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Closed Loop Control of an Isolated semi-SEPIC DC-DC Converter using PID Controller

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Abstract**:** ***This paper presents the closed loop control scheme of the semi-sepic coupled inductor based DC DC converter using a PID controller, enhancing the overall performance of the system. The PID controller usually enhances the transient and steady state performance of the system. The objective here is to maintain the output voltage of the DC/DC converter constant irrespective of the variations in the input/source voltage, components and load current. The implementation of the proposed scheme is done using the blocks of MATLAB Simulink and the model is tested with the controlled voltage source by giving some disturbance at the input where the output is well regulated irrespective of the changes in the input/source voltage. Comparative analysis on the performance of the converter with and without PID controller is carried out using MATLAB Simulink. The output voltage of the converter with PID controller is regulated under disturbed input voltages.***

Keywords**:** ***DC/DC converter, PID controller, Semi-SEPIC, Voltage Regulation.***

I. INTRODUCTION

Due to the growth in the negative side effects of conventional energy resources, there is an increase in the use of renewable energy resources such as wind turbines, photo voltaic systems, fuel cells etc [1]. However, due to the intermittent nature of these renewable energy resources, they cannot be connected directly to the grid. Besides that the output generated by these renewable energy sources is much low. Hence, the power electronic circuitry is usually used to overcome such issues and convert their output power to match the load demand. Therefore, DC/DC converters play an important role in renewable energy systems. Usually these widespread applications are desirable to have converters that achieves high efficiency, improved power factor and minimum THD at load side with reduced cost and small size[2][3]. The DC/DC converters are always desirable to have a constant output voltage irrespective of the variations in the input source voltage, load current and changes in the element values of the converter circuit [4][5]. However these disturbances tend to originate from second harmonic periodic variations of an offline power system usually generated from the rectifier circuit and are applied to the DC/DC converter.

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The source voltage variation can be the effect of load current variations and switching of neighboring power system loads. The PI controller, PID controller, Fuzzy Logic controller and Artificial Neural Network (ANN) are some of the control techniques proposed to ensure the stability and fast transient response of the system [5][6][7].

The traditional and most commonly used converters are Buck, Boost and Buck-Boost converter. Among these, the Boost converter is the most widely used converter which boosts the input voltage and provides higher voltage at the load side. Many of the modern industrialized applications require the high voltage gain DC/DC converters for stepping up the voltages [8][9]. Operation of the boost converter in open loop mode does not provide much voltage regulation and the desirable dynamic response as needed. Hence the operation of the converter in closed loop mode is much preferred over the open loop mode which enhances the performance of the system.

This paper presents a proper voltage regulation of a semi-SEPIC isolated DC/DC (Boost) converter [10][11], using a PID controller. For improving the converter performance, the PID controller used is tuned using the trial and error method in order to get the appropriate values for proportional, Integral and Derivative gains. The section II of this paper describes the operation of the semi-SEPICisolated DC/DC converter. The section III gives the brief idea about the PID controller followed by the simulation results of the converter with the proposed scheme in section IV which demonstrates the effectiveness of the proposed scheme.

II. OPERATION OF SEMI-SEPICCONVERTER

The schematic of the proposed semi-SEPIC DC/DC converter is shown in Fig.1 which is similar to the traditional SEPIC converter except with the modification that the impedance network replaces the intermediate inductor present in the traditional SEPIC converter . The converter consists an input inductor (L), an intermediate capacitor (C2), an output diode (D2), an output capacitor (C), a controllable switch (S) and an impedance network consisting of a diode (D1), one capacitor (C1) and the coupled inductor with the turns ratio $n = N_P / N_s$.

Since the CCM mode of the operation is considered, the following assumptions are made:

(1) All the components are assumed to be ideal.
(2) All the capacitors are large enough and the voltage across them is held constant.
(3) The current across the inductor is always continuous and positive.
(4) The coupling coefficient of the transformer is assumed to be one which means it has zero leakage inductance.

(5) The switch is open for time interval (1-D)T andclosed for the time DT having T as the switching period.

