PSIM Simulation of a Buck – Boost DC-DC Converter with Wide Conversion Range

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***Abstract*— Non-isolated DC-DC converters with wide conversion range have many applications such as battery charging, renewable energy harvesting, fuel cell etc. Incorporating coupled inductors in non-isolated DC-DC converters encourages many advantages including providing a high voltage gain. Introducing coupled inductors in the conventional buck and boost DC-DC converters and the integration of both produces a two switch buck-boost topology which has better conversion range. This paper provides the simulation of the converter which can step-up as well as step-down the input voltage. PSIM simulation software is used.**

Keywords— Buck; Boost; Buck-boost; Coupled Inductors; Wide Conversion Range DC-DC Converter.

I. INTRODUCTION

The non-isolating type DC-DC converters are generally used for relatively small ratio step-up or step-down of the input voltage where there is no problem of isolation. Theoretically the conventional converters can provide almost any voltage; but practically the output voltage range is limited by extreme duty ratio operation of the switches and high component stresses. Introduction of transformers attains large step-up or step-down voltage conversion; but it causes problems associated with the magnetizing and leakage inductances.

Among the several studies taking place in non-isolated DC-DC converters, widening the conversion range is of typical interest. Authors proposed various techniques to improve the conversion range of the converters such as using converters with non-linear characteristics. Converter topologies with single-transistor were proposed in [1] which had achieved wide step-down conversion range. Single-switch non-isolated high step-up DC-DC converters with simple topologies were proposed in [2]. These uses hybrid switched capacitor technique for providing high voltage gain without extreme duty cycle operation yet enabling the use of a lower voltage and $R_{DS\text{-}ON}$ MOSFET switch so as to reduce cost, switch conduction and turn-on losses. Two boost converters cascade connection is one of solution for high voltage gain. It usually integrates two boost converters by using a common switch [3]. However, the output diode reverse-recovery problem and the high voltage stress across switch are severe. The switched-capacitor and boost converters can be integrated together to obtain a stepless voltage gain. A family of single-switch DC-DC converters with high voltage gain is proposed in [4]. It consists of a boost multiplier cell, which can obtain a voltage conversion as the conventional boost converter, and a capacitor–diode multiplier, which is in series to enlarge the voltage gain and to reduce the switch voltage stress. A new, two-inductor, two-switch boost converter topology and its variations suitable for applications requiring very high voltage gains were described in [5]. The output voltage regulation of the proposed converters is achieved in a wide load and input-voltage range by employing an auxiliary transformer that couples the current paths of the two boost inductors.

A different approach to obtain wide conversion range is by utilizing coupled inductors. The voltage gain can be extended by proper turns ratio design of the coupled inductors. [6] proposes a tapped-inductor buck converter which can extend the duty cycle and has a low component count. The tapped-inductor boost converters proposed in [7] attains comparable voltage step-up preserving relative circuit simplicity. The concept of the coupled inductor and the switched capacitor can be combined to derive high-step-up converters [8]. The output-diode reverse-recovery problem is avoided by the leakage inductance of the coupled inductor. A soft-switching tapped inductor buck converter was proposed in [9]. It shows the current injection method, which gives an additional design freedom which can maximize the efficiency. A modification of tapped buck converter for power factor correction was realized in [10]. The modification involves addition of only a line-frequency commutated switch and a diode. Families of high-efficiency high step-up DC-DC converters were proposed in [11]. [12] presents an interleaved soft-switching buck converter with coupled inductors to extend duty ratio for high step-down voltage applications. With the proposed converter, conversion efficiency can be improved significantly. Similarly a boost converter with coupled inductors and a buck–boost type of active-clamp circuit was proposed in [13]. It can yield a high step-up voltage ratio and a proper duty cycle, resulting in low component stresses.

