Industrial Engineering Journal
ISSN: 0970-2555
Volume: 52, Issue 8, No. 1, August: 2023

EFFECT OF TEMPERATURE VARIATION ON THE PERFORMANCE OF A SOLAR CELL POWER CURVE

Sachin Vrajlal Rajani, Assistant Professor, Electrical Engineering Department, VVP Engineering College, Rajkot, Gujarat, 360005, sachin.rajani.el@vvpedulink.ac.in

Abstract
Solar cell modeling is one of the topics of interest since many years. Solar cell output power varies with the level of irradiation and temperature. The solar cells are designed considering the standard operating conditions of 25^0 C and 1000 W/m^2. In this paper, an attempt is made to understand measure the output power of solar photovoltaic system with variation of irradiance from 200 W/m^2 to 1000 W/m^2 and temperature variations from 20^0 C 40^0 C. Solar cell is modeled with a standard double diode model. MATLAB/Simulink® simulations are carried out for a system and current, voltage, power characteristics are also addressed. The temperature dependency of a solar cell and it mathematics is also given a due consideration. When the temperature is increased beyond the standard temperature for a solar cell, that is 25^0 C, its output is negatively impacted. This output variation due to temperature variation and keeping the irradiance level constant is also quantified.

Key words: Solar Cell, Modeling, Power Curve, Temperature Variations, MATLAB/Simulink®

I. Introduction
With the rising fuel prices and problems associated with the burning of fossil fuels, the focus of energy production is shifting largely towards renewable energy domain and especially towards solar photovoltaic energy. The stand-alone and grid connected solar photovoltaic systems have already become popular and gaining even more popularity in an exponential way [1-4]. Solar thermal power applications, solar heating applications and electricity generation applications are rising all around the world. Solar cells, also known as photovoltaic cells, are semiconductor devices that convert sunlight directly into electricity, offering a clean and renewable energy source. These cells work by utilizing the photovoltaic effect, where photons from sunlight dislodge electrons in the semiconductor material, generating an electric current. Solar cells come in various types, such as monocrystalline, polycrystalline, and thin-film, each with its own efficiency and cost considerations. The energy generated by solar cells can be harnessed for a wide range of applications, from powering homes and businesses to providing electricity for remote areas and space exploration. As technology advances, research continues to improve the efficiency, durability, and affordability of solar cells, contributing to the global shift toward sustainable and environmentally friendly energy solutions [5-11]. One of the research areas is the temperature dependency of a solar cell. In this paper, an attempt is made to address the dependency of solar cell and its power curve on temperature.

II. Materials and Methods
Materials and methods employed for the research work carried out are highlighted in the subsequent sections.

2.1 Modeling of a solar cell
A well-established two parallel diode solar cell model is shown in Figure 1. It is clear from the figure that it consists of a photovoltaic current source I_{ph}, two diodes D_1 and D_2, a parallel resistance Rp and a series resistance R_s. The output current, I for the model is given by an equation,

$$I = Iph - Is * (e^{(V+I*Rs)/(N*Vt)} - 1) - I_{s2} * (e^{(V+I*Rs)/(N_2*Vt)} - 1) - (V + I*Rs)/Rp \quad \ldots(1)$$

The photovoltaic generated current I_{ph} can be written as;

$$I_{ph} = I_{ph0} * (I_r/I_{r0}) \quad \ldots(2)$$

Industrial Engineering Journal
ISSN: 0970-2555
Volume: 52, Issue 8, No. 1, August: 2023

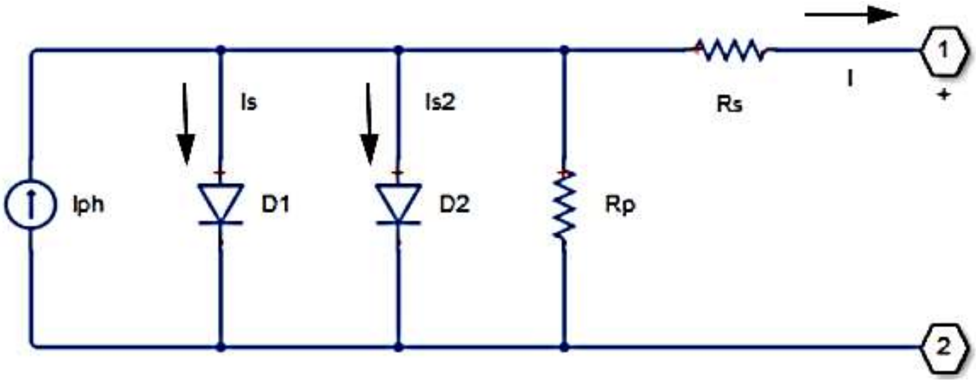

Figure 1. Two parallel diode-model of a solar cell.

