Closed Loop Modified SEPIC Converter for Photovoltaic System

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Abstract:- The high static gain modified single ended primary coil (MSEPIC) converter is presented in this paper. The proposed converter presents low switch voltage and high efficiency for low input voltage and high output voltage applications. The configuration of MSEPIC converter is presented and analyzed. Closed loop feedback control with PID controller based on triggering system is developed for MSEPIC converter to maintain constant output voltage. Furthermore, the model is integrated with Photovoltaic generator where the input voltage and current depend on the solar irradiation rates. The proposed model is analyzed and simulated in Matlab/Simulink and m-file code. Simulation model is developed with a maximum power at full sun equal to 315 W, which presents efficiency equal to 99.03%. The PID controller works as intended, as the output voltage can approach the expected value. Furthermore, performance and robustness are tested by load variations and set point variations.

Key-Words: - Renewable Energy, DC-DC Power Conversion, Modified SEPIC Converter, PID Controller.

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1 Introduction

Traditional electrical sources suffer greatly from the expected depletion, the fluctuations of the global market, and the global political crises, or economic consequential crises. As well-known alternative sources of energy are inexhaustible, environmental friendly and fulfill the world demand toward minimizing the needs of reserve fossil fuels. Photovoltaic solar energy presents one of the most effectively used sources [1, 2, 3]. Power electronic converters such as DC-DC converters are primarily implemented to improve energy conversion efficiency when extracting electric power .DC-DC converters are circuits which typically supply a constant output and convert DC voltage to a different voltage level [4, 5, 6].

These converters have diverse applications in electric traction, electric vehicles, and distributed-DC systems like space applications, ships, and airplanes [6, 7]. Solar photovoltaic and specialized electrical machine drives are other areas where the converters are useful [8, 9, 10, 11].

This paper focuses on the modified single-ended primary-inductance DC-DC Converter (MSEPIC). The MSEPIC converter is able to reduce or raise the electrical potential (voltage) at the output and can be considered as a buck/boost converter [5, 12, 13]. To maintain the output voltage of MSEPIC, a feedback closed loop control is necessary as shown in Fig. 1. The voltage sensor is used to measure the voltage of MSEPIC converter, which is comparing continuously with a set reference voltage and a desired control signal is produced and improved with the help of PID Controller operation [12, 13, 14]. Controller corrects the error between measured value and a required set point value that can adjust the whole process accordingly by which dynamic response can improve and also reduce the steady-state error in the system [15, 16]. The output signal generated by the PID controller is used as the input signal to control the suitable range of duty cycle (D) in a suitable range for the MSEPIC converter, and the required output voltage is then obtained [17].

In dc-dc converter, the MOSFET switching are done by PWM technique in which oscillator frequency is constant and value of average voltage provides to the given load to turn on and off quickly by which controls the operation [18].

This paper has been focused on design of PV system with the MSEPIC converter as using closed loop feedback control. Simulation input and output performance of converter such as voltage, current and power, are compared and verified on MATLAB software.

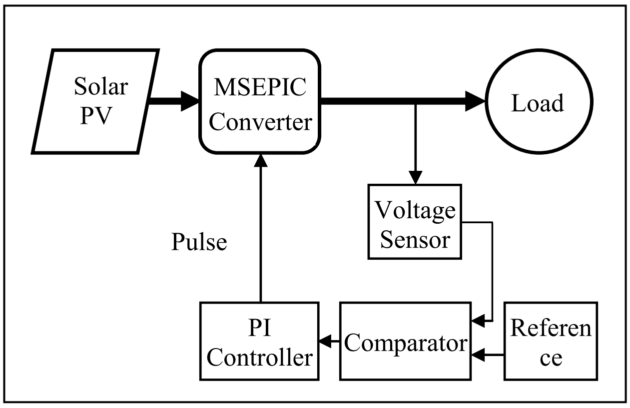

Fig. 1 Block diagram of closed loop MSEPIC converter

2 Analysis and Design of the MSEPIC

The modified SEPIC converter is accomplished by including of the diode - capacitor circuit in basic SEPIC converter as shown in Fig. 2. The voltage multiplier technique is used to increase the static gain of single-phase boost dc–dc converters. Many operational characteristics of the basic SEPIC converter are changed with the proposed modification. This converter comprises the main switching device (S), three capacitors (C_1, C_2, and C_o), two diodes (D_1 and D_2) and two inductors (L_1 and L_2). The presence of the diode-capacitor circuit is able to reduce switching voltage stress on switching device.