As already said the conventional buck and boost converters can be modified by using coupled inductors. Thus a Wide-Input-Wide-Output (WIWO) DC-DC converter which is an integration of buck and boost converters with coupled inductors was proposed in [14]. It retains both buck and boost converter features with wider step-up and step-down DC-DC conversion range. Here this non-isolated topology proposed is simulated using PSIM simulation tool.

This paper presents the open-loop and closed-loop simulation of the converter. In section II, the overview of the converter, its control scheme and its operating principle is discussed. Section III presents the open loop and closed loop PSIM model of the converter. Section IV presents the simulation results obtained and concluding remarks are presented in section V.

II. SYSTEM OVERWIEW

A. Converter Topology

The converter is shown in Fig. 1. It has two active switches S_1 and S_2, coupled inductors L_1 and L_2 with turns ratio $n = n_2 : n_1$, a diode D, capacitive filter C and a resistive load R.

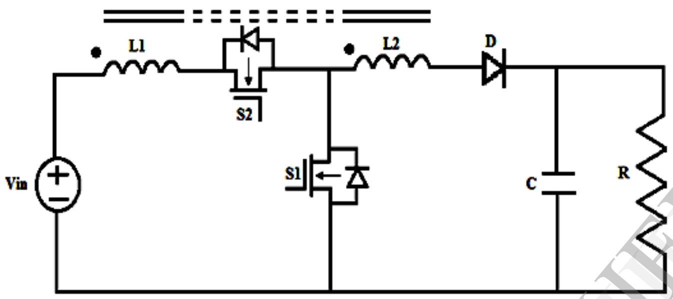

Fig. 1. Converter Topology

It can operate in Buck as well as boost mode. Its operation can be explained with assumption that the circuit comprises of ideal components, unit coupling coefficient and under continuous conduction mode.

In buck charging mode, the switch S_2 is turned on and S_1 is turned off. The diode D conducts and Coupled inductors are charged. In buck discharging mode, the switch S_2 is turned off cutting current in L_1. S_1 is turned on and D conducts L_2 current to the load. In boost charging state, S_1 and S_2 are turned on charging L1. D is reverse biased by L2 and output voltage is supported by capacitor C. In boost discharging mode, S_2 is on and S_1 is off. L_1 and L_2 conduct through D to the output.

B. Control Scheme

Modified PWM control circuitry is used for control of operation. Open loop control circuitry is shown in Fig. 2. The modulation index m, actually defines the buck and boost operation here. WIWO operates in buck mode when $0 \leq m < 1$. Then the upper comparator provides the required duty cycle pulses for S_2 and lower comparator outputs a 1 state; thus NAND gate produces the complimentary pulses for S_1. While when $1 \leq m < 2$, it operates in boost mode. Then the upper comparator produces a 1 state which keeps S_2 ON and the lower comparator together with NAND gate produces the required pulses to S_1.

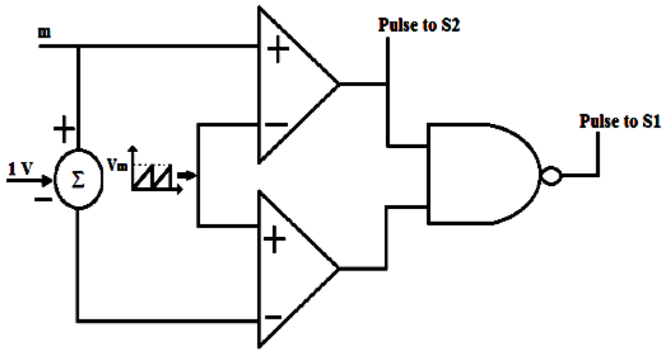

Fig. 2. Open-loop control Scheme for WIWO Converter

Closed loop control circuitry is shown in Fig. 3. It has two control voltages V_c and V_c '. V_c is obtained by compairing the reference voltage with the output voltage. V_c ' is obtained by downshifting the control voltage V_c by V_m ; V_c ' $= V_c - V_m$. Sawtooth ramp has an amplitude of V_m .The relationship between V_c and V_m is $V_c = mV_m$. So WIWO operates in buck mode when $0 \leq V_c < V_m$. While when $V_m \leq V_c < 2V_m$, it operates in boost mode.