In the above equations,

- I_r is the light intensity or irradiance in W/m^2, falling on the cell.
- I_{ph0} is the solar generated current measured for the irradiance I_{r0}.
- I_s is the saturation current for the first diode.
- I_{s2} is the saturation current for the first diode.
- V_T is the thermal voltage given by kT/q with k = boltzmann constant, T = Device simulation temperature and q = elementary charge of an electron.
- N = Quality factor or commonly known as the diode emission coefficient.

2.2 Simulating the solar cell with MATLAB/Simulink®

The complete solar cell parameters considered for the simulations are presented in table 2. The system taken for simulation is shown in Figure 2.

Table 1. Solar cell parameters

Parameter	Value
Diode saturation current Is	$3.015 * 10^{-7}$ A
Solar generated current for measurement I_{ph0}	3.80 A
Irradiance used for measurements, I_{r0}	800 W/m^2
Quality factor, N	1.4
Quality factor, N_2	2.0
Series resistance R_s	0.0042 Ohms
Parallel resistance, R_p	10.1 Ohms
Number of cells in series	700

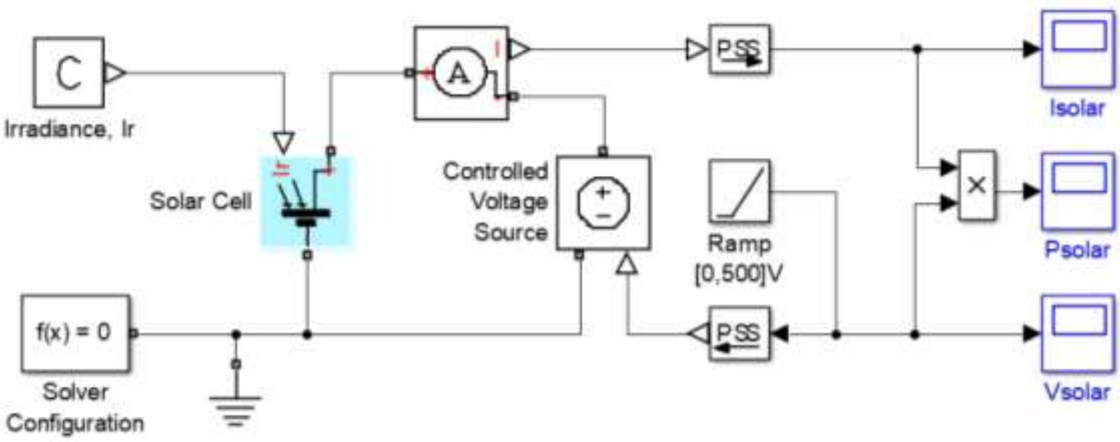

Figure 2. MATLAB/Simulink® model of a solar cell.

Industrial Engineering Journal
ISSN: 0970-2555
Volume: 52, Issue 8, No. 1, August: 2023

2.3 Temperature dependency of a solar cell

The known relationship between solar cell induced current Iph and a solar cell temperature T is;

$I_{ph}(T) = I_{ph} * (1+TIPH1 * (T-T_{meas})$ …(3)

Here,

TIPH1 is the first order temperature coefficient for I_{ph}.

T_{meas} is the measured temperature.

The temperature dependency parameters of a solar cell are presented in Table 2.

Table 2: The temperature dependency parameters of a solar cell

First order temperature coefficient for Iph, TIPH1	0.000805/K
Energy gap	1.14 eV
Temperature exponent for Is, TXIS1	3.38
Temperature exponent for Is2, TXIS2	3
Measuremt Temperature	25^0 C

III. Results and Discussion

With the above listed parameters in Table 1 and Table 2, a MATLAB/Simulink® model of a was simulated and results are presented hereunder.