The output voltage from Boost converter is used to charges C_2. Furthermore, the voltage of second capacitor V_{C2} is applied to the L_2 during the conduction period of the switching device S. This condition increases the voltage gain that is obtained when compared to the conventional step-up converters.

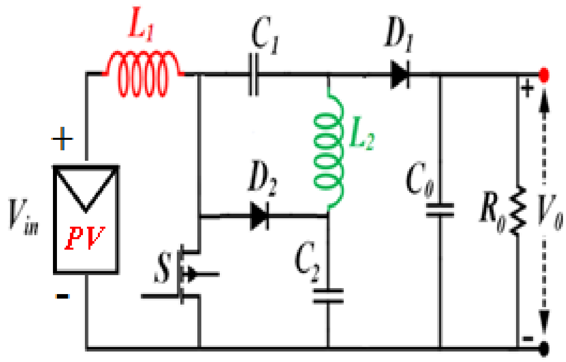

Fig.2 PV-Modified SEPIC converter

Each component parameter in MSEPIC converter is calculated by formulas respectively stated in table 1 [5]. Each parameter of modified MSEPIC converter is selected by default based on of formulas stated in table1, and its obtained results are presented in table 2.

Table 1 MSEPIC Converter Formulas

Parameters	**Formulas**
Duty Cycle	$D = \frac{V_o - V_{in}}{V_o + V_{in}}$
Inductances	$L_1 = \frac{V_{in} D}{\Delta i_{L1} f_s}$ $L_2 = \frac{L_1}{2}$
Capacitors	$C_1 = C_2 = \frac{i_{L2} D}{\Delta V_C f_s}$ $C_o = \frac{I_o D}{\Delta V_o f_s}$
Static Gain	$G = \frac{V_o}{V_{in}} = \frac{1 + D}{1 - D}$
Capacitor Voltages	$V_{C1} = \frac{D V_{in}}{1 - D}$ $V_{C2} = \frac{V_{in}}{1 - D}$ $V_{Co} = V_o$

The consideration design parameters of MSEPIC converter are explained for the converter duty cycle of D=0.5, at which the current ripple becomes maximum [19].The input (inductor) ripple current is considered to be approximately 40% of the maximum input current [20]. As the average input current is higher than the average output current for a step-up converter, the volume of 2nd inductor L_2 is lower than the volume of 1st inductor L_1, meaning that the value of L_2=50% L_1as stated in table 2 [5].

Table 2: MSEPIC Converter Parameters

Parameters	Value
Vin, V	Variable
Vo, V	Variable
D	0.1 – 0.9
L1, mH	1.98
L2, mH	0.99
C1, µF	660
C2, µF	660
Co, µF	10
Ro, Ω	Variable

The maximum capacitor voltage ripple of C_1 equals to nearly 7% of the output voltage for traditional and modified SEPIC converters [20, 21].The output voltage ripple of the output filter capacitance Co is considered equal to 1% of the average output voltage.

The highest efficiency at constant duty cycle (D = 0.5) for modified MSEPIC is obtained by a switching frequency (f_s) of 50 kHz [5]. In [5], the distinction of MSEPIC converter's efficiency over the other step-up converters is shown.

3 Photovoltaic Performance

For simulation issue, the SUNPOWER photovoltaic panel type SPR-315E-WHT-D with 315 Watts peak with conversion efficiency of 19.3% is used, where the panel I-V and P-V performances are shown on Fig. 3 for various irradiation rates [22, 23].

From Fig. 3, the main useful PV parameters values (V_{MPP}, I_{MPP} and P_{MPP}) are determined for various irradiation rates at temperature of 25°C, which are declared in Table 3.

