Irradiation and Temperature effects on Modified SEPIC Converter Performance for PV Systems

ABDEL-KARIM DAUD, SAMEER KHADER
Department of Electrical Engineering
Palestine Polytechnic University (PPU)
P.O. Box 198, Hebron
PALESTINE

Abstract: - The changing position and nature of the sun due to changes in ambient temperature and irradiance level throughout the day is the main difficulty with photovoltaic (PV) systems. This leads to fluctuations in power levels. Therefore, maximum power point tracking (MPPT) under these conditions is the main challenge. This paper proposes a new approach for directly operating at the maximum power point (MPP) at any value of solar irradiation and cell temperature without applying further mathematical processing to operate at that point. This technique is applied to a PV system containing a high-static-gain modified single-ended primary coil MSEPIC converter, which is characterized by high efficiency and high gain voltage. The performance of this converter is obtained with respect to load and output voltage variation under different climatic conditions in Hebron, Palestine. Solar panel type LG450N2W-E6 is selected as the PV generator in this system with 450 W at 41.1 V at MPP. The proposed model is analyzed and simulated in Matlab/Simulink, and m-file code.

Key-Words: **-** Modified SEPIC Converter, PID Controller, Photovoltaic Source, PWM, MPPT.

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1 Introduction

Renewable energy (RE) resources are being progressively integrated into power systems to support a continuous increase in power generation due to the limitation of fossil fuel supply and to reduce negative environmental impacts [1]. Among the RE resources, the energy from the solar photovoltaic (PV) effect can be considered the most necessary and sustainable resource due to its ubiquity, large quantity, and sustainability [2].

This PV system consists of solar panels, a DC chopper, a smoothing unit, and a power management unit for operating the generator at maximum extracted power, called the Maximum Power Point Tracker (MPPT) [3, 4]. Usually, photovoltaic systems operate at a point near the point of maximum power, known as MPP, in order to obtain maximum system efficiency.

Therefore, the need for an MPPT system is an essential stage in the energy conversion procedure to obtain maximum energy with reduced switching losses of the chopper and minimized overall system losses at high efficiency. There are several MPPT techniques used to track the maximum power of the PV system, such as Perturb and Observation (P&O), Incremental Conductance (IC), and Fuzzy Logic Control (FLC) [5, 6]. The P&O method uses iteration procedures for reaching maximum power at the knee of power performance. The IC method uses a similar iteration process that uses the change in current rather than the change in power with respect to the voltage, while the FLC method with artificial intelligence implementation is used very successfully when applied for MPP searching and the sliding mode control.

The P&O approach is the one that is most frequently utilized among the others because it is so straightforward. Despite this, this approach performs well in conditions when the sun's irradiance and temperature change slowly over time. It takes a long time and cannot follow the MPP rapidly, which results in power loss before achieving the MPP value due to oscillation and iteration, as well as voltage stress being generated across the chopper switch as a result of duty cycle change.

In this paper, the simulation model is built for direct detection of the maximum power at any value of solar irradiation and temperature during the daytime without oscillation around the MPP for a modified single-ended primary-inductance DC-DC Converter (MSEPIC), as shown in Fig. 1 [7-9]. Closed-loop feedback control with a PID controller based on a triggering system is developed for the MSEPIC converter to maintain a constant output voltage, as shown in Fig. 2. The proposed model is analyzed and simulated in Matlab/Simulink, and m-file code.

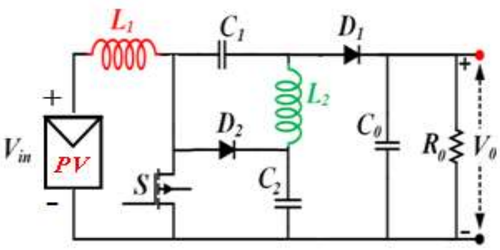


Fig. 1: Modified SEPIC Converter [14]

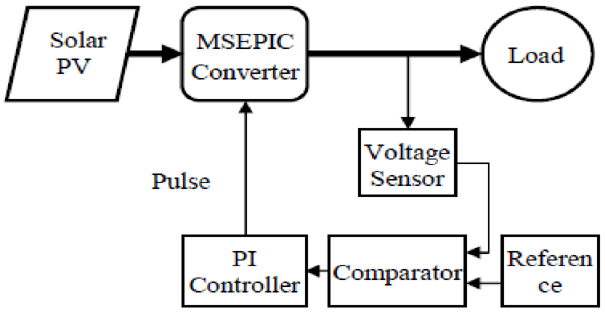


Fig. 2: Block diagram of closed loop MSEPIC converter

2 Mathematical Modelling

For the simulation issue, the solar panel type LG450N2W-E6 with 450 watts peak and a conversion efficiency of 20.5% is used, and the panel I-V and P-V performances are shown on Fig. 3 for various irradiation rates [10]. From Fig. 3, the main useful PV parameter values (V_{MPP}, I_{MPP} and P_{MPP}) are determined for various irradiation rates at 25 °C, which are declared in Table 1 [11].