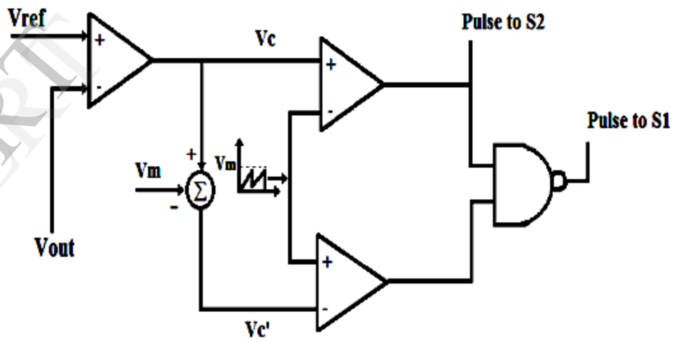

Fig. 3. Closed-loop control Scheme for Converter

C. Operating Principle

It is assumed that the circuit comprises of ideal components, unit coupling coefficient and under continuous conduction mode. The dark connections show the current path in each mode.

1) Buck Mode

State 1: Buck –mode charging state ($0 \leq m < 1$).

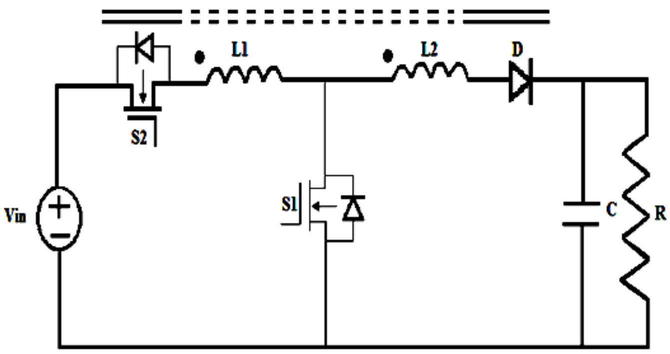

Fig. 4. Buck mode charging state

State 2: Buck-mode discharging state ($0 \leq m < 1$).

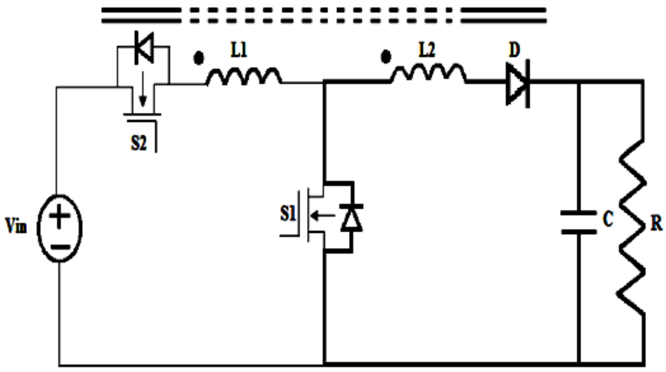

Fig. 5. Buck mode discharging state

2) Boost Mode

State 1: Boost –mode charging state ($1 \leq m < 2$).

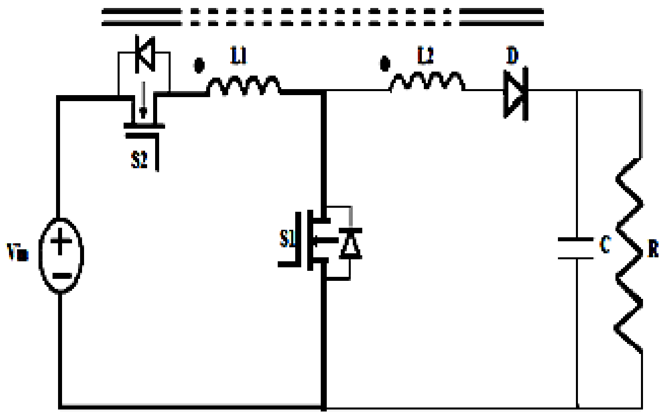

Fig. 6. Boost mode charging state

State 2: Boost-mode discharging state ($1 \leq m < 2$).