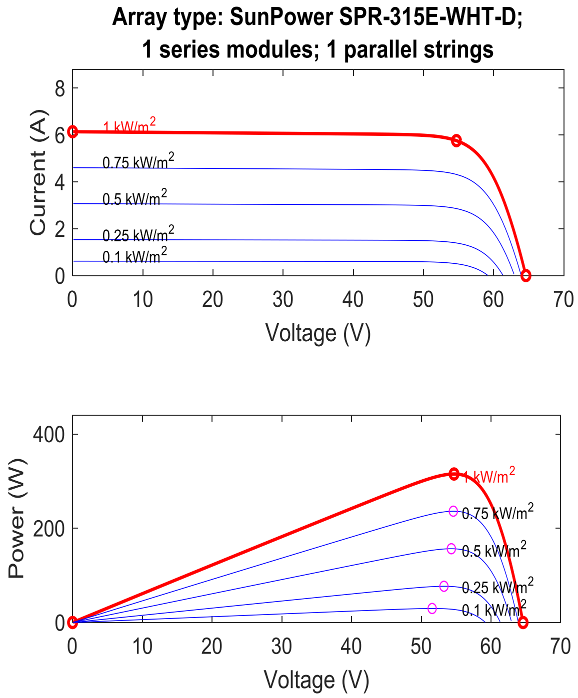

Fig. 3 Panel I-V and P-V characteristics [17]

Table 3: Some important data specification for SPR-315E-WHT-D at STC

Parameters / Irradiation G (W/m²)	V_{MPP} (V_{in}) (V)	I_{MPP} (I_{in}) (A)	P_{MPP} (P_{in}) (W)
100	51.75	0.575	29.75
250	53.26	1.443	76.86
500	54.32	2.881	156.50
750	54.60	4.324	236.10
1000	54.70	5.760	315.00

4 Simulation Results

The designed parameters of the modified SEPIC system are given in table 2. The closed loop Simulink model for the modified SEPIC converter based solar system is shown in Fig. 4.

From Fig. 5, input voltage, current, and power at full sun is 54.7 V, 5.817 A and 318.2 W respectively. Similarly, from Fig. 6, output voltage, current, and power is 152 V, 2.074 A and 315.1 W respectively. Therefore, MSEPIC efficiency in % = (Output Power / Input Power) ×100 = 99.03 %, which is verified by [5].