Table 1. PV data at MPP for LG450N2W-E6

G(W/m^2) / Para-meters	1000	750	500	250	100
V_{MPP}, V	41.8	41.70	41.52	40.68	39.16
I_{MPP}, A	10.79	8.07	5.37	2.69	1.08
P_{MPP}, Watt	451	336.4	223	109.4	42.29

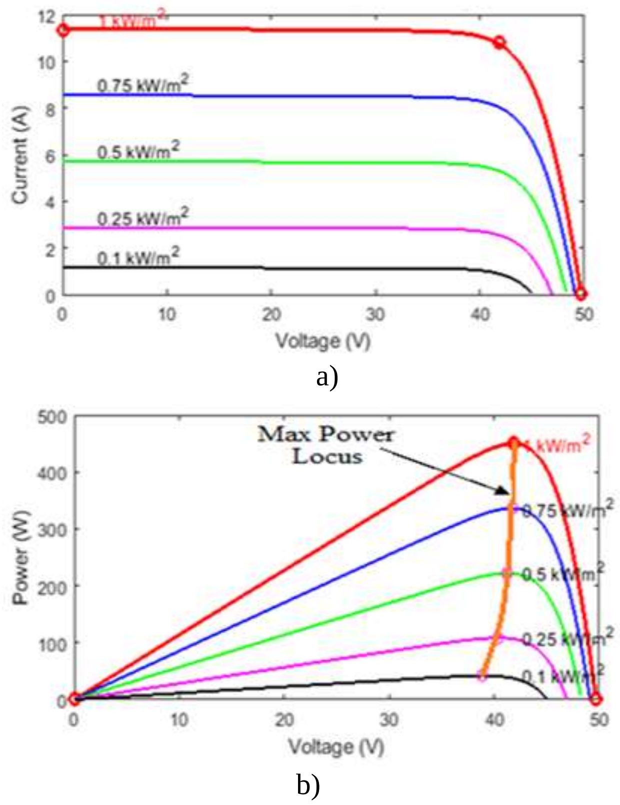


Fig. 3: Characteristics solar panel type LG450N2W-E6: a) I-V and b) P-V characteristics

However, this I-V curve of the PV array relies on irradiance and temperature conditions. When the irradiance increases with constant temperature, the PV current also increases in direct proportion, with negligible effect on the PV voltage. Similarly, if the temperature increases with constant irradiance, the PV voltage decreases substantially while the PV current increases slightly. Hence, a tracking algorithm known as MPPT is needed to regulate the PV panel output, which varies non-linearly with irradiance, temperature, and load.

2.1 Voltage and Power Equations

Let's start with the data specification related to the solar panel type LG450N2W-E6, where the voltage is displayed in Fig. 4a with an interpolated equation stated in (1), while the power performance versus irradiation has a linear change and is presented as a first-order equation (2) as shown in Fig. 4b. It's shown that the MPP voltage shows a slight change when the irradiation varies from weak to full sun. The interpolated voltage equation is presented as follows:

$$V_{MPP} = a_4 Z_V{}^4 + a_3 Z_V{}^3 + a_2 Z_V{}^2 + a_1 Z_V + a_0 \quad (1)$$

where

$$Z_V = \frac{G_T - 485.70}{328.80}; \text{ and}$$

$$a_4 = 0.04477; \ a_3 = 0.05022; \ a_2 = -0.2980;$$

$a_1 = 0.7952;\quad a_0 = 40.13.$

While the power equation can be stated as follows:

$$P_{MPP} = 148\, Z_V + 218.6 \tag{2}$$

2.2 Solar Irradiation Calculation

In order to determine the maximum power at a given irradiation, it is necessary to determine the daily solar irradiation at any time of the year [4, 12, 13] as follows:

$$\mathrm{G(t)} = \mathrm{G_{max}} \sin\left(\frac{\pi}{\mathrm{T_d}}(\mathrm{t} - \mathrm{t_{sr}})\right);\quad \text{for } \mathrm{t_{sr}} \le \mathrm{t} \le \mathrm{t_{sr}} + \mathrm{T_d} \tag{3}$$

where t_{sr}, t_{ss}, T_d are the sunrise time, sunset time, and day duration, respectively. These parameters are briefly described in [12–14]. G_{max} is the solar radiation at noon.

