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Analysis & Design of Bi-Directional Converter with a Common Inductor for Optimal Operation

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ABSTRACT*:* Usually the conventional bidirectional dc-to-dc converter works on buck or boost mode by using the same inductor. For same load capacity it gives an optimized inductance value for both the buck and boost operation. But for different load capacity it does not gives the optimized inductor value for both the operating modes. By using same inductor, either it gives an optimized inductor for buck or boost mode and the another mode operates with relatively larger or smaller than the optimized inductor value.

To solve this problem, this paper proposes a bidirectional dc-to-dc converter with a common inductor, which can select an optimal inductor for buck and boost operation using a switch. Simulation of the proposed bidirectional DC-DC converter is carried out using MATLAB / SIMULINK software and the results are presented.

I. INTRODUCTION

In a battery operated vehicle it employs a bidirectional dc-to-dc converter, which has buck and boost operating modes. At a boost mode, it increases a dc-link voltage of an inverter resulted in reduction of the number of the battery stacks. A buck mode charges a battery stack when the motor is in regeneration. For all modes, the bidirectional dc-to-dc converter works with a single inductor. Under the same load capacity, an optimal inductance value of inductor is equal for bidirectional operation. The conventional converter with a single inductor is simple to configure. when the load capacity for buck and boost mode is different from each other, it is difficult to design the inductor to satisfy all operating modes with an optimal inductance value. In this case, one mode operates with an optimal inductor, but another is relatively larger or smaller than an optimal one. If an inductor is designed for the boost mode, the inductance value is lower than an optimal value of buck mode. On the other hand, if an inductor is designed for the buck mode, the inductance value is larger than an optimal value of boost mode. The losses will be more by not using optimized inductor. As a result, efficiency drops.

To improve the problem mentioned the above, this work proposes a bidirectional dc-to-dc converter, which can select an optimal inductor for buck and boost operation.

II. CONVERTER TOPOLOGIES

The various converter topologies are discussed below,

A. Bi-Directional Converter with Single Inductor.
B. Bi-Directional Converter with different Inductors.
C. Bi-Directional Converter with a common Inductor

A. Bi-Directional converter with single Inductor

A buck-boost converter (dc-dc) is shown below. Generally the switch is belongs to the transistor family. Also, a diode is used in series with the load. The connection of the diode may be noted, as compared with its connection in a boost converter. The inductor, L is connected in parallel after the switch and before the diode. The load is of the same

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type as given earlier. A capacitor, C is connected in parallel with the load. The polarity of the output voltage is opposite to that of input voltage here.

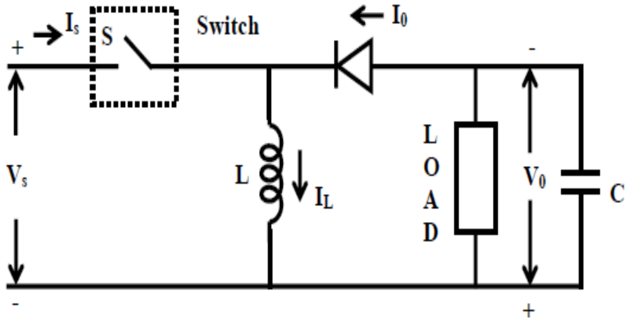

Fig.1 Buck-Boost converter

When the switch, S is ON, the supply current (i_s) flows through the path, , S and L, during the time interval. The currents through both source and inductor (i_L) are same. The polarity of the induced voltage is same as that of the input voltage. Then, the switch, S is put OFF. The inductor current tends to decrease, with the polarity of the induced emf reversing. Now, the polarity of the output voltage V_O, being opposite to that of the input voltage, V_S. The path of the current is through L, parallel combination of load & C, and diode D, during the time interval, T_{OFF} . The output voltage remains nearly constant, as the capacitor is connected across the load.