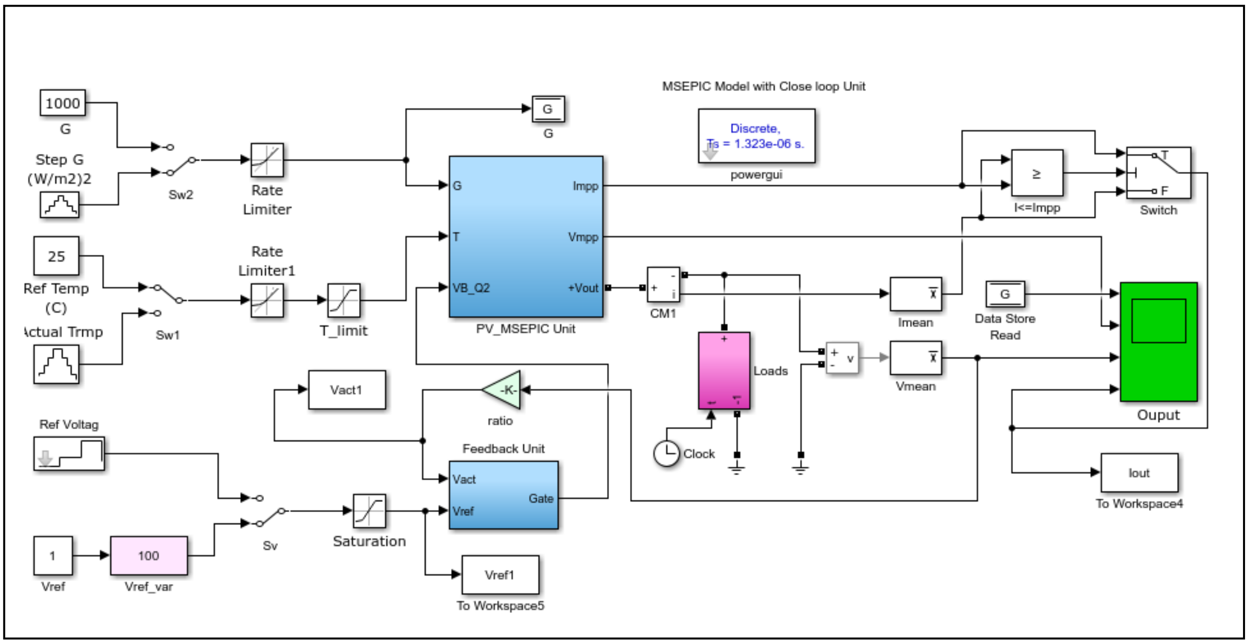

Fig.4: The Closed Loop Simulink Model of the MSEPIC

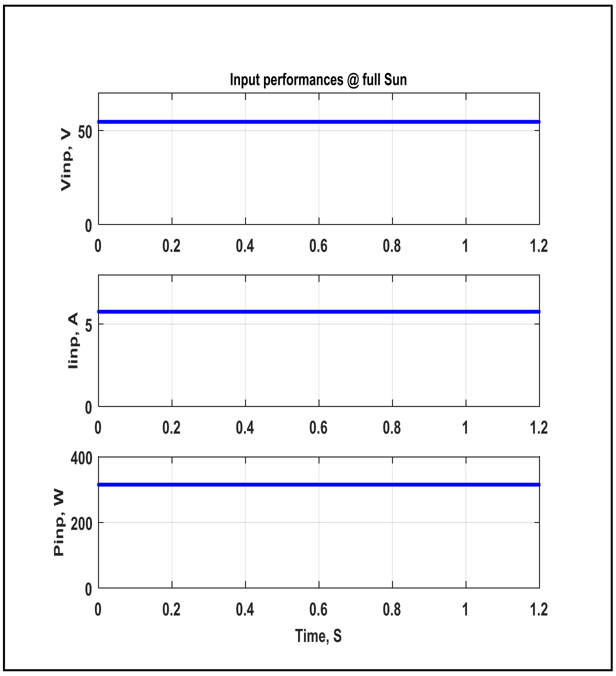

Fig. 5 MSEPIC Inputs voltage, current, and power versus time

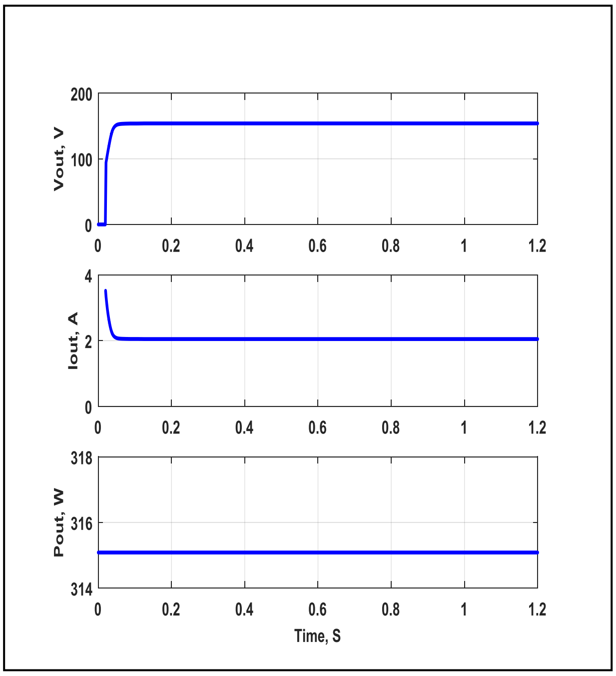

Fig. 6 MSEPIC Outputs voltage, current, and power versus time

Fig. 7 shows the output voltage stabilization at 60V, 90V, 120Vand 150V step voltage references at time t=0, t=0.3, t=0.6 and t=0.9s respectively at constant input voltage and constant input power ($P_{in}\approx$ 315 W).

Fig. 8 shows the input voltage, current and power variation according to solar irradiation rates, where it can be shown that:

- The input voltage which is corresponding to MPPT values varies between 51.7V to 54.7 V at full sun.