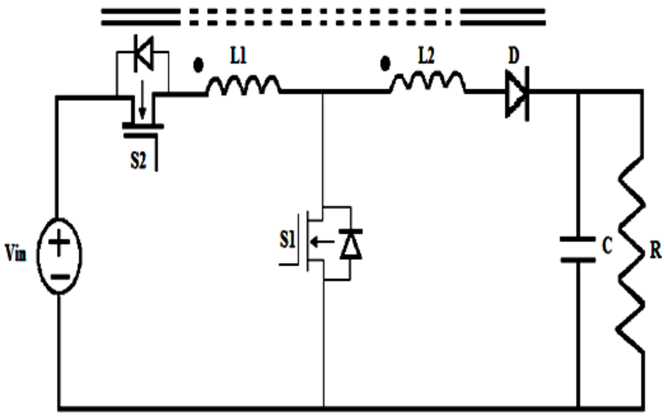

Fig. 7. Boost mode discharging state

Fig. 8.

III. SIMULINK MODEL

A. Open- Loop Simulink Model.

PSIM simulation tool is used to simulate the DC-DC converter with the logics discussed above. The turns ratio was set to n = 1. The switching frequency of 20 kHz was chosen. L_1 and L_2 were chosen as 56.53μH. Input voltage of 12V is given. Filter capacitor value should be high.

1) Open-loop model

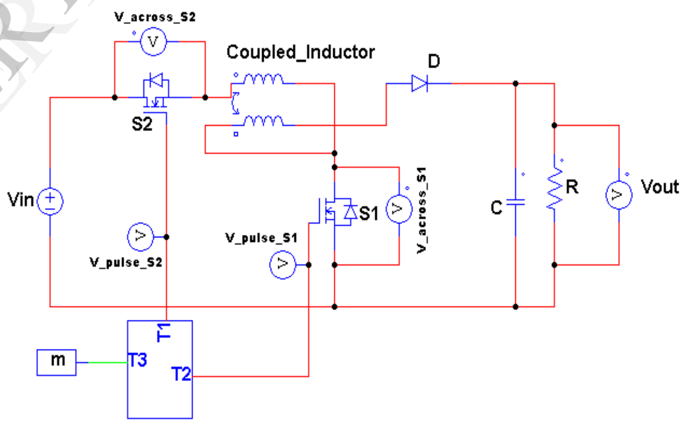

Fig. 9. Open-loop model of converter topology

Fig. 8 shows the open-loop circuit model of the topology. Fig. 9 shows the model of the open-loop control scheme. Here m controls the mode of operation. So whenever m changes the mode of operation changes.

2) Open-loop control scheme.