2.3 Effect of temperature

For a given daily temperature change at any time of the year, with discrete values or an interpolated equation, and taking into account the effect of irradiation changes according to (3), the general equations of the MPP voltage and power are expressed as follows:

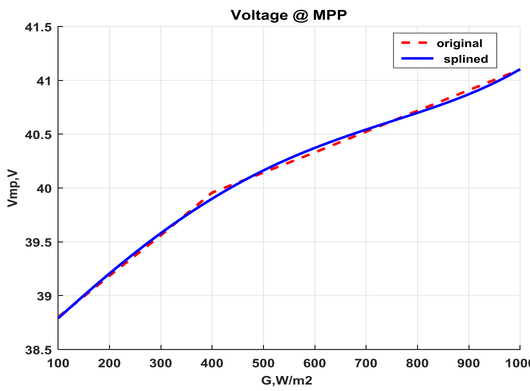
$$\mathrm{V_{MPP}(T_t, G_T)} = \mathrm{V_{MPP}(G_T\,, STC)} * \left[1 - \frac{\Delta V}{^{\circ}C}(\mathrm{T_t(t)} - 25)\right] \tag{4}$$

$$\mathrm{P_{MPP}(T_t, G_T)} = \mathrm{P_{MPP}(G_T, STC)} * \left[1 - \frac{\Delta P}{^{\circ}C}(\mathrm{T_t(t)} - 25)\right] \tag{5}$$

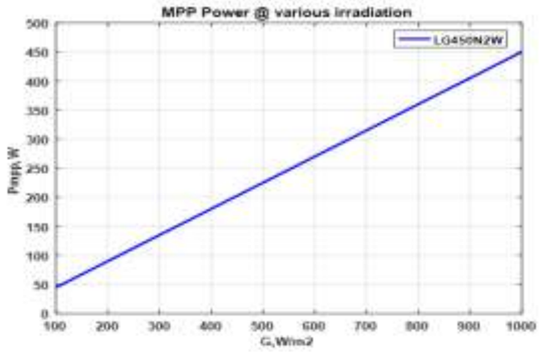
where

$$\frac{\Delta V}{^{\circ}C} = -0.26\,\%\,\frac{V}{^{\circ}C};\quad \frac{\Delta P}{^{\circ}C} = -0.33\,\%\,\frac{W}{^{\circ}C_4}.$$

V_{MPP} (STC) and P_{MPP} (STC) are the rated panel voltage and power at full sun and standard test conditions. The obtained results related to voltage and powers at MPP are displayed in Fig. 4 for various irradiations of the LG450N2W-E6 solar panel type.



a) Voltage at MPP



b) Power at MPP

Fig. 4: Voltage and power at MPP for various irradiations of solar panel type LG450N2W-E6

3 Simulation Results and Discussion

The derived equations for solar irradiation, power, and duty cycle at MPP are simulated using the MATLAB/SIMULINK platform for MSEPIC, as shown in Fig. 1. The built-in simulation program is illustrated in Fig. 5.

The proposed MPP approach is now applied to real measured data taken from a weather station installed over the roof top of the university buildings, where the irradiation rate for May 23, 2022, is shown in Fig. 6, while the real temperature measured for the same date is shown in Fig. 7 [15].

The generated equations for irradiation (G_T) and temperature (T_t) are stated in (12) and (13) as follows:

$$\mathrm{G_T(t)} = \delta_4 Z_g^4 + \delta_3 Z_g^3 + \delta_2 Z_g^2 + \delta_1 Z_g + \delta_0 \tag{6}$$

$$\mathrm{T_t} = 0.21\, Z_t^4 + 3.2\, Z_t^3 - 2.4\, Z_t^2 + 3.2\, Z_t + 19; \tag{7}$$

where

$$Z_g = \left(\frac{t - 11.61}{4.062}\right),\quad Z_t = \left(\frac{t - 1.6}{0.88}\right)$$

and

$\delta_0 = 999.6\,;\ \delta_1 = 1.441e - 13;\ \delta_2 = -410.71\,;$
$\delta_3 = 2.491e - 14;\ \delta_4 = 25.46\,.$