- The input current varies between 0.57A to 5.7 A at full sun, and
- The input power varies between 29.7W to 315 W at full sun.

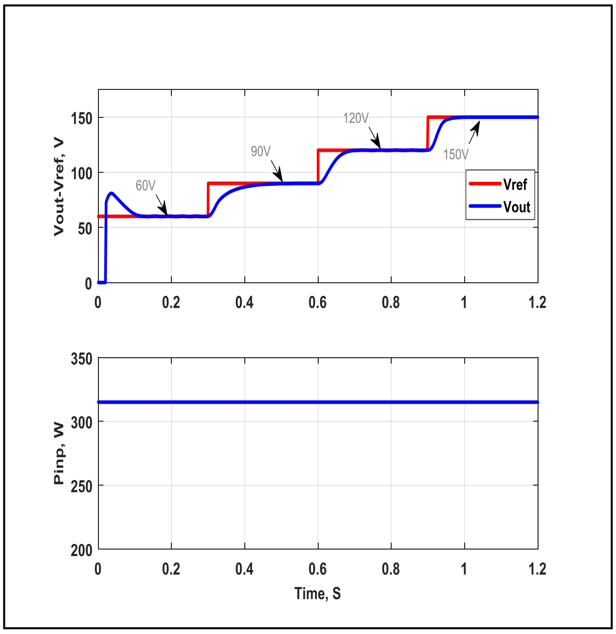

Fig. 7 Output voltage variation Waveforms of MSEPIC at constant input voltage V_{in} = 54.7 V and constant input power P_{in} = 315 W

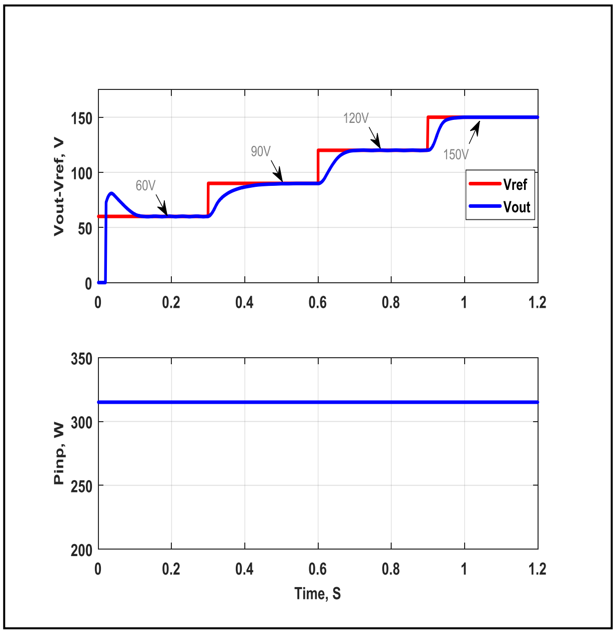

Fig. 8 Input Voltage, current and power variation waveform

While, figure 9 shows the output voltage, current and power variation according to solar irradiation rates, where it can be shown that:

- Irrespective of input voltage variation the chopper maintains the output voltage at constant value of 100V as a result of applied PID controller.
- Voltage which is corresponding to MPPT values varies between 51.7V to 54.7 V at full sun.
- The load (output) current at varies irradiation rates is determined mainly based on the output voltage and load resistance and cannot exceed the available input current corresponding to instant irradiation. For example, at full sun the input current is 5.7A, while the output current is 3.12 A drawn by a load of Ro=31.2Ω.
- At full sun the output power equals or a little bit less than the input power with high efficiency equal to 99.04%.