3.1 Volatge, current and power variation

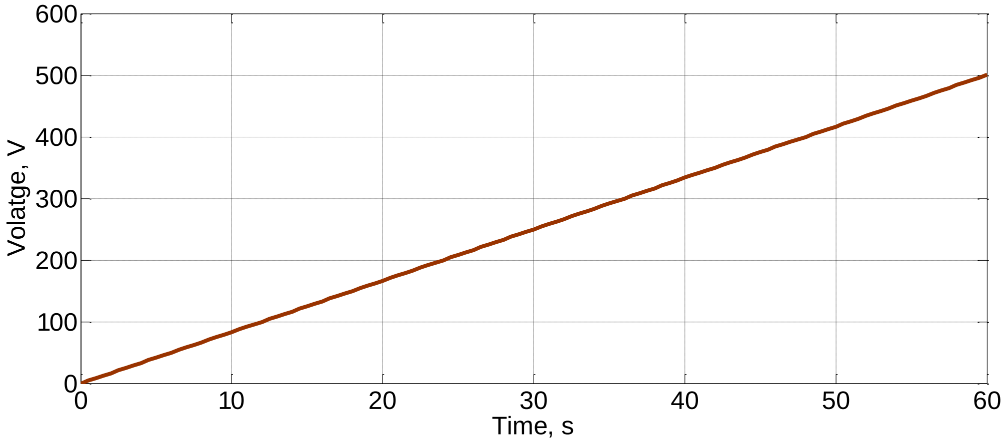

Figure 3. Volatge variation in the simulation

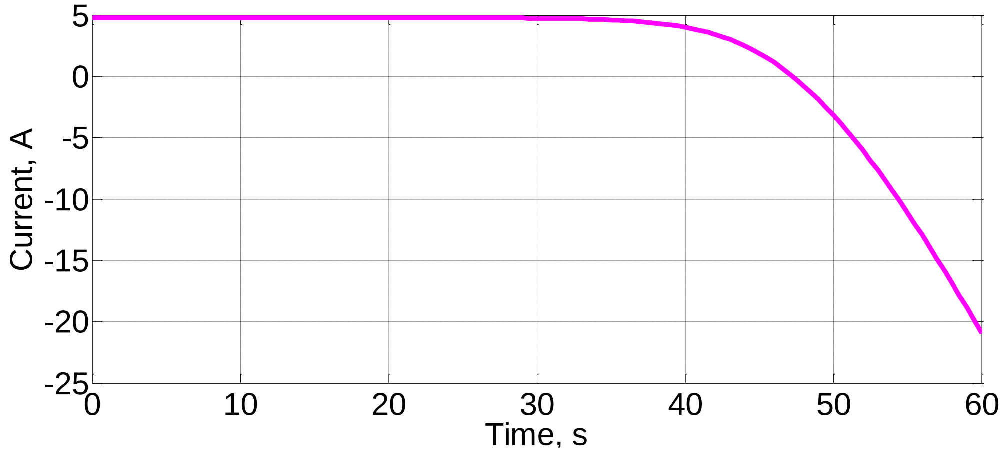

Figure 4. Current variation in the simulation

Industrial Engineering Journal
ISSN: 0970-2555
Volume: 52, Issue 8, No. 1, August: 2023

As shown in figure 3, ramp voltage was varied from 0 to 500 V in the time frame of 0 to 60 seconds. The current characteristics of a solar cell are shown Figure 4. Up to 37 to 38 s (from0 s) the current was constant, and it is going down 38 s onwards. The power for solar cell as it is producing DC, should be a straight multiplication of a voltage and a current. The power variation is shown in Figure 5 where peak power is also visible.