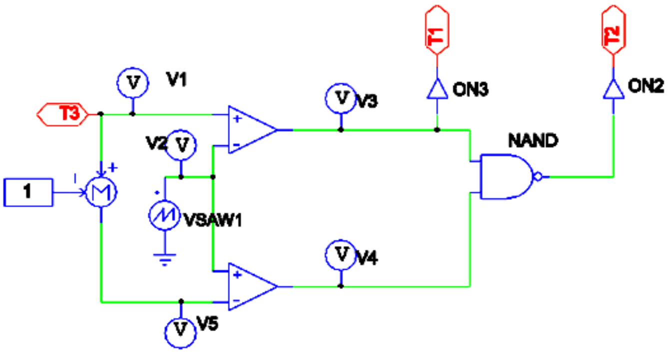

Fig. 10. PSIM model of open-loop control scheme

B. *Closed-loop model*

1) *Closed-loop model*

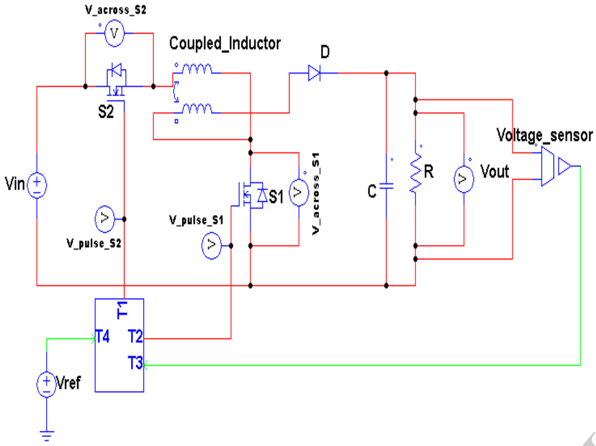

Fig. 11. Closed-loop model of converter

2) *Closed-loop control scheme.*

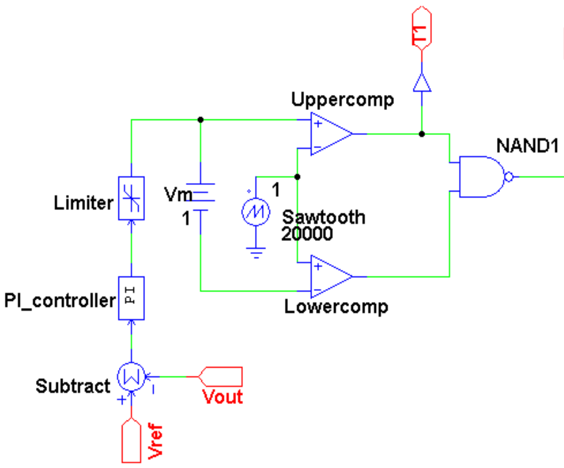

Fig. 12. PSIM model of closed-loop control scheme

Fig. 10 shows the closed-loop model. Fig. 11 shows the model of the closed-loop control scheme. A PI controller and a limiter is used to obtain the required value of duty cycle during closed loop operation.

IV. RESULT ANALYSIS

A. *Gain vs Duty Cycle*

1) *In Buck Mode*

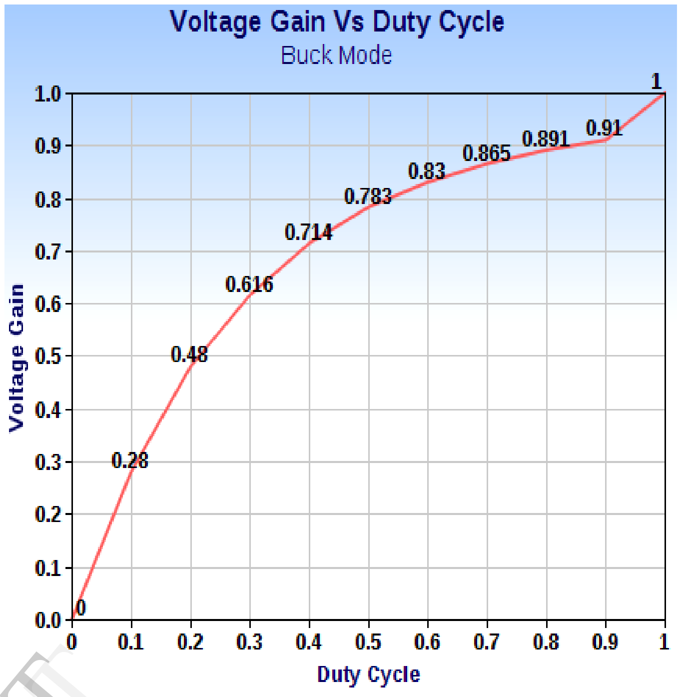

Fig. 13. Gain Vs Duty Cycle graph in buck mode

Fig. 12 is the graph showing the voltage gain against duty cycle in buck mode. It can be seen that the voltage gain is about 0.28 for a duty cycle of 0.1. It shows a good step-down capability of the circuit.

