

MODELING AND SIMULATION OF 1.8 KW GRID-CONNECTED PHOTOVOLTAIC SYSTEM USING MATLAB

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Abstract: A maximum power point tracking (MPPT) DC/DC converter for a photovoltaic (PV) system is an important component in a PV system. The converter is used to convert the value of DC voltage produced by PV panels to a value accepted by the inverter for on-grid, or battery for off-grid system. In addition, the MPPT is used to extract and maintain the solar PV to its maximum power in all conditions. However, the values of components used in literature of MPPT DC/DC converter for a specific PV module cannot be applied for different capacity. Although sets of equations are given in literature to determine the values of inductor and capacitor used in the circuit, the calculated values do not produce the desired output in most cases because of unclear explanation. The validation of input parameters of the converter is also not properly presented for different solar irradiance and temperature. The efficiency of the converter is still low. Hence, this paper presents step-by-step process on how to design a MPPT DC/DC boost converter in MATLAB/Simulink environment. The incremental conductance method is used as MPPT algorithm to control the duty cycle of the converter. Then, a thorough analysis is done by simulating the developed model under different solar irradiance and temperature. Simulation results are then compared with the theoretical values from I-V and P-V curves of the selected PV modules. The results show that the proposed MPPT DC/DC converter is able to extract maximum power from PV modules and the output power produced by the converter also indicates that the converter has a high efficiency at 99.7% in all selected values of solar irradiance and temperature.

Keywords: PV system, MATLAB/simulink, MPPT, DC/DC boost converter, incremental conductance method.

Introduction

Among the renewable energy (RE) sources, solar energy has become the world's fastest growing energy technology due to factors such as the PV system utilizing the most abundant RE resource on the planet, i.e. the sun, low maintenance, low solar PV prices compared to other RE technology (Kusch-Brandt, 2019) and can be mounted on a small or large scale. Unlike large-scale PV plants, small-scale PV systems offer solar potential assessments in urban areas, do not cost land and reduce transmission and distribution costs. Therefore, increasing the number of installations of this system is important and related research has been growing in the literature.

To understand the behavior and dynamic characteristics of the PV system, mathematical models are widely used in the literature using MATLAB/Simulink software to model components in the PV system and vary the input parameters to the PV modules to observe the output of the system (Al-Shamani *et al.*, 2017; Al-Waeli *et al.*, 2018; Bellia *et al.*, 2014; Krismadinata *et al.*, 2013) the techno-economic assessment of a Grid-Connected Photovoltaic Thermal (GCPVT. A grid-connected PV system (Huang *et al.*, 2017) consists of PV modules, MPPT DC/DC converter and inverter to convert the DC into AC signal compatible to the grid standard. Whereas, in the off-grid system (Ghafoor & Munir, 2015) Pakistan (31.42°N, 73.08°E, 184 m, the battery is used to interface

between MPPT DC/DC converter and inverter, to store the energy from PV modules and is also as a power supply to a DC load. The MPPT DC/DC converter is a key component to ensure the PV modules operate at maximum point in all weather conditions, thus increasing the efficiency of the PV system.

A number of researchers have studied the models of MPPT DC/DC converter in the literature. The research on these components can be categorized into two, first they focus on the design of the converter (Mohamed *et al.*, 2016; Raj *et al.*, 2020; S.Sheik & Devaraj, 2014; Sahu *et al.*, 2016) daily available, and environment friendly renewable energy source. All PV modules provided in markets gives 12 or 24V (2 up to 5 A and second, they improve MPPT techniques (Ahmed & Salam, 2015; Alik & Jusoh, 2018; Loukriz *et al.*, 2016; Tey & Mekhilef, 2014). To design the converter, it involves determination of inductor and capacitor values used in the circuit. Different equations were used in literature and the performance of the system is measured by efficiency. Meanwhile, research that focus on improving MPPT techniques cater to the problems in transient analysis such as overshoot, ripples, and response time during drastic changes in solar irradiance or temperature. Among the MPPT techniques proposed in the literature, the incremental conductance (IncCond) is complex but more efficient compared to the most popular and simple method, Perturb and Observe (Jain *et al.*, 2018).

From the literature, there is room for improvement in designing the MPPT DC/DC converter, especially on the validation and efficiency of the system. Mohamed *et al.* (2016) and Sahu *et al.* proposed a MPPT DC/DC boost converter, but the validation of the developed models for different solar irradiance and temperature were not done, and they only

focus on the improvement of transient states using PI and fuzzy logic controllers (Mohamed *et al.*, 2016) daily available, and environment friendly renewable energy source. All PV modules provided in markets gives 12 or 24V (2 up to 5 A). S.Sheik and Devaraj (2014) discussed PV characteristics under different solar irradiance and temperature using current-voltage (I-V) and power-voltage (P-V) curves. However, the presented results only focus on the output voltage and current without considering the effect of converter on PV parameters. They did not use MPPT but the duty cycle was set manually. Gomathy *et al.* (2012) discussed the input and output parameters of converter under different solar irradiance, however, their PV voltage changed in similar trends as PV current and power, which is not true based on the theoretical values. In terms of efficiency, (Raj *et al.*, 2020) proposed different types of MPPT DC/DC converters, however, their methods only tested Standard Test Conditions (STC) condition and produced low efficiency with the highest at 93.98%. The highest efficiency of MPPT DC/DC converter system found in literature was proposed by Sahu *et al.* (2016) at 97.54%.