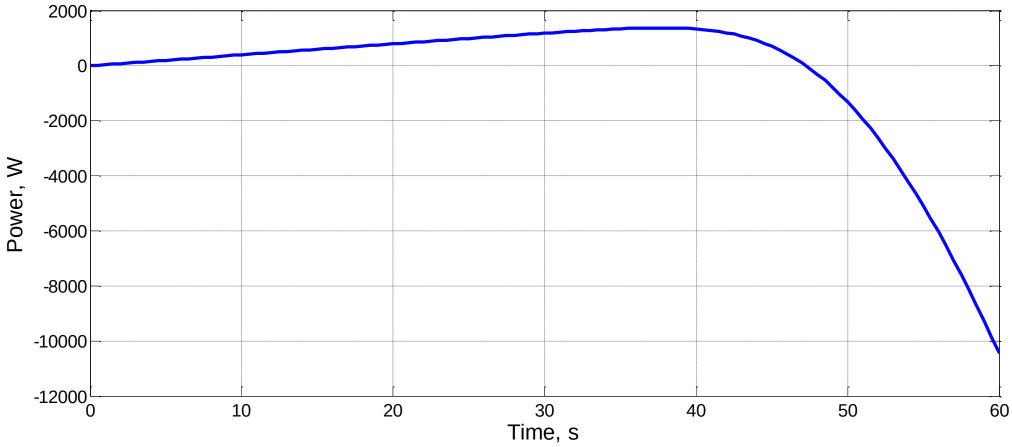

Figure 5. Power variation in the simulation

3.1 Variation of output power with irradiance variation and temperature variation

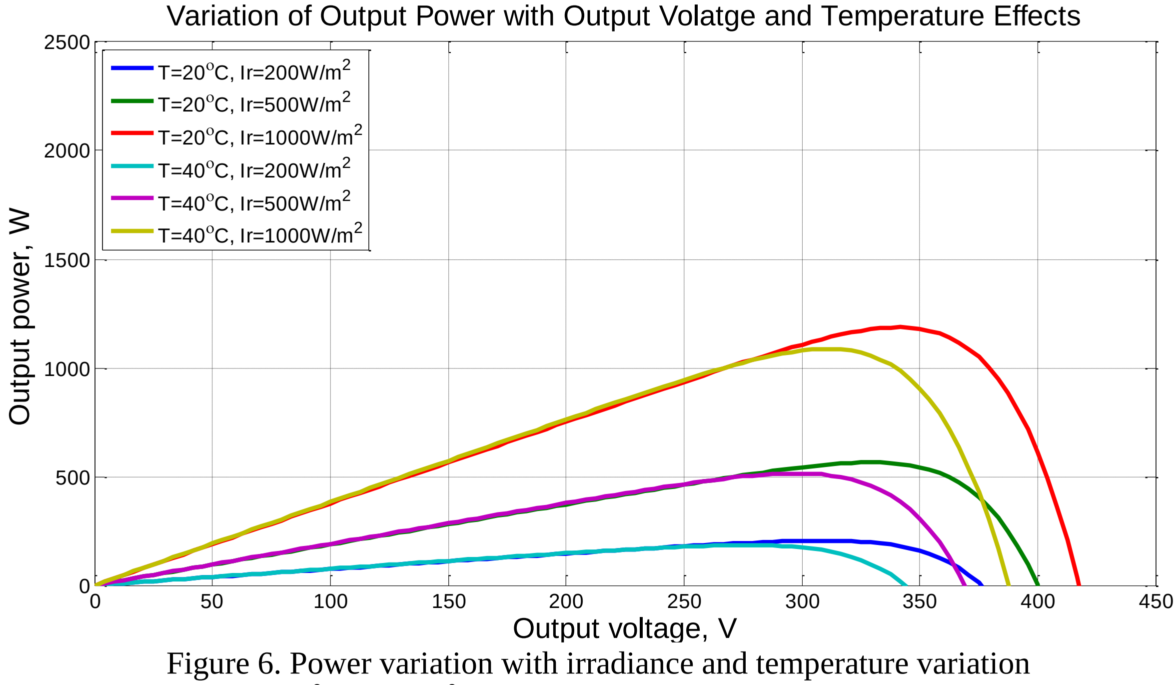

Figure 6. Power variation with irradiance and temperature variation

Two cases of temperature 20^0 C and 40^0 C were considered with the irradiance variation of 200 W/m^2, 500 W/m^2 and 1000 W/m^2 were taken for simulations. Various graphs of power-voltage (P-V Curve) are drawn for all these parameter variations. It is clear from Figure 5 that increasing the irradiance and keeping the temperature constant (20^0 C or 40^0 C), the power output of the solar photovoltaic system increases but when the cell temperature increases beyond 25^0 C, it creates negative impact on the performance of a solar cell. For example, at T = 20^0 C, and irradiance = 1000 W/m^2, redline shows the output. Whereas, at T = 40^0 C, and irradiance = 1000 W/m^2, yellow line shows the output. It is clear from the Figure 6 that the final output power variation with these two curves is approximately 10%+. It means that solar cells are negatively affected by higher temperatures.