B. ***Bi-directional converter with different Inductors***

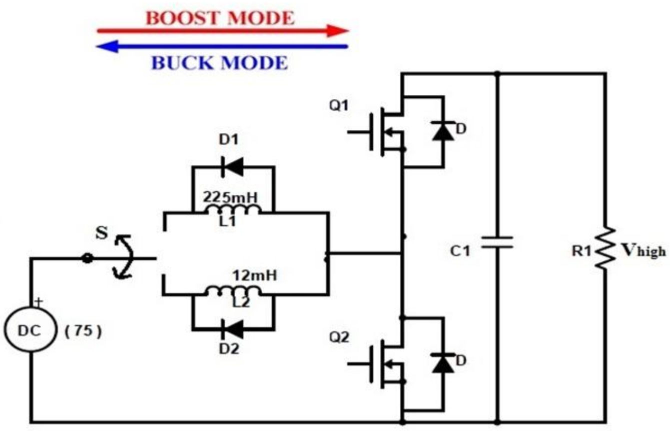

Fig.2 Bi-bidirectional converter with selective switch

Fig.2 shows a circuit configuration of the bidirectional dc-to-dc converter. The operation of this converter divides into two modes, i.e., buck and boost mode. By a selective switch (S), inductor (L_1) operates in a buck mode, and inductor (L_2) is designed to operate in a boost mode. During a buck mode, when switch Q_1 works, Q_2 is in off-state. During a boost mode, switch Q_1 maintains off and Q_2 works. By employing a selective switch, the proposed converter is able to select an optimal inductor for buck or boost mode. It minimizes loss by using an inadequate inductor. As a result, this approach improves the system efficiency.

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Modes of operation:
Boost Mode

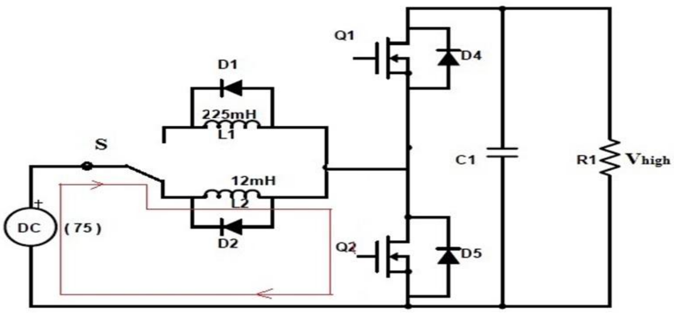

Fig.3 Boost Mode when Q_1 is OFF (a) Q_2 = ON , (b) Q_2 = OFF

Fig.3 shows boost mode when Q_1 is OFF, (a) Q_2=ON, (b) Q_2=OFF During a boost mode a selective switch connects with an inductor L_2 and Q_1 is in off-state. When Q_2 turns on as shown in Fig.3.2.and an inductor L_2 starts to save energy from a source voltage V_{low}. When Q_2 turns off, an inductor L_2 discharges the energy to output terminal via a body diode of Q_1.

Buck Mode

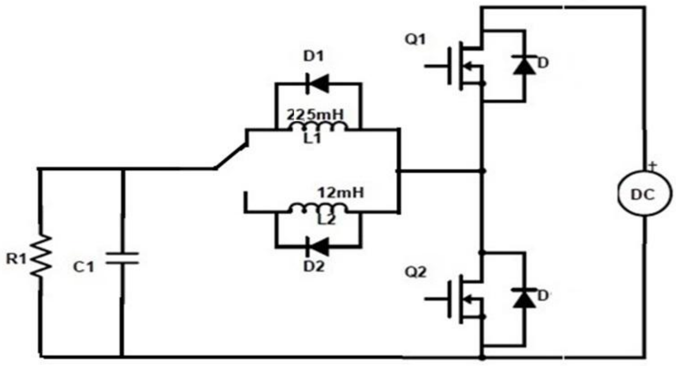

Fig.4 Buck Mode when Q_2 is OFF (a) Q_1 = ON , (b) Q_1 = OFF

Fig.4 shows buck mode operation. During this mode, the selective switch connects with an inductor L_1 and Q_2 turns off. When Q_1 turns on, an inductor L_1 starts to save energy from a source voltage V_{high} and a capacitor (*C*) discharges as shown in Fig.4. When Q_1 turns off, the inductor energy continuously transfers to a battery through the body diode of Q_2.