Hence, this research focuses on designing, modeling and simulation of the MPPT DC/DC boost converter using MATLAB/Simulink software. The block diagram of the system is shown in Figure 1 and the MPPT technique used in this study is IncCond. This study shows the process, step-by-step on how to calculate the converter circuit. Then, the validation of the converter is presented by comparing the PV parameters obtained from the simulation and theoretical values from I-V and P-V curves under different solar irradiance and temperature. The duty cycle generated by the MPPT algorithm is also presented to confirm the operation of the written algorithm. The output parameters of the converter are also discussed and the efficiency of the system is determined for all cases.

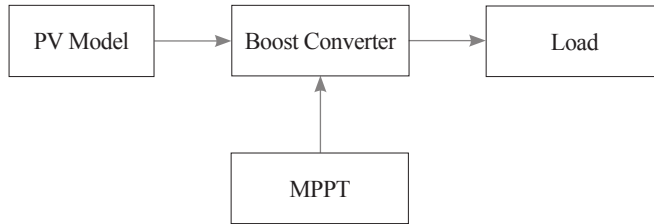


Figure 1: The block diagram of GCPV system

Materials and Methods

The model of PV and boost converter circuit are shown in Figure 2.

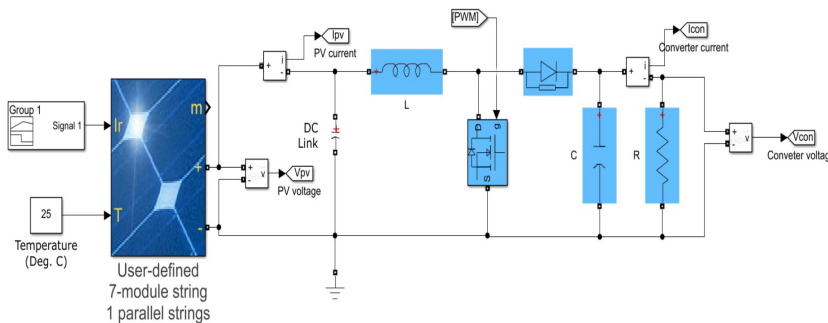


Figure 2: Model of PV and boost converter circuit in MATLAB/simulink

The model is developed in MATLAB/Simulink. The details of the model are explained as the following:

PV Model

The specifications of the PV model at STC, with ambient temperature at 25°C and the solar irradiance is at 1000 W/m² are shown in Table 1.

Table 1: PV module characteristics at STC for a module

PV Module	Specifications
STC power rating	260 W
Maximum point voltage, V_{mp}	31.1 V
Short circuit current, I_{sc}	8.98 A
Maximum point current, I_{mp}	8.37 A
Open circuit voltage, V_{oc}	38.1 V

The proposed PV model consists of seven modules of 260 W. Figure 3 below shows the graph of current versus voltage, or known as I-V curve for the modules used in the model. Since the seven modules are connected in series, the PV voltage increased and the PV current is maintained. In Figure 3, a new V_{oc} of seven modules is 266.7 V, obtained by multiplying the corresponding voltage for a single module by seven. By varying solar irradiance, the current produced by PV vary accordingly. The lower the solar irradiance, the lower the PV current generated. However, the V_{oc} is almost constant as the temperature is maintained at 25°C and is not affected by the change in solar irradiance. The power versus voltage, or known as P-V curve is also shown. Maximum power point obtained from seven modules is 1822 W at 217.7 V for STC. Similarly, it can be clearly seen that the changing in solar irradiance changes the maximum power point accordingly, but the voltages are almost constant.

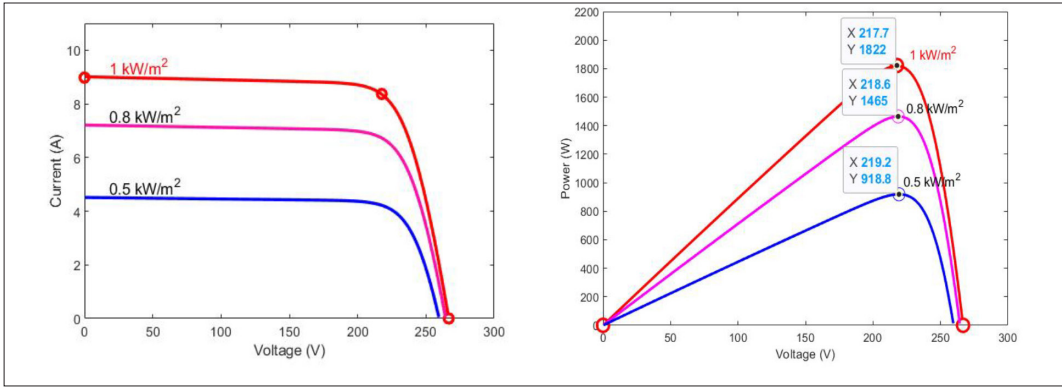


Figure 3: I-V and P-V curves of seven modules PV model under different solar irradiance