2) *In Boost Mode*

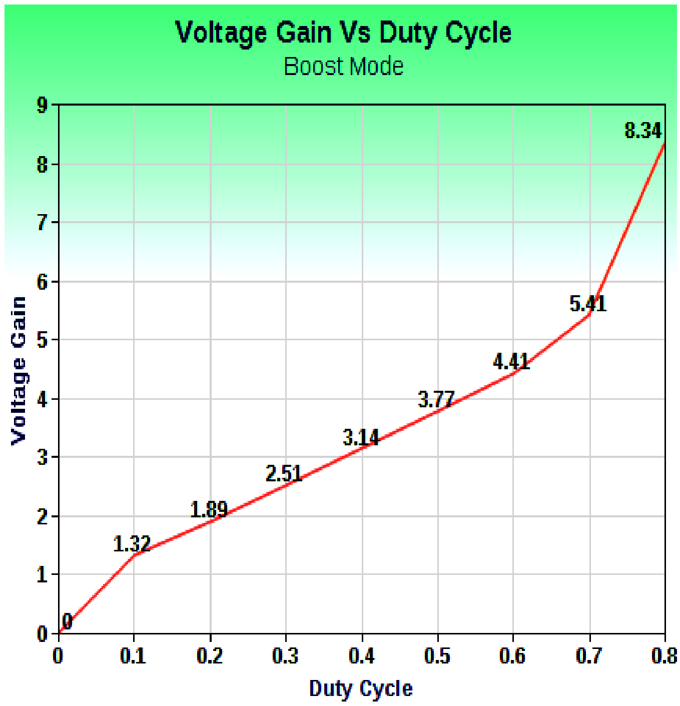

Fig. 14. Gain Vs Duty Cycle graph in boost mode

Fig. 13 is the graph showing the voltage gain against duty cycle in boost mode. It can be seen that a voltage gain of 8.34 is obtained for a duty cycle of 0.8. It shows a good step-up capability of the circuit. In boost mode the duty cycle cannot be extended beyond 80%.

B. *Buck Mode*

The output waveforms for a duty cycle of 0.5 are shown here. Fig. 14 shows the output voltage waveform.

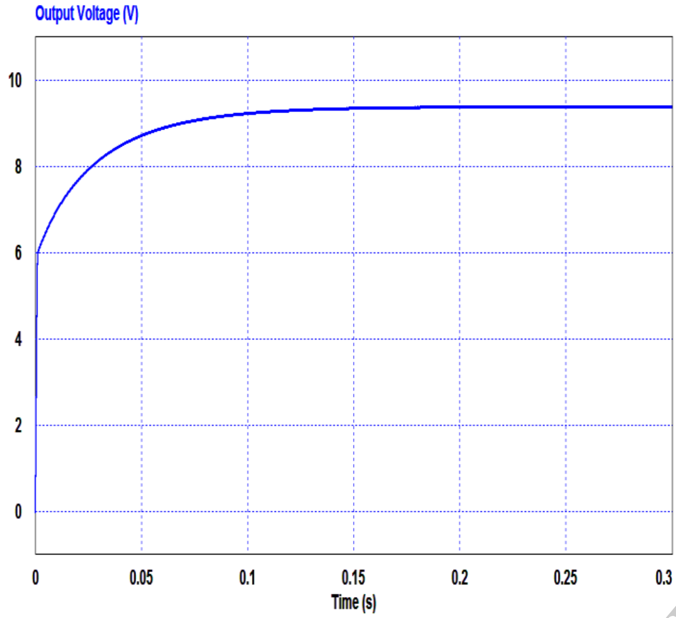

Fig. 15. Output Voltage (Buck Mode)

Fig. 15 shows the voltage across S_1.