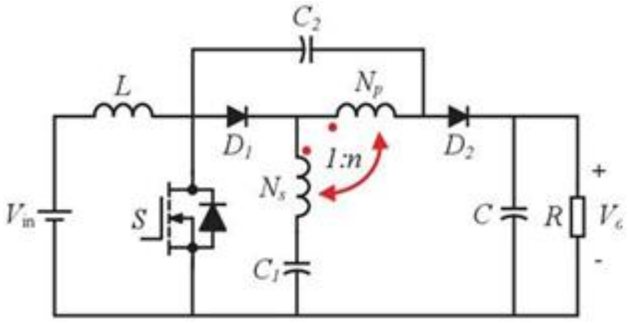

Fig.1 Schematic of the semi-SEPIC converter

The operation of the semi-SEPIC DC/DC converter in the continuous conduction mode (CCM) with the above assumptions is as follows:

When the switch is ON, both the diodes D1 and D2 are reverse biased as shown in Fig.2(a) and the input inductor L is charged by the input source. As the diode D2 is off the output load is isolated from the input source, the load R is powered by the output capacitor C. By considering the Fig.2(a) we can write:

$$V_S = \frac{V_{C1} - V_{C2}}{n-1}$$

Where V_S is the secondary side inductance voltage, V_{C1} is the voltage across the capacitor C1 and V_{C2} is the voltage across the capacitor C2.

When the switch is OFF, both the diodes D1 and D2 are forward biased as shown in Fig.2(b) and the energy stored in the input inductor L is released to the load. The current in the inductor decreases as the output capacitor C is charged. Now from the Fig.2(b) we can write:

$$V_S = \frac{V_{C1} - V_O}{n-1}$$

Where V_O is the output voltage.

By applying the volt second balance principle the voltages across C1, C2 and the output voltage can be obtained:

$$DV_{in} + (1 - D)(V_{in} - V_{C2} - V_O) = 0$$

$$D\ \frac{V_{C2} - V_{C1}}{n-1} + (1 - D)\ \frac{V_{C1} - V_O}{n-1} = 0$$

The voltage gains V_{C1}, V_{C2} and V_0 are given as:

$$V_{C1} = \left(1 + \frac{nD/n-1}{1-D}\right) V_{in}$$

$$V_{C2} = \left(\frac{nD/n-1}{1-D}\right) V_{in}$$

$$V_O = \left(\frac{1+nD/n-1}{1-D}\right) V_{in}$$

This proves that with the decrease in the turns ratio the gain of the converter increases and the duty cycle range of the converter can be varied in a wide range ($0 < D < 1$) between 0 and 1.

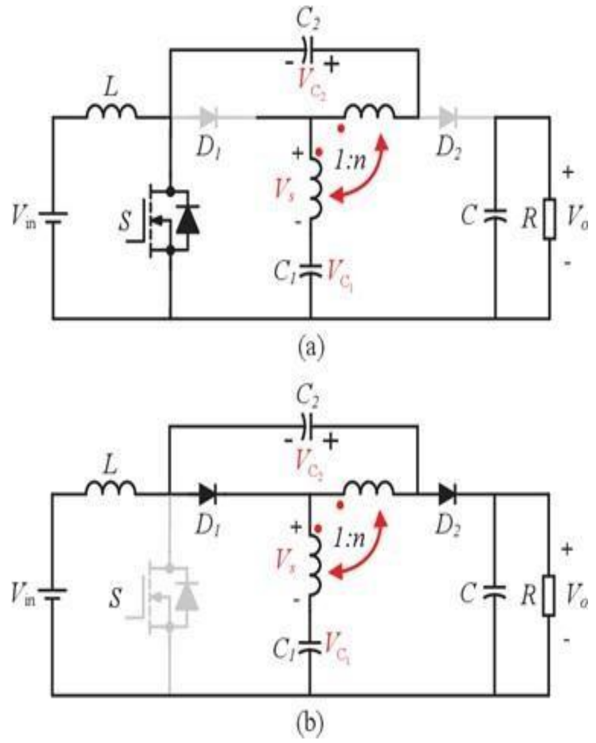

Fig.2 Equivalent circuits of the semi-SEPIC DC/DC converter (a) when the switch is ON (b) when the switch is OFF

III. CLOSED LOOP CONTROL WITH PID CONTROLLER

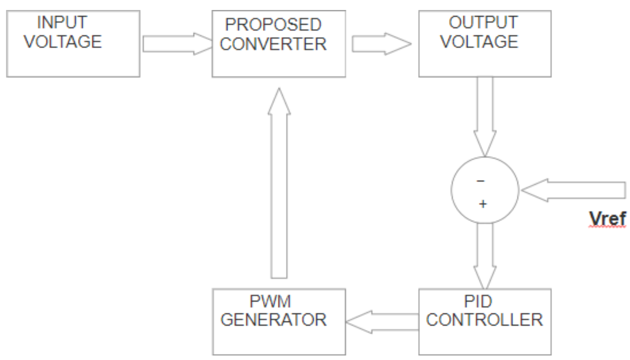

Fig.3 Block Diagram of closed loop control with PID controller

The system or procedure that regulates the characteristics of other systems for obtaining the desired results is called a control system. The closed loop system is considered to be the most important type of control system which uses the feedback mechanism to adjust the input signal. The closed loop control system uses the PID controller as the feedback mechanism.The output of the PID controller is delivered on the basis of the measured error and the three gains of the controller which are proportional gain K_p, integral gain K_i and derivative gain K_d.