The I-V and P-V curves under different temperatures at a constant solar irradiance 1000 W/m² are plotted in Figure 4 and it can be clearly observed that varying the temperature

changes the and maintains the current produced by solar panel. From the P-V curve, the higher the temperature, the lower the maximum power point.

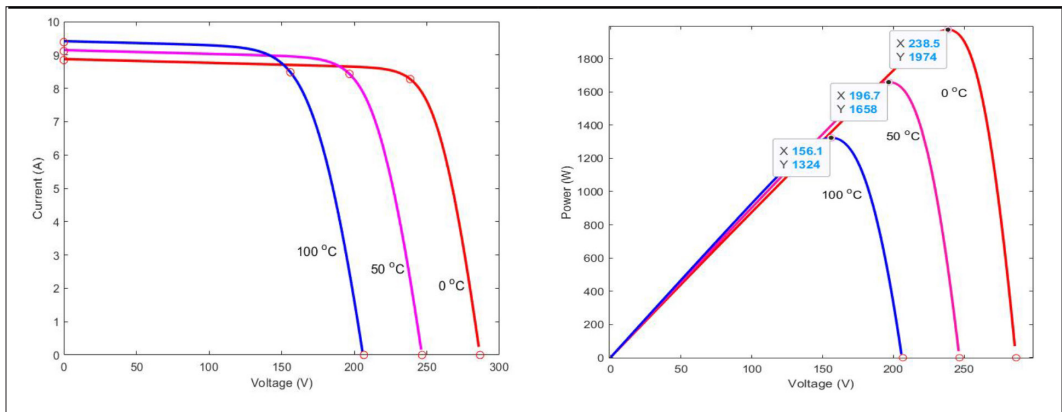


Figure 4: I-V and P-V curves of seven modules PV model under different temperatures

Develop Boost Converter Model

To design a boost converter for this PV system, the value of duty cycle, D is calculated using equation (1).

$$D = 1 - \frac{V_{IN}}{V_{OUT}} \tag{1}$$

Since PV output is connected directly to the converter input, and this design considers at STC, then $V_{IN} = V_{mp} = 217.7$ V and V_{OUT} is a desired output voltage that is set at 500V, then D can be obtained as 0.5646. Then the suitable

load, R can be computed from Ohm’s Law, $V_{OUT} = I_{OUT}R$ by assuming the converter is ideal as in equation (2).

$$P_{IN} = P_{OUT} = V_{IN}I_{IN} = V_{OUT}I_{OUT} \tag{2}$$

R in this case is equal to 137.2 Ω. To find the inductance value L, the following equation can be used:

$$L = \frac{V_{IN} \times D}{\Delta I_L \times f_s} \tag{3}$$

where f_s = switching frequency, ΔI_L = inductor current ripple. The inductor ripple current

is normally set between 25% to 40% of root mean square (RMS) input current. In this study, the ripple current is set at 30% of I_{IN} which is equal to 2.511 A. Then, the L can be computed from equation (3) and the value is 1.958 mH, considering the switching frequency is equal to 25 kHz.

To compute the value of the boost converter, the following equation is used:

$$C = \frac{V_{OUT} \times D}{2 \times R \times f_s \times \Delta V_{OUT}} \quad (4)$$

where ΔV_{OUT} is output voltage ripple, that has taken 5% of ΔV_{OUT} , which is 25 V. The calculated value of C is 1.646 uF. It is also noted that the value of DC link capacitor is set at 0.5 mF. This value is obtained by trial and error method where it can be seen that the higher the value of the capacitor, the longer is the time taken by the capacitor to reach the V_{OC} based on equation (5). By trial and error with simulation time, t , the suitable value of the capacitor can be obtained.

$$I_{PV} = C_{dc\ link} \frac{dV_{PV}}{dt} \quad (5)$$

MPPT Model

From I-V curve in Figure 3, the current of PV panel is almost constant for certain range and drops drastically at one point to zero. In other words, as $P = IV$, the higher the I or the V , the higher the P . However, as can be observed from P-V curve of Figure 3, the P increases as the V increases during constant I , and after maximum point of P , the P drops as the I drops to zero. To ensure the PV output constantly produce maximum power, the switching of boost converter must be controlled at pulse width modulation (PWM) using MPPT technique. The algorithm of IncCond method is written in MALTAB Function with the inputs are PV voltage and current and the output is a duty cycle as illustrated in Figure 5. The details of the algorithm can be found in (Gomathy *et al.*, 2012).

