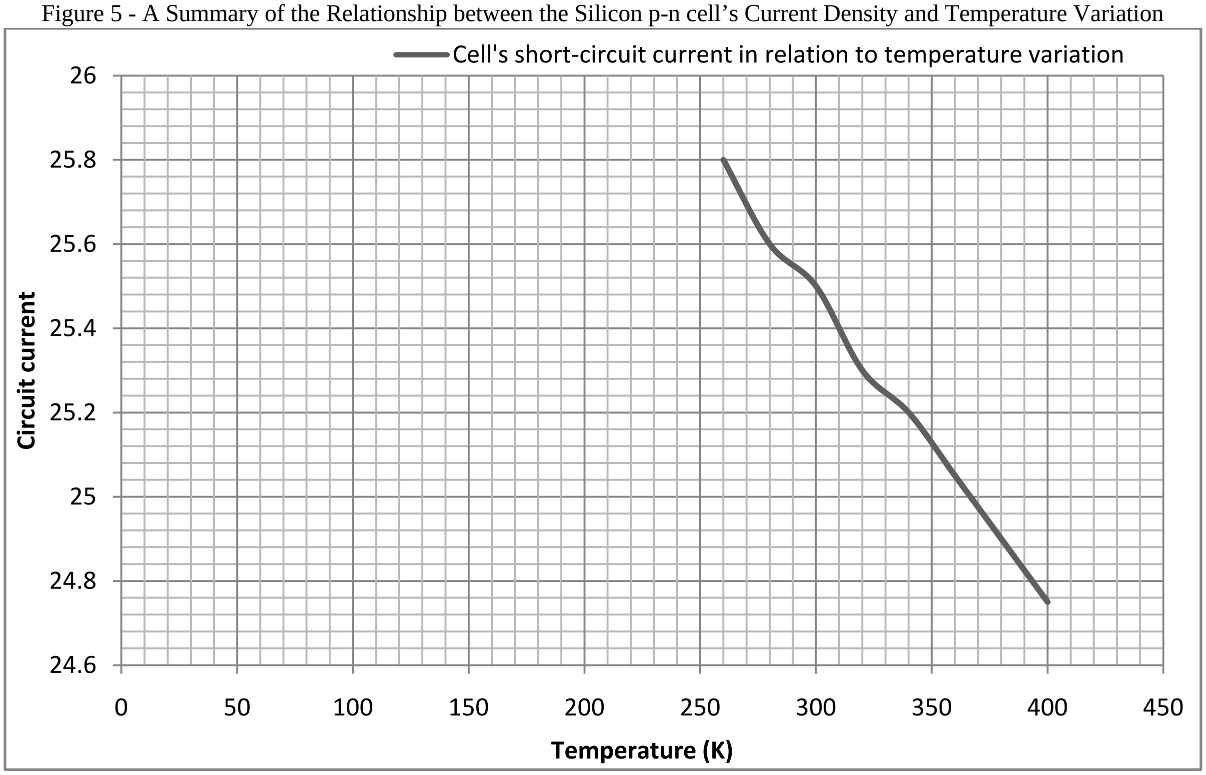

Figure 6 - Relationship between Circuit Current and the Temperature of the Silicon p-n cell

From Figure 7 above, the experimental results demonstrated that as temperature (in K) increases, the cell's circuit current in the PV simulation decreases. It is also imperative to highlight that in the first phase, which constituted PV simulation, the relationship between the silicon p-n cell's fill factor and temperature variation was investigated. The results that were obtained are summarised in Figure 8 below.

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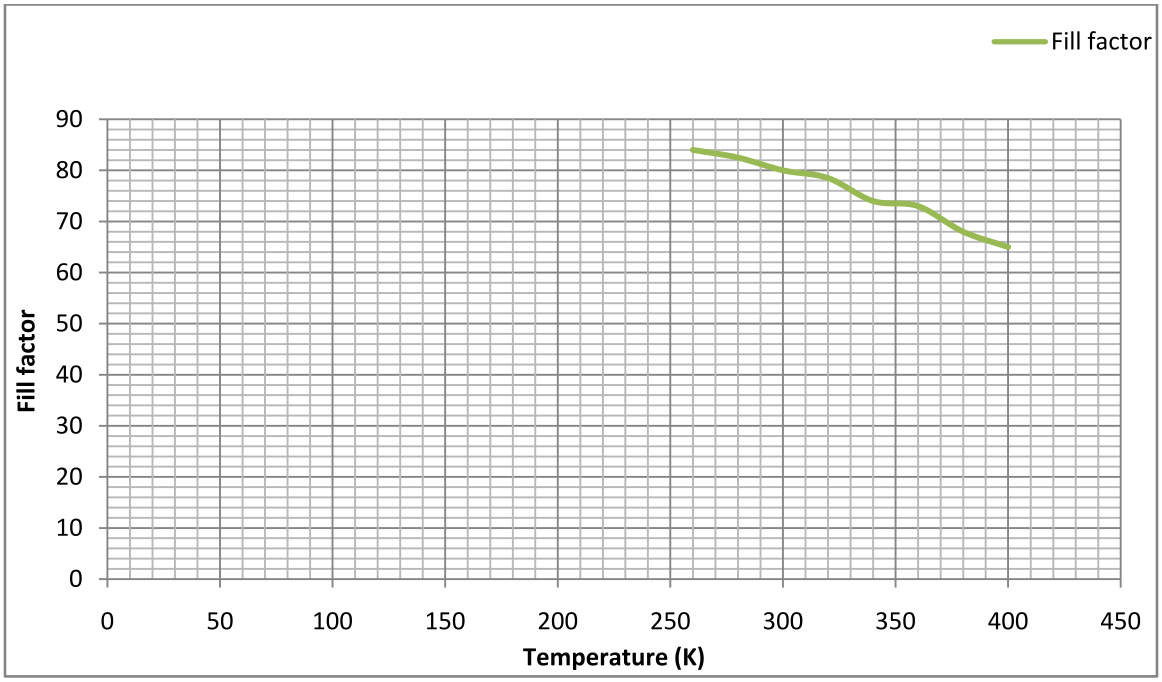