The closed loop control operation of the semi-SEPIC coupled inductor based DC/DC converter starts from obtaining the output voltage. T he output voltage obtained and the reference voltage are fed to the comparator where the output voltage is compared with the reference voltage and generates an error signal. The error signal generated is fed as input to the PID controller. Now by adjusting the control variable, the PID controller tries to decrease the error and a new value is determined at the end of the process. The output of the PID controller is fed to the PWM control as the reference signal. The basic principle behind the working of this converter is to control the switching of the MOSFET by creating a square pulse called duty cycle, which controls the output voltage. The duty cycle controls the switching of the MOSFET. The output of the PID controller fed as the reference signal to the PWM control is now compared with the triangular carrier signal which produces the square pulses. This signal obtained from the PWM generator is used to control the switching of MOSFET. The main characteristics of using this control scheme is the system has reduced errors, improved stability, increased sensitivity and reliable performance. The advantage of this scheme is the system will have the ability to automatically adjust the output voltage by controlling the duty cycle feeding back the output signal. Thus this scheme allows the converter to operate efficiently which gives the high voltage gain.

IV. SIMULATED RESULTS

The proposed closed loop control scheme using PID controller for semi-SEPIC DC/DC converter is simulated in MATLAB/Simulink software and the results are presented. The parameters used for simulation of the circuit are given in the below Table 1.

Table I. Design parameters of the converter

Parameters	Values
Input Inductor L	640 μH
Capacitors C1 C2 C	100 μF
Input Voltage	25V
Output Voltage	112V
Turns Ratio	31: 4
Frequency	50K Hz
Duty Ratio	0.62

The Fig.4 shows the simulation circuit of the semi-SEPIC DC/DC converter for an open loop condition in which the output voltage varies with the variation in the input voltage. For this condition the gain cannot be controlled easily due to absence of the feedback in the system. The output voltage of the converter after simulation is shown in Fig.7 along with the input voltage. The output voltage obtained is 110.5V for the input voltage 25V which is very close to the theoretical value.Fig.5 shows the voltages of the capacitors C1 and C2. the inductor current and the voltages of both diodes D1 and D2.