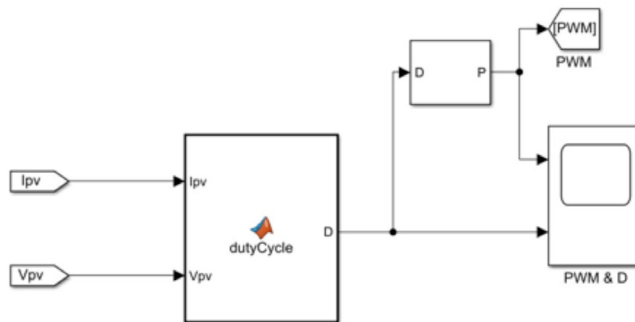


Figure 5: The simulink model of IncCond method

Results and Discussion

This section is divided into two subsections which are the results before and after the MPPT technique is applied to the system. Without MPPT algorithm, the duty cycle of boost converter is changed manually, meanwhile using the MPPT technique, the value of duty cycle is generated by the MPPT to be applied on MOSFET to ensure the PV power is always maximum at different solar irradiance.

Performance of the DC/DC Converter without MPPT

Before the boost converter is connected to MPPT block, the PWM of the converter is connected to pulse generator and its duty cycle, D is changed manually. For this case, the solar irradiance is set at STC condition. The results show input and output power of boost converter at $D = 0.3$, $D = 0.6$ and $D = 0.8$ in Figure 6 to Figure 8, respectively.

From Figure 6, it can be seen that when the duty cycle is set lower ($D = 0.3$) than the ideal calculated $D = 0.5646$, the output PV produced is 1216 W and the RMS power output boost converter is 1134 W. When the duty cycle is set higher ($D = 0.6$) than the calculated duty cycle, it is found that the output PV is 1423 W and output

boost converter is 1319 W. The output of boost converter is worse when the duty cycle is further increased at $D = 0.8$ where the output power boost converter drops to 159.9 W and PV output power is 181 W. For all selected duty cycle, the PV power produced is not at maximum point as referred to Figure 3.