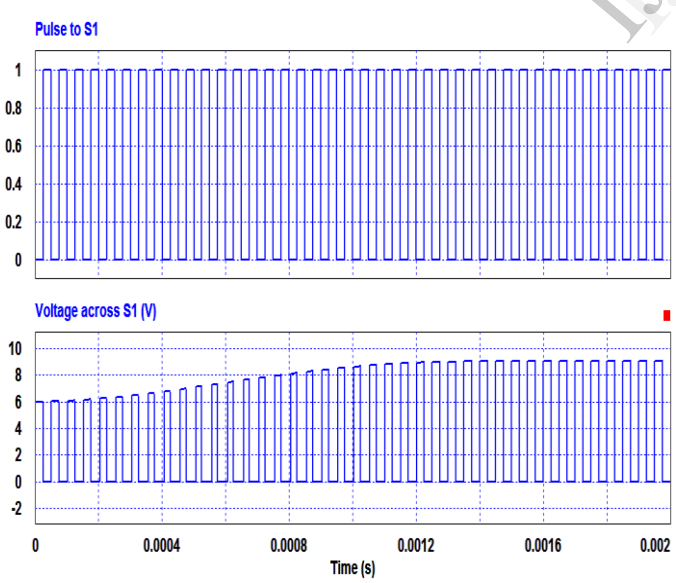

Fig. 16. Voltage across S_1

Fig. 16 shows the voltage across S_2. There occurs a turn off voltage spike across the switch as can be seen from the waveform. These can be reduced by designing effective snubber circuit. About 0.75 times and 1.46 times the input voltage appears across S_1 and S_2 in steady state.

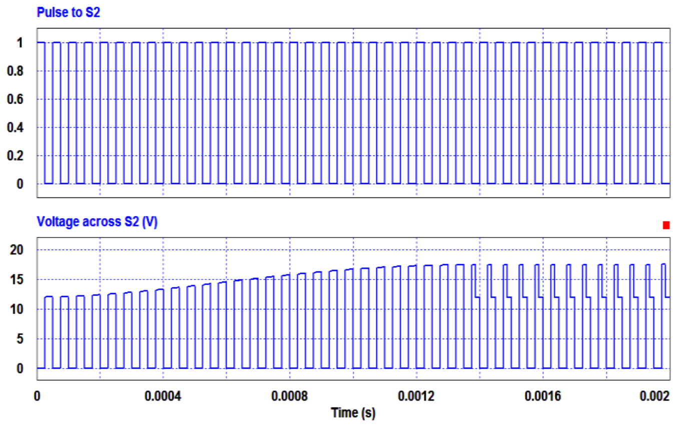

Fig. 17. Voltage across S_2

C. *Boost Mode*

The output waveforms for a duty cycle of 1.5 are shown here. Fig. 17 shows the output voltage waveform.

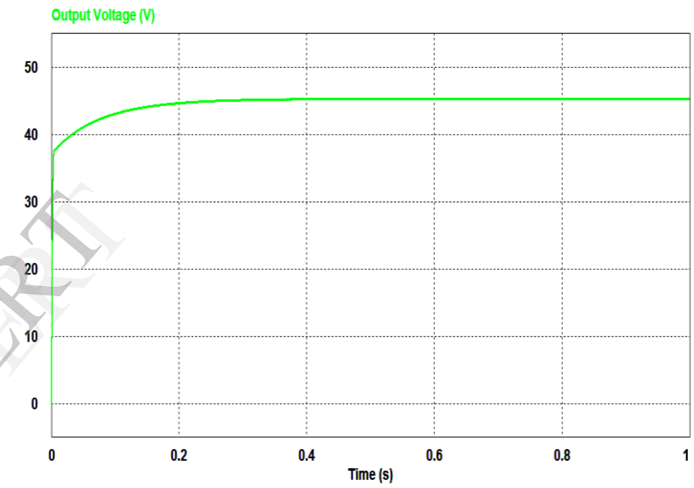

Fig. 18. Output Voltage (Boost Mode)

Fig. 18 shows the voltage across S_1. There occurs a high transient voltage across the switch as can be seen from the waveform. These can be reduced by designing effective snubber circuit. About 2 times the input voltage appears across S_1 during steady state.