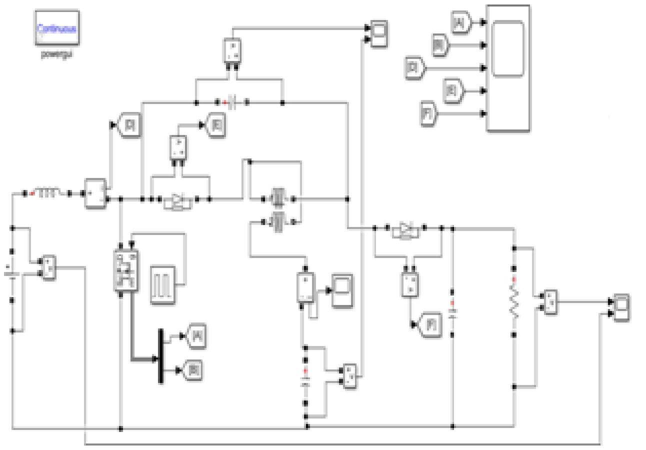

Fig.4 Simulation circuit for the semi-SEPIC converter for open loop condition

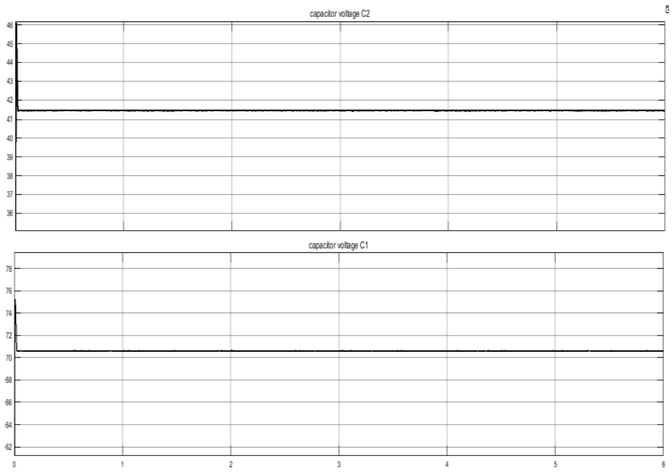

Fig.5 Voltages of the capacitors C1 and C2 in open loop condition

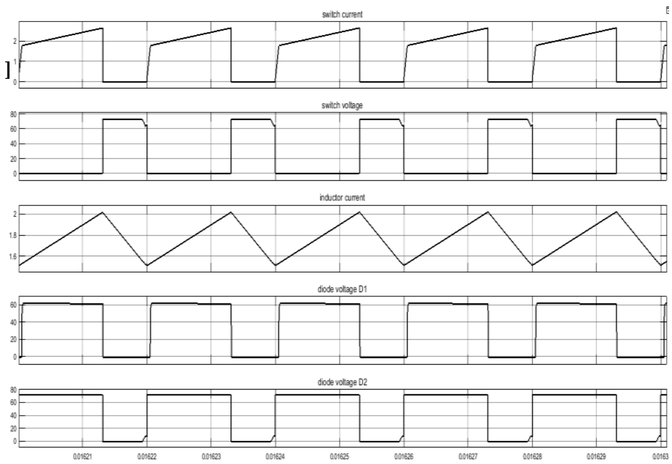

Fig.6 Switch current and voltage along with inductor current and diode voltages D1 and D2 in open loop condition.

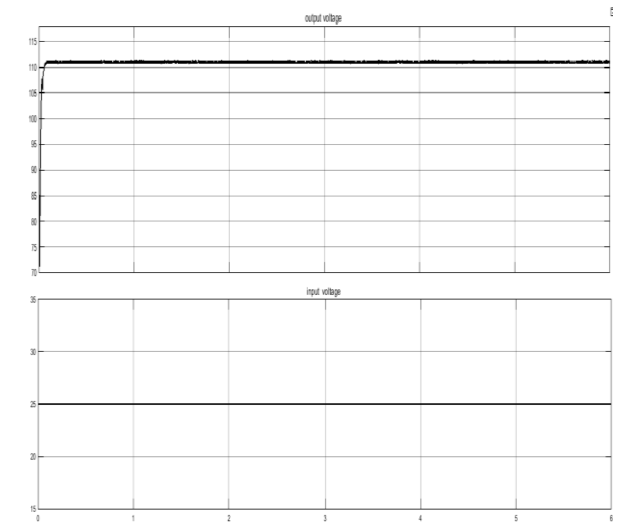

Fig.7 Output and input Voltages in open loop condition

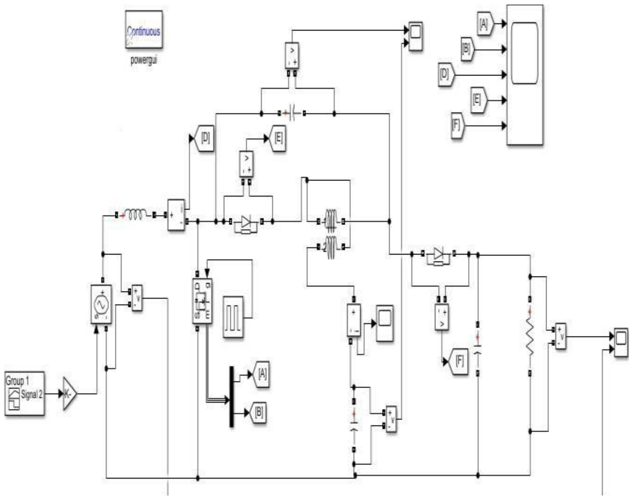

Fig.8 Simulation circuit for open loop condition with a controlled voltage source.

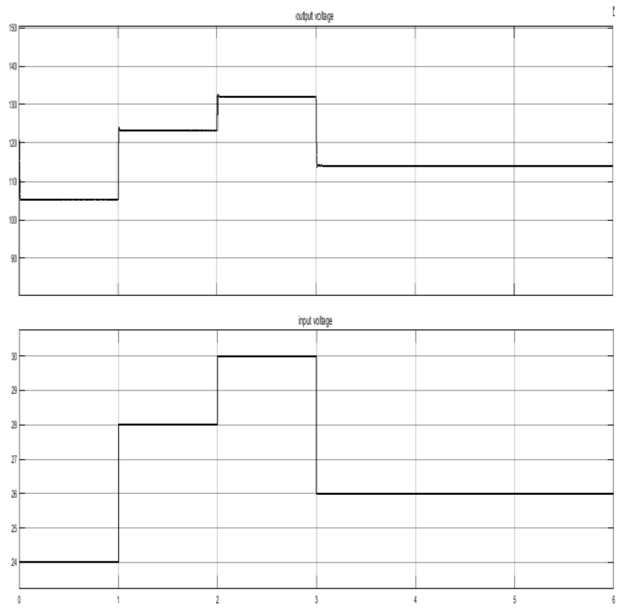

Fig.9 output voltage for open loop condition with disturbance in the input voltage.