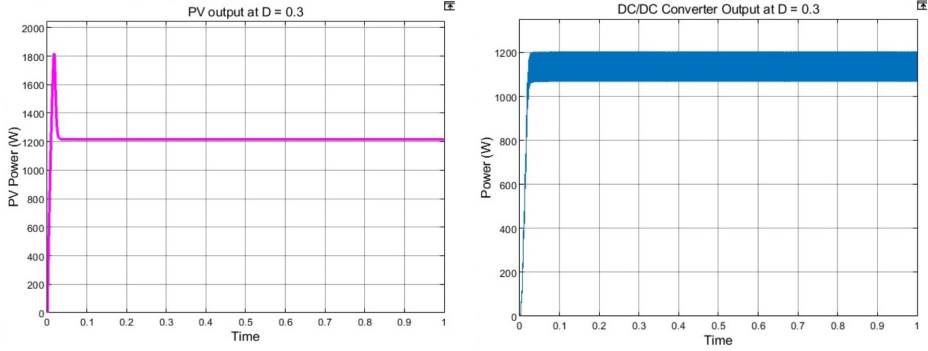


Figure 6: Input and output power of boost converter at $D = 0.3$

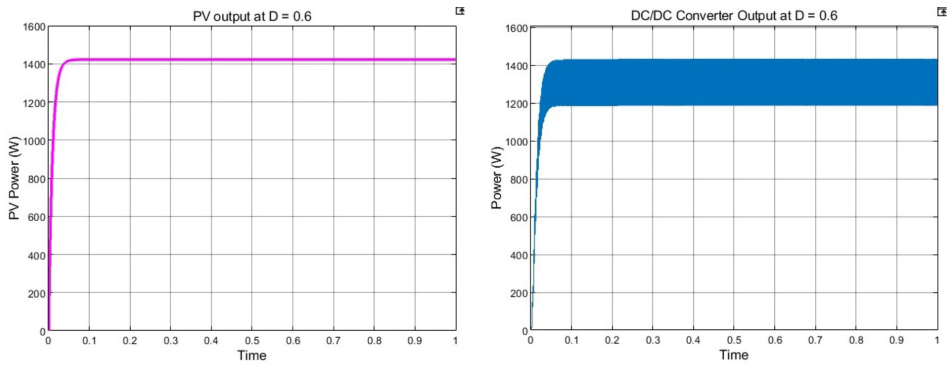


Figure 7: Input and output power of boost converter at $D = 0.6$

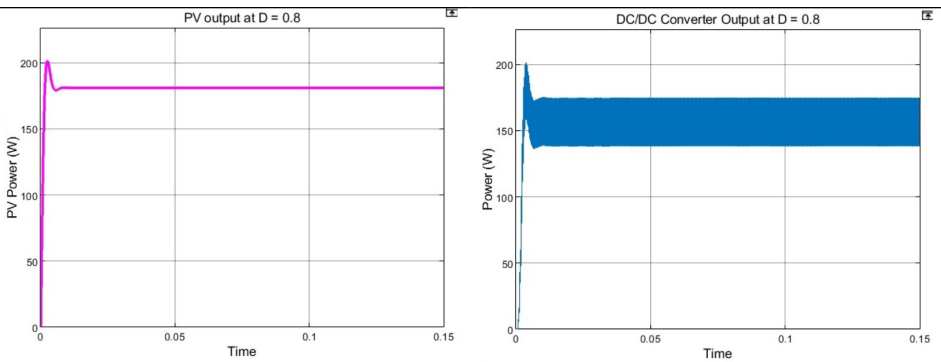


Figure 8: Input and output power of boost converter at $D = 0.8$

The full parameters of input and output boost converters for different values of duty cycle are written in Table 2 for comparison.

From all the three values of duty cycle, $D = 0.6$ has the best tolerance to the ripple voltage since it produces the highest output voltage and the ripple is 5%.

Table 2: Input and output power of boost converters for different duty cycle

Duty Cycle	Input Boost Converter (PV Output)			Output Boost Converter		
	Power (W)	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)
0.3	1216	247.7	4.910	1134	394.0	2.876
0.6	1423	161.2	8.828	1319	424.8	3.1.1
0.8	181	20.14	8.988	159.9	147.8	1.079

Performance of the MPPT DC/DC Boost Converter

The results presented in this section were obtained when the duty cycle produced by MPPT model is connected to PWM of boost converter. It is found that the PV output power is maximum at 1819 W as in Figure 9, voltage and current are 217.7 V and 8.354 A, respectively. The required boost converter output voltage considered in

calculation is 500V, however simulation shows that the measured output voltage is 484 V. The output power of boost converter is 1814 W, thus the efficiency of the boost converter is 99.7%. The current flow out of the converter is 3.533 A. Comparing the values of input and output power of converter with and without MPPT as in Table 2, the maximum power is obtained when the boost converter is connected to MPPT.

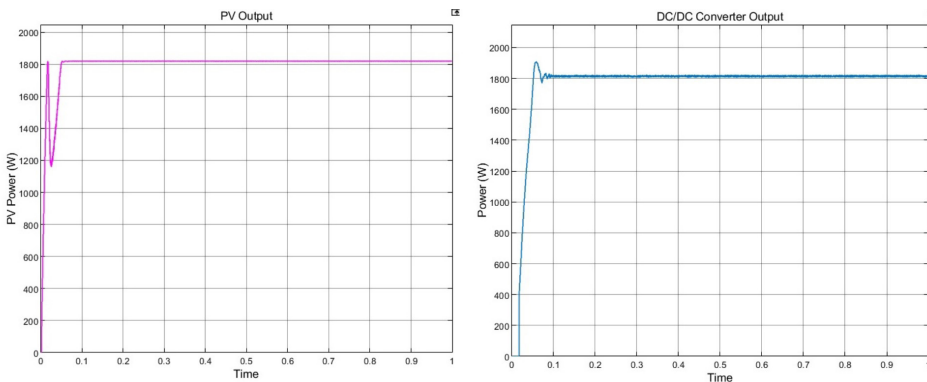


Figure 9: Input and output power of MPPT DC/DC boost converter

From the measured voltage of input and output boost converter, the actual duty cycle produced by MPPT model can be calculated using equation (1) and the value is 0.55, almost similar to the ideal calculated duty cycle $D = 0.5646$. The duty cycle generated by MPPT and the corresponding PWM signal are shown

in Figure 10. From the figure, it can be seen that the MPPT keep changing the duty cycle around 0.575 during steady state to maintain the value at maximum power point. In other words, the MPPT model in this study is successful in controlling the PV modules to produce maximum power.