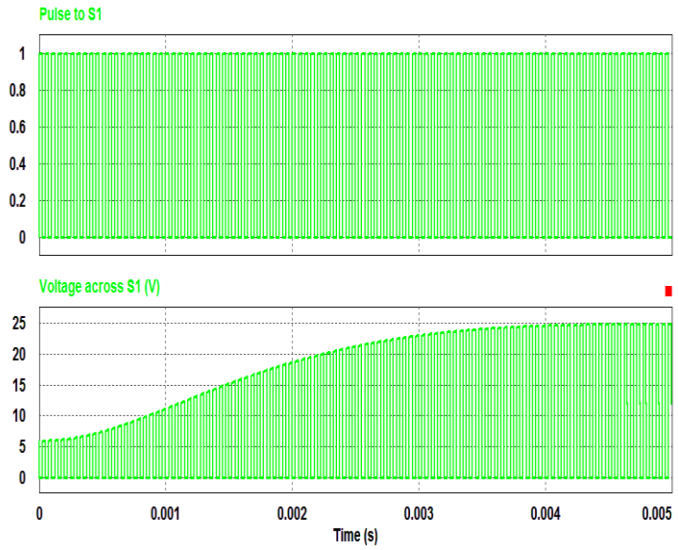

Fig. 19. Voltage across S_1

D. *Closed-loop Simulation Result*

Fig. 19 shows the output voltage for input voltage of 100 V and reference voltage of 50 V. The voltage is found to be constant at 50 V under closed loop operation.

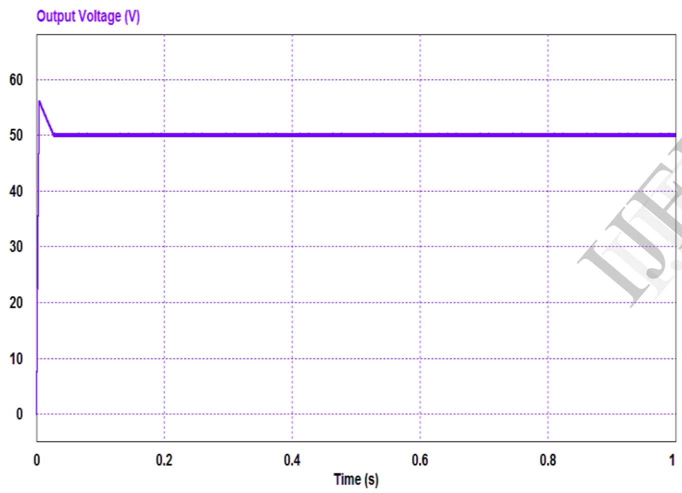

Fig. 20. Output Voltage in closed-loop operation

V. CONCLUSION

This paper presented the open-loop and closed-loop PSIM simulations of wide-Output DC-DC Converter which is an integration of buck and boost converter via coupled inductors. Simulation results were also presented. The discussed converter can be used for battery charging and discharging operation as both stepping up and stepping down the input voltage can be done. There are various advantages for this particular topology such as wider step-up and wider step-down DC-DC conversion range, moderate component count, simple structure, high efficiency, smooth transition between operating modes, avoid operation in extreme duty cycle, can operate with broadly varying input source etc. A disadvantage is the coupled inductor leakage causing transient and turn off voltage spikes across the switches. A passive lossless snubber cell can be used to improve the turn-on and turn-off transients in non-isolated pulsewidth modulated (PWM) dc/dc converters [16]. Switching losses and EMI noise are reduced by restricting $\frac{di}{dt}$ of the reverse - recovery current and $\frac{dv}{dt}$ of the drain-source voltage. However here there is a need to design two separate snubber circuits for S_1 and S_2. Numerous advantages of WIWO make it suitable for many industrial applications.

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