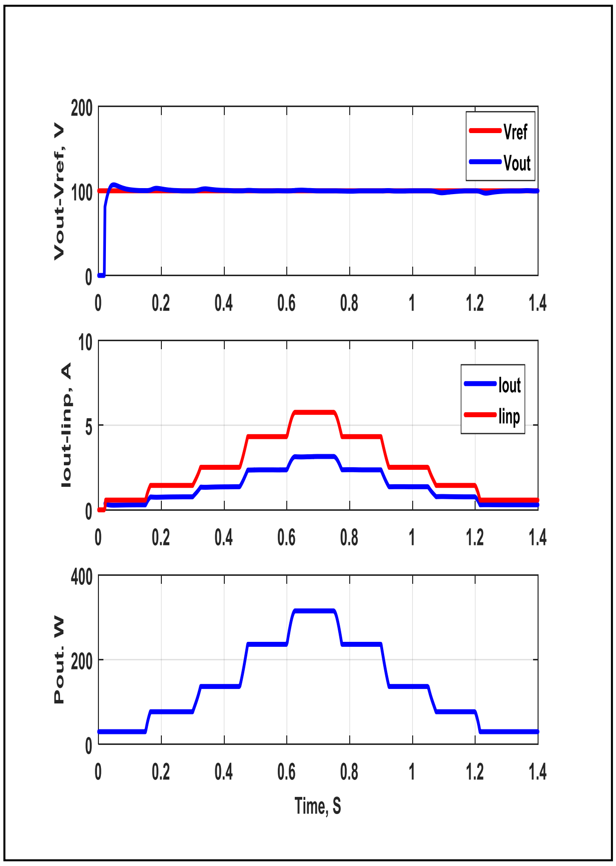

Fig. 9 Constant output Voltage with reference value (V_{ref} = 100 V) at various irradiation rates

Figure 10 shows the MPPT current and output load current at various loading levels and irradiation rate, where three loads are added t =0, 0.4 & 0.8 seconds with values R_1=140 Ω, R_2=30 Ω, and R_3=40 Ω with currents 0.71A, 3.33A, and 2.5A respectively.

It can be noticed that there is no limitation on the output current while $I_{out} \leq I_{inp}$ at given irradiation, while when $I_{out} \geq I_{inp}$ the load current is limited to the input current value at given irradiation .

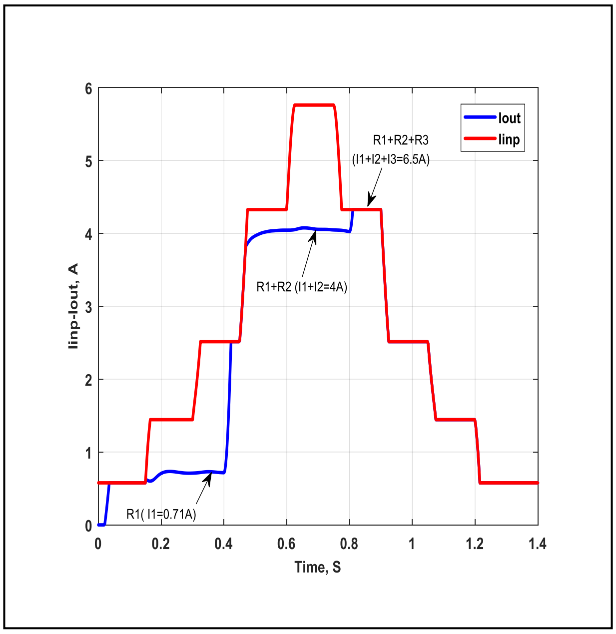

Fig. 10 Input current and output load current at various loading levels and irradiation rate

6 Conclusions

Taking into account the built simulation model and obtained results for MSEPIC converter the following conclusions can be stated:

- MSEPIC converter allows wide range of output voltage regulation at various MPPT voltage according to available irradiation.
- The output voltage can be maintained constant irrespective of input MPPT voltage that varies according to available irradiation. While the input voltage varies in the range of 51.7 to 54.7, the output voltage can be boosted till 150V and much more without significant voltage stress across the transistor switch and the load due to added closed loop and PID controller.
- The input MPPT voltage variation becomes significant when Photovoltaic panels are connected in series forming strings, where the closed loop system with added PID module becomes important module in maintaining the output voltage at fixed value irrespective of irradiation rates.
- The drawnoutput current cannot exceed the input current values, which in turns the output power cannot exceed the available input MPPT power at given irradiation, where at full sun the maximum power that can be extracted from the system is 315.1 W. In case of requesting additional power a parallel and series connected panels that forming solar arrays and strings can be proposed.

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

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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.