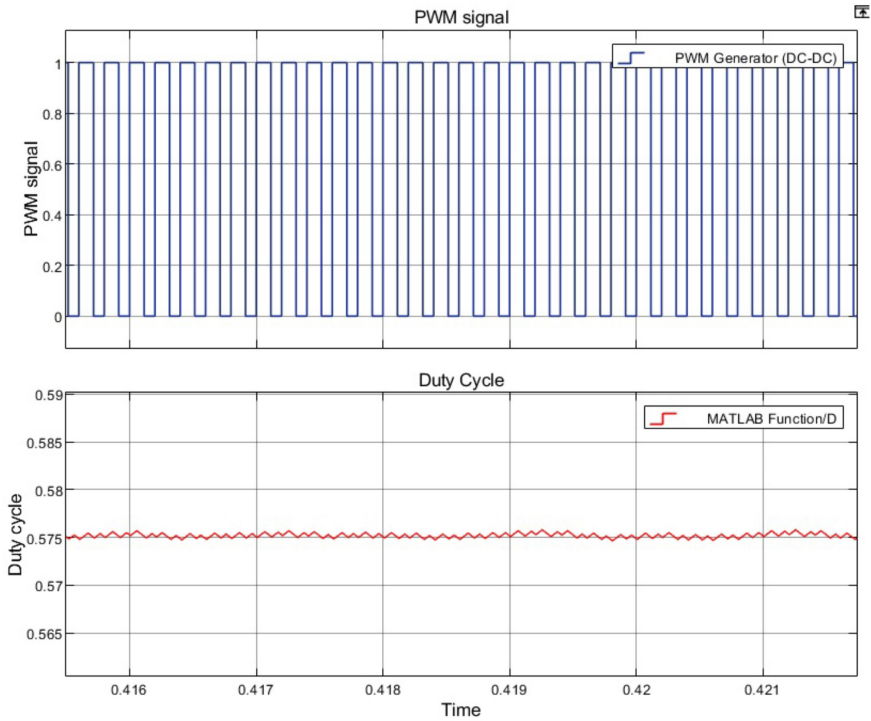


Figure 10: Duty cycle generated by MPPT and the corresponding PWM signal

The MPPT boost converter was also tested with three different values of solar irradiance as depicted in Figure 11 at 1000, 500 and 800 W/m². Different solar irradiance is set in signal builder as input to solar PV modules at constant temperature $T = 25^{\circ}\text{C}$. From the figure, it can be seen that the PV voltage is almost constant for different values of solar irradiance. However, the measured value is slightly different as stated in the figure. Small ripple occurs during transition

where a little drop is found at 1s during a drastic change of solar irradiance from high to low and a small increase during a sudden change from low to high. The PV current and power follow the shape of solar irradiance and the values are as stated. Comparing the value of maximum power obtained from simulation and theoretical values in P-V curve of Figure 3, it is found that the results are validated successfully.

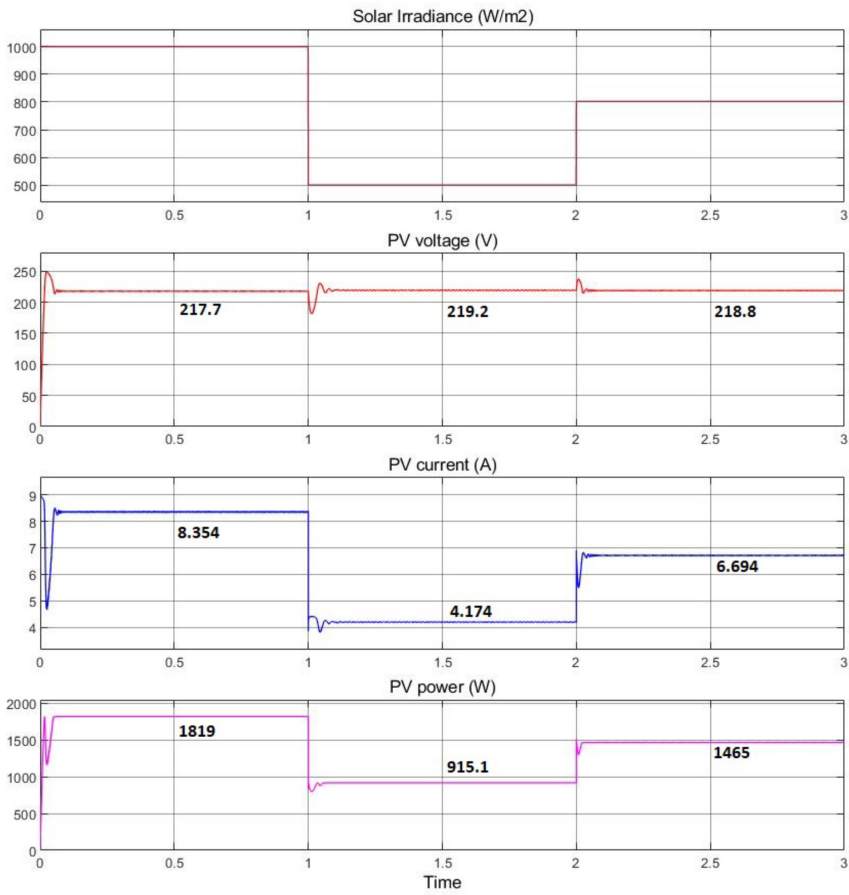


Figure 11: Input boost converter for different solar irradiance

Figure 12 shows the output converter parameters for different solar irradiance. From the power delivered to the output of converter, it

is found that the lowest efficiency of converter occurs at solar irradiance 800 W/m² at 99.4% and 99.7% at the other two conditions.