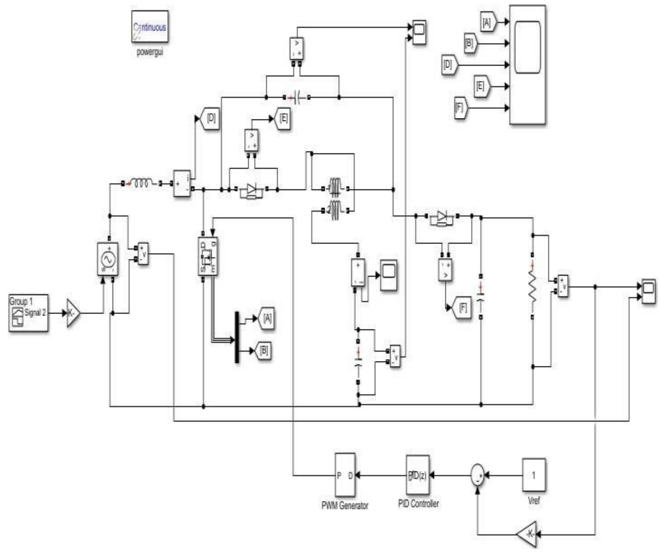

Fig.10 simulation circuit for closed loop condition with a controlled voltage source.

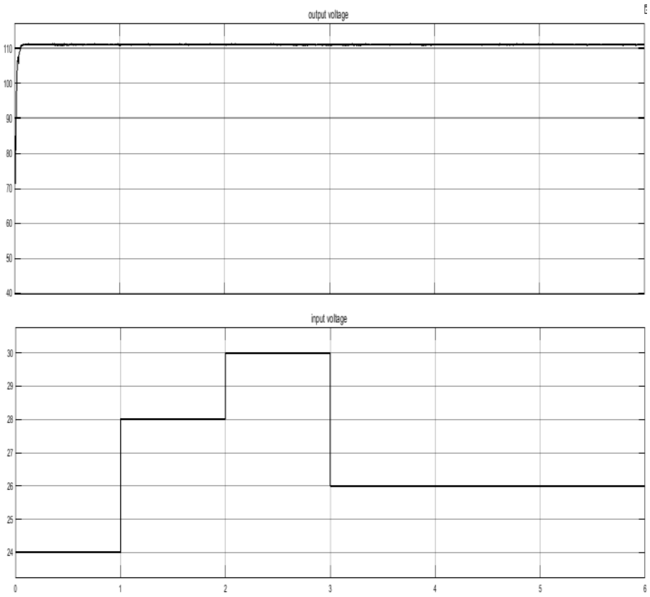

Fig.11 Output and input voltage for closed loop condition.

The Fig.8 shows the open loop system of the semi-SEPIC converter with a controlled voltage source. Fig.9 shows the step rise in the input voltage appearing at t=1s and t=2s as a result of which the output voltage increases. The closed loop system for the semi-SEPIC DC/DC converter with a controlled voltage source is shown in Fig.10 where the output voltage of the converter is sensed and compared with the reference voltage. The error obtained from this is processed by a PID controller and its output adjusts the pulse width for maintaining a constant output voltage. Fig.11 shows the output and input voltage of the closed loop operation of the converter where by sensing the step change in the input voltage the output voltage reduces and reaches the set value. Therefore the output voltage is well regulated.

Table II: Comparison of output for different input voltage.

Input voltage (Volts)	Output Voltage (Volts)	
	Without PID controller	With PID controller
10	43.4	110.5
15	65.8	110.5
20	88.3	110.5
25	110.5	110.5
30	133.1	110.5

The above table II shows the comparison between the outputs of the converter with and without PID controller for different input voltages. It is observed that the output voltage of the converter in the closed loop condition with PID controller is constant for varying input voltages where as for the open loop condition without PID controller the output voltage increases with the increase in the input voltage. From this we can conclude that the performance of the converter with PID controller is much better than without PID controller.

V. CONCLUSION

The paper presents the closed loop control of the semi-SEPIC isolated DC/DC converter with a PID controller. The PID controller provides a better voltage regulation and reduces the steady state error making the system more stable. The performance analysis is done using the blocks of Simulink. From the result it is observed that the system has better transient response and can give a high voltage gain. The comparison between the outputs of the converter in closed and open loop condition is made. The performance of the converter in the closed loop is much better than the open loop.

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