IV. Conclusion

The paper presents the idea of checking the performance of a solar cell with respect to the variation of temperature and irradiance level. When the temperature was kept constant and irradiance was increased, the solar photovoltaic output t=which is linearly proportional to the irradiance level, also increases. But, when the solar cell temperature was increased from 20^0 C to 40^0 C, keeping the irradiance level same as 1000 W/m^2, the output of the solar cell was negatively impacted. For a temperature increment of 40^0 C - 20^0 C = 20^0 C, this output power decrement can be as high as 10%+.

VI. Conflict of interests: There is No conflict of interests for the author regarding this research work and a research paper.

VII. Acknowledgement

This work is sponsored by Gujarat Council on Science and Technology (GUJCOST), Gandhinagar, India. This work is supported by V.V.P. Engineering College, Rajkot.

References

[1] Shih-Ming Chen; Tsorng-Juu Liang, Ke-Ren Hu, Design (2013), "Analysis, and Implementation of Solar Power Optimizer for DC Distribution System", IEEE Transactions on Power Electronics Vol. 28, 2013, pp.1764–1772.

[2] F. L. Luo and H. Ye (2004), "Positive output multiple-lift push-pull switched capacitor Luo-converters", IEEE Trans. Ind. Electron., Vol. 51, 2004, pp.594–601.

[3] Mohamed S. Emeara, Ahmed F. AbdelGawad, Ahmed El Abgay (2021), "Orientation-Optimization Simulation for Solar Photovoltaic Plant of Cairo International Airport", The Egyptian International Journal of Engineering Sciences and Technology, Vol. 33, 2021, pp. 45–56.

[4] Sachin Vrajlal Rajani, Vivek J Pandya (2016), "Experimental verification of the rate of charge improvement using photovoltaic MPPT hardware for the battery and ultracapacitor storage devices", Solar Energy, Vol. 139, 2016, pp. 142 – 148.

[5] Panel Stefano Pasini, Donato Spoltore, Antonella Parisini, Stefano Marchionna, Laura Fornasini, Danilo Bersani, Roberto Fornari, Alessio Bosio (2023), "Innovative back-contact for Sb2se3-based thin film solar cells", Solar energy, Vol. 249, 2023, pp. 414–423.

[6] Savita Kashyap, Jaya Madan, Rahul Pandey, Jeyakumar Ramanujam (2022), "22.8% efficient ion implanted PERC solar cell with a roadmap to achieve 23.5% efficiency: A process and device simulation study", Optical Materials, Vol. 128, 2022, pp. 112–121.

[7] Sachin Vrajlal Rajani, Dr. Vivek Pandya, Varsha A Shah (2016), "Experimental validation of the ultracapacitor parameters using the method of averaging for photovoltaic applications", Journal of energy storage, Vol. 5, 2016, pp. 120–126.

[8] Sachin Vrajlal Rajani, Vivek J Pandya (2015), Simulation and comparison of perturb and observe and incremental conductance MPPT algorithms for solar energy system connected to grid, Sadhana, Vol. 40, 2015, pp. 139–153.

[9] P Kapil, C Vibhakar, S Rajani, K Bhayani (2013), Voltage Sag/Swell Compensation Using Dynamic Voltage Restorer (DVR), International Journal of Application or Innovation in Engineering & Management, Vol. 4, 2013, pp.1–6.

[10] L. Zhang, K. Sun,Y. Xing, L. Feng, and H.Ge (2011), "A modular grid-connected, photovoltaic generation system based on DC bus" IEEE Trans. Power Electron., Vol. 26, 2011, pp. 523–536.

[11] W. Derouich, M. Besbes, J.D. Olivencia (2014), "Prefeasibility Study of a Solar Power Plant Project and Optimization of a Meteorological Station Performance", Journal of Applied Research and Technology, Vol. 12, 2014, pp. 72–79.