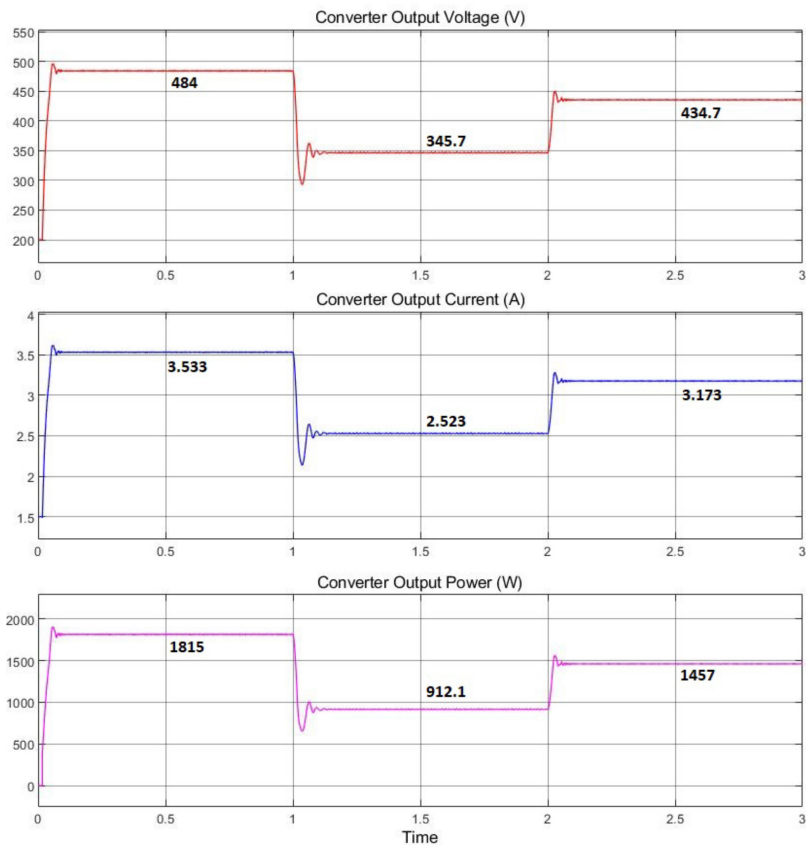


Figure 12: Output boost converter under different solar irradiance

Figure 13 shows the input parameters at three different temperatures. For this case, the current is almost constant at around 8 A, but the changes in voltage and power show the inverse of temperature. Comparing the simulation

results and theoretical values in Figure 4, the results are validated correctly. Figure 14 shows the parameter for output converters. From the output power, the efficiency of the converter is high for all temperature which is at 99.7%.