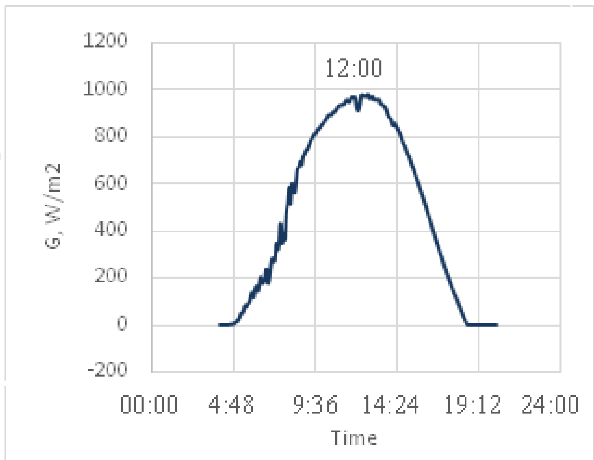


Fig.6: Measured real irradiation

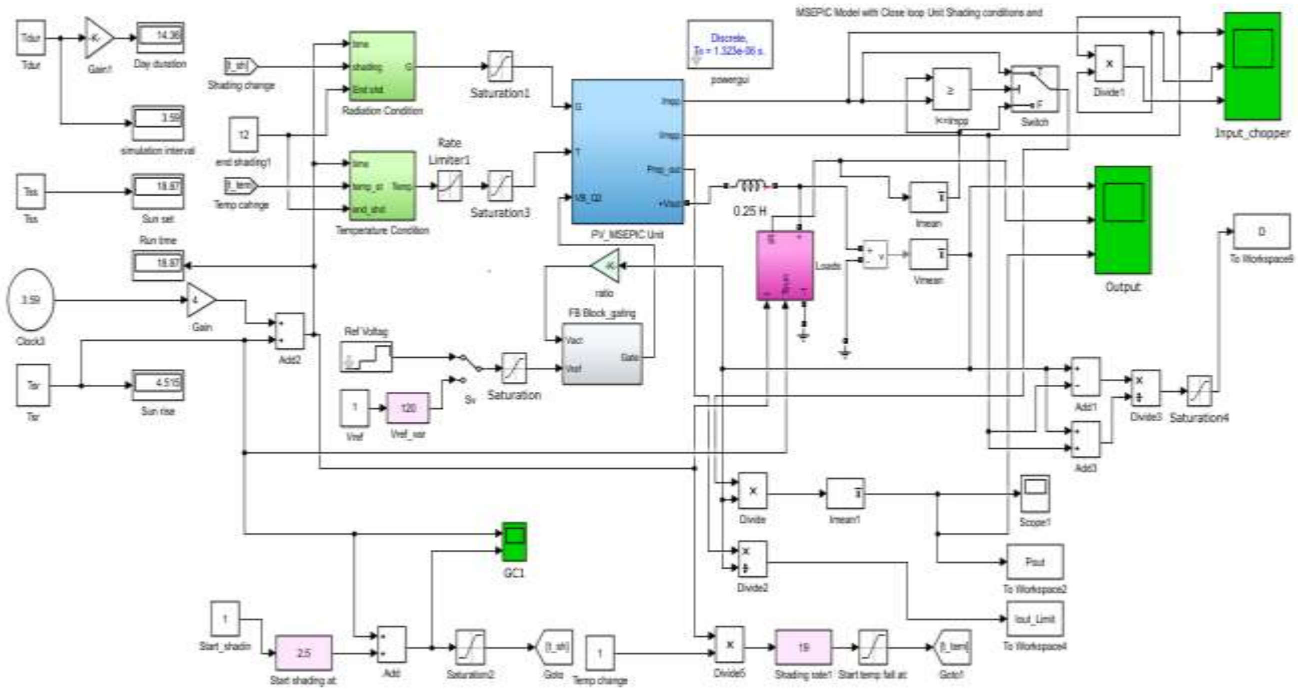


Fig. 5: Matlab/ Simulink Model

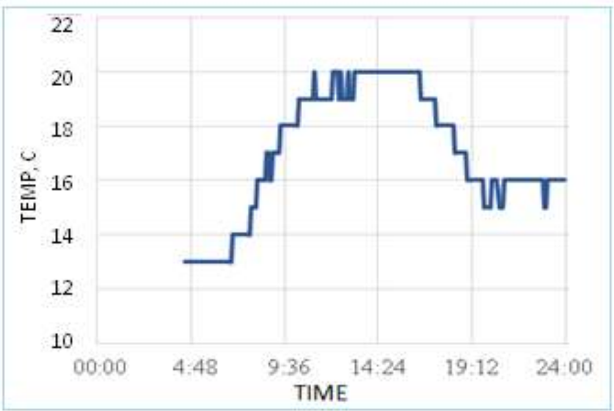


Fig.7: Measured real temperature

After generating approximated equations for both irradiation and temperature, the MPP voltage and power [9] are calculated according to (4) and (5) and displayed on Fig. 8, taking into account the effect of temperature change for performance test conditions.

It can be noticed that the MPP voltage is higher than that of STC because the maximum temperature for that day (May 23rd, 2022) was detected at around 20°C at noon time. The MSEPIC chopper duty cycle is expressed according to (8) in order to generate PWM pulses capable of regulating and boosting up the MPP voltage according to the reference values [9]:

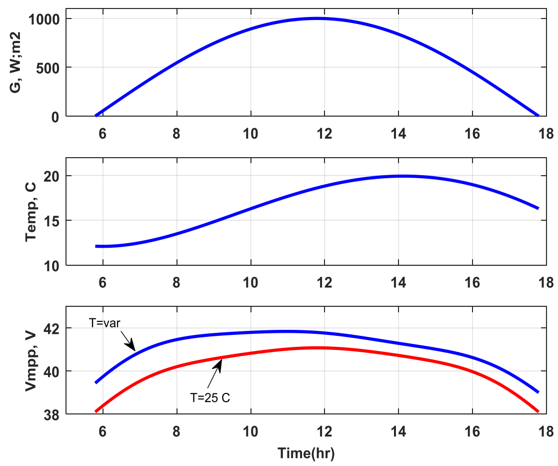


Fig. 8 MPP voltage at various irradiation & temperature

$$D(t) = \frac{V_{REF} - V_{MPP}}{V_{REF} + V_{MPP}} \quad (8)$$

Figure 9 shows the continuous character of solar irradiation and temperature changes on May 23, 2022, taken from the weather station installed over one of our university buildings. A duty cycle is generated, and MPP power is treated as input to the chopper parameters, while the output parameters are reference voltage, load voltage, current, and output power under various loading rates.

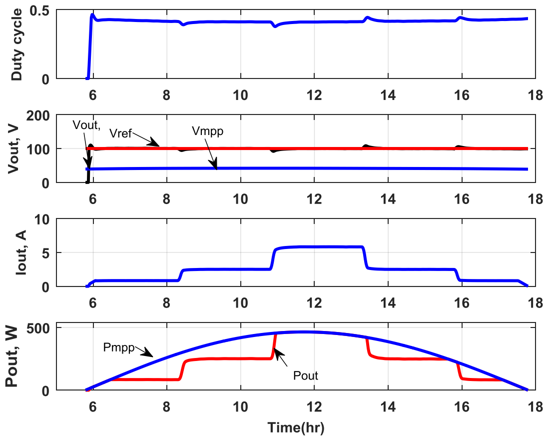


Fig.9: Main Input -output performances of the proposed system

4 Conclusion

The proposed new approach presents a simple and fast-responding method to determine the MPP voltage and power at continuous changes in irradiation and temperature, while till now, proposed MPPT methods did not take into consideration the continuous change in temperature during irradiation changes.

Furthermore, applying such an approach reduces the voltage stresses and oscillations across the chopper elements, leading to better efficiency and voltage stability.

The proposed approach used the PV key specification provided by the panel's manufacturer at different irradiation rates, where a continuous power function was derived for MPP points without running any kind of iteration procedure.

The proposed model validation was verified based on the real measured data for solar irradiation and panel temperature.

For future research, a hardware prototype model should be built and experimentally implemented in order to practically validate the discussed analytical and simulation results. This should be the main objective of the upcoming article.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Abdel-Karim Daud has performed the literature review, carried out the mathematical model, analyzed the numerical results, discussed the results, drawn a conclusion, and finalized the paper.

Sameer Khader implemented the SIMULINK model and presented building performances, conclusions, and paper preparation.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.