Figure 7 - The Relationship between the Silicon p-n cell's Fill Factor and Temperature Variation

Given different temperature values, the table below summarises the results that were obtained regarding power generation by the proposed PV-TE module.

Table 3 - The Generated Power for Different Temperature Values in the PV-TE Hybrid Framework

Coefficient value (C)	PV-TE generated electrical power
0.0200	92.1400
0.0270	86.5100
0.0360	85.1600
0.0580	109.2200

Transforming the values into a graphical form gives:

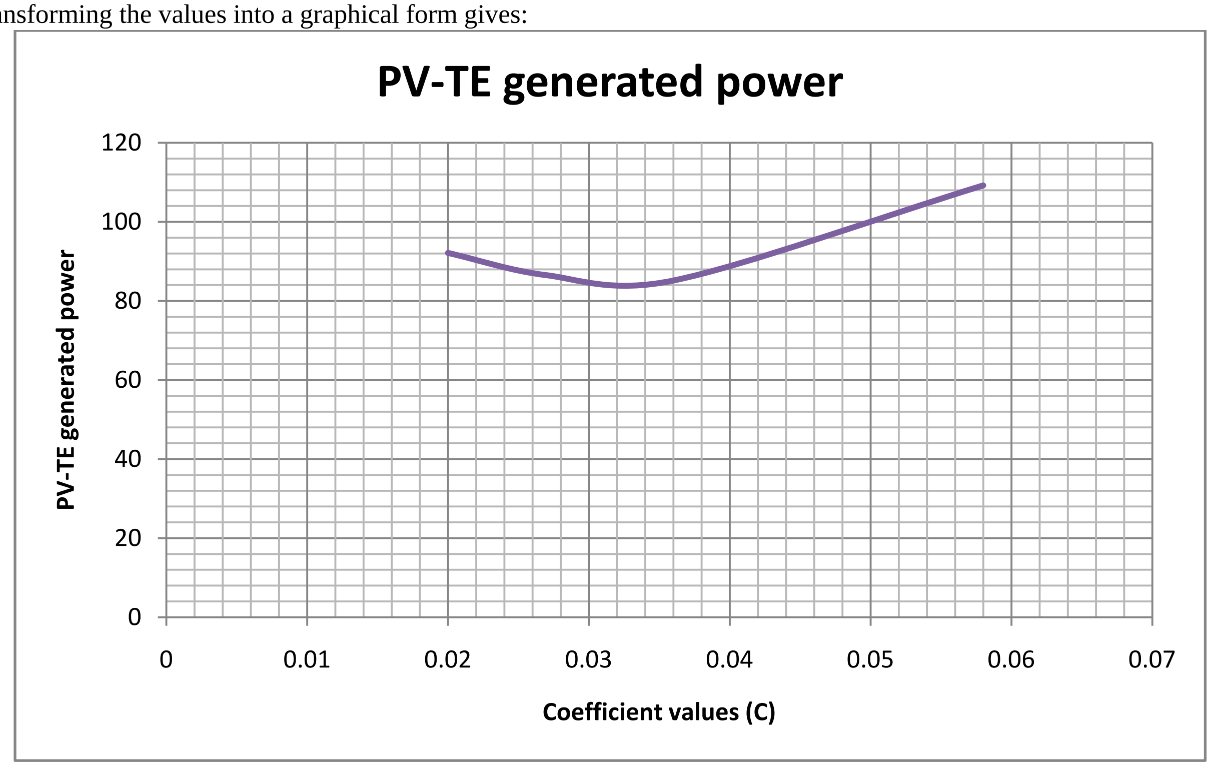

Figure 8 - The Proposed PV-TE Hybrid Module's Power Generation at Different Temperatures

IV. Conclusion

In summary, there is likely to be an estimated 25-percent reduction in solar cell efficiency if 100.00^0C temperature is considered, having increased significantly from room temperature. Therefore, this study proposed a PV-TE hybrid system involving solar cells with which a TE device is coupled. In this arrangement, experimental results pointed to an increase in the PV module's efficiency. It is also notable that the experimental setup utilised a pn silicon cell and a large area pn-junction TE framework, having been coupled with each other. From the simulation observations, an introduction of the TE device to the PV framework's back side causes an increase in the efficiency of the PV model, having conducted the investigated at a temperature set at 83.0^0C. Specifically, the range in which the efficiency was observed relative to the use of the proposed PV-TE hybrid system was 6.80 to 10.92 percent. Overall, factors that were observed to affect the performance of the proposed system (PV-TE) included how sufficient the back side is cooled (to achieve ambient temperature), the type of TE device material, and the type of framework integration.

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