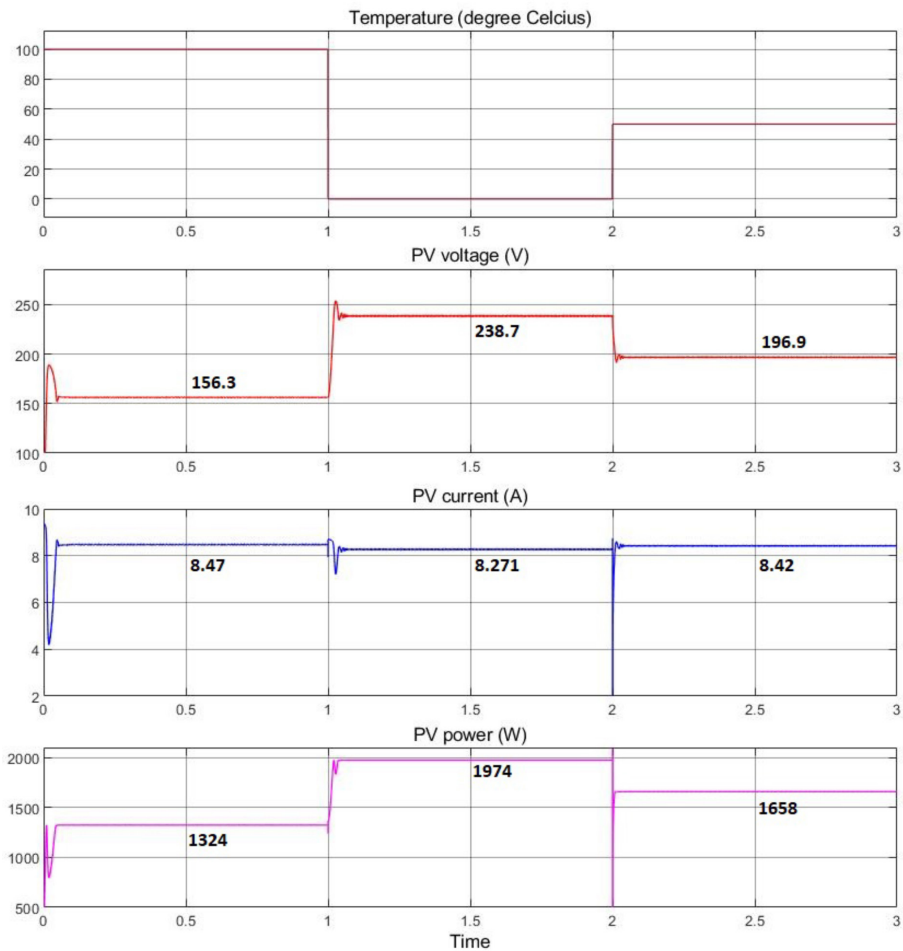


Figure 13: Input boost converter under different temperature

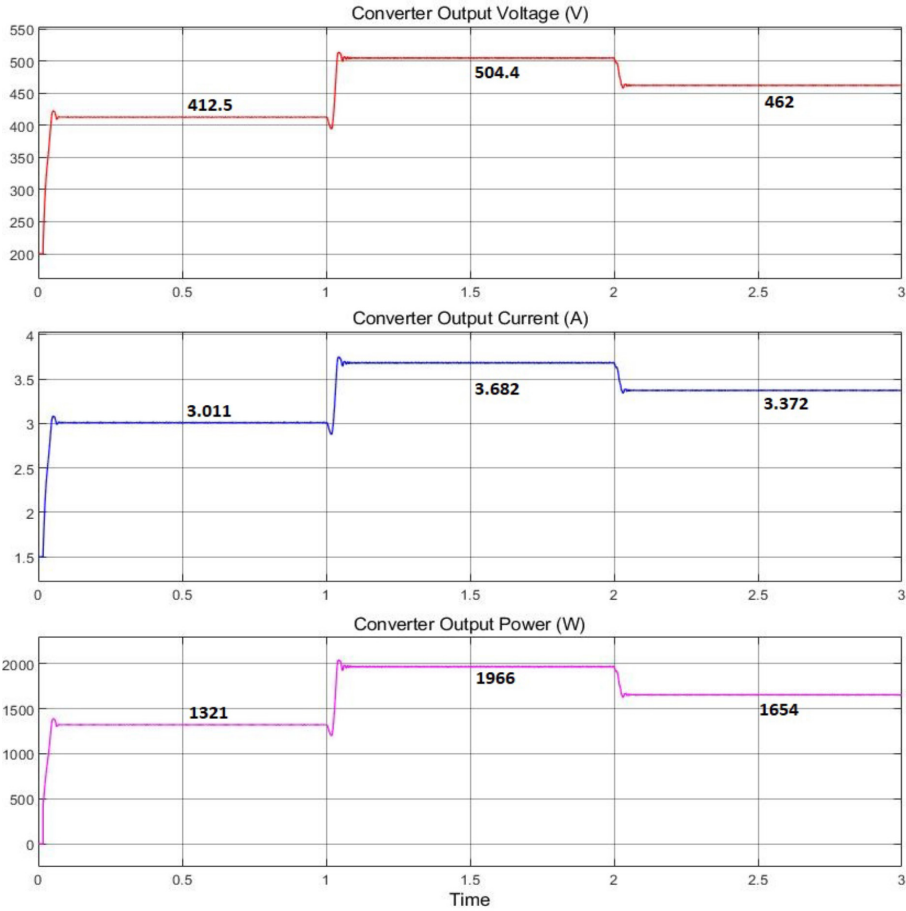


Figure 14: Output boost converter for different temperatures

The duty cycle generated by the MPPT block for three different solar irradiance and temperature are shown in Figure 15 in which the duty cycle takes small time at transient state to adjust to the best duty cycle before maintaining

it during the steady state at 0.575, 0.3713 and 0.5251 for the corresponding solar irradiance, and at 0.65, 0.55 and 0.6 for the corresponding temperature. It shows the MPPT algorithm is successfully functioning.

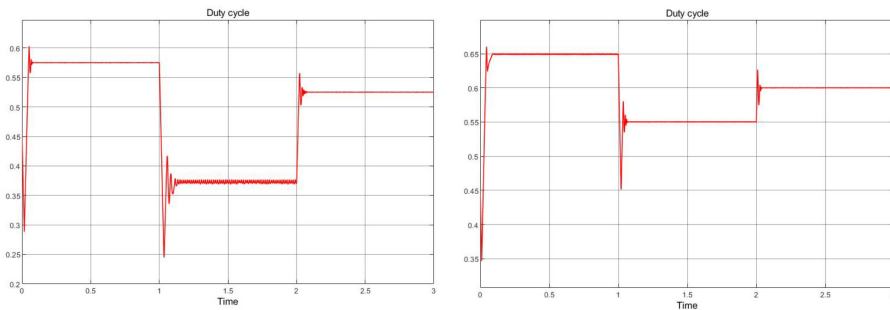


Figure 15: The duty cycle for different solar irradiance and temperature

Conclusion

A MPPT DC/DC boost converter for 1.8 kW PV modules is successfully modeled and simulated. The input parameters have been validated using I-V and P-V curves for different solar irradiance and temperature. From the output parameters, the efficiency of the converter is 99.7% for almost all conditions. The generated duty cycle from MPPT algorithm shows that it works as it is supposed to be, i.e. extract and maintain the maximum power point from PV modules.

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