C. Bi-Directional Converter with a common Inductor

Fig.5 shows a modified circuit configuration of the proposed bidirectional dc-to-dc converter comprises with a selective switch and inductors L_1, L_2 and the common inductor L_3. The operation of the proposed converter divides into two modes, i.e., buck and boost mode. By a selective switch (S_1), inductors (L_1) and (L_3) operates in a buck mode, and inductors (L_2) and (L_3) is designed to operate in a boost mode. During a buck mode, when switch Q_1 works, Q_2 is in off-state. During a boost mode, switch Q_1 maintains off and Q_2 works. By employing a selective switch, the proposed converter is able to select an optimal inductor for buck or boost mode.

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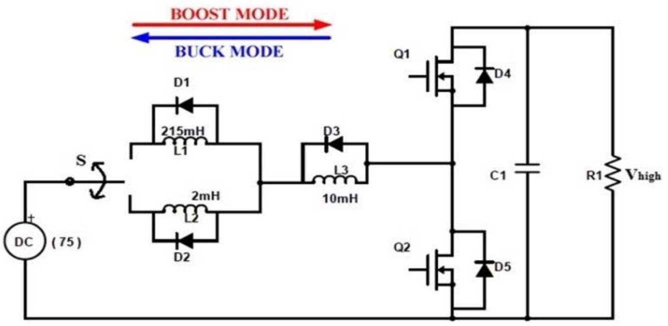

Fig.5 Modified Converter with selective switch and common Inductor

Modes of operation :

Boost Mode

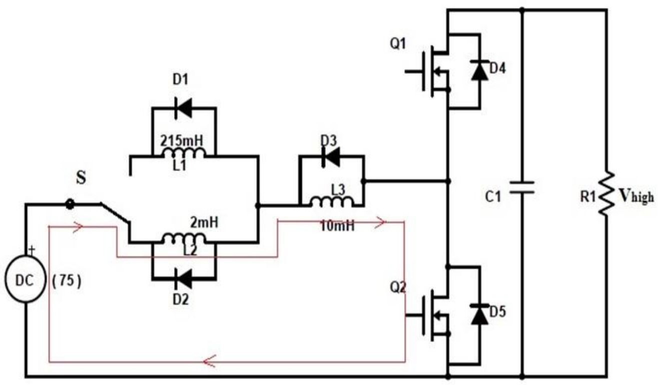

Fig.6 Converter with common inductor for Boost mode

Fig.6 shows boost mode when Q_1 is OFF, Q_2 is ON, during a boost mode a selective switch connects with an inductor L_2 and L_3 and the thyristor Q_1 is in off-state. When Q_2 turns on an inductor L_2 and L_3 starts to save energy from a source voltage V_{low}. When Q_2 turns off, an inductor L_2 & L_3 discharges the energy to output terminal via a body diode of Q_1.

Buck Mode

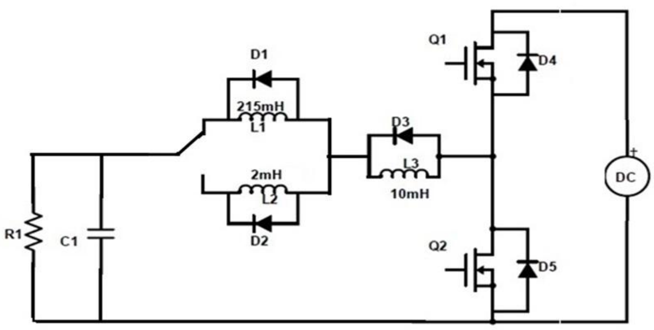

Fig.7 Converter with common inductor for Buck mode

Fig.7 shows buck mode operation, during this mode, the selective switch connects with an inductor L_1& L_3 and Q_2 turns off. When Q_1 turns on, an inductor L_1 & L_3 starts to save energy from a source voltage V_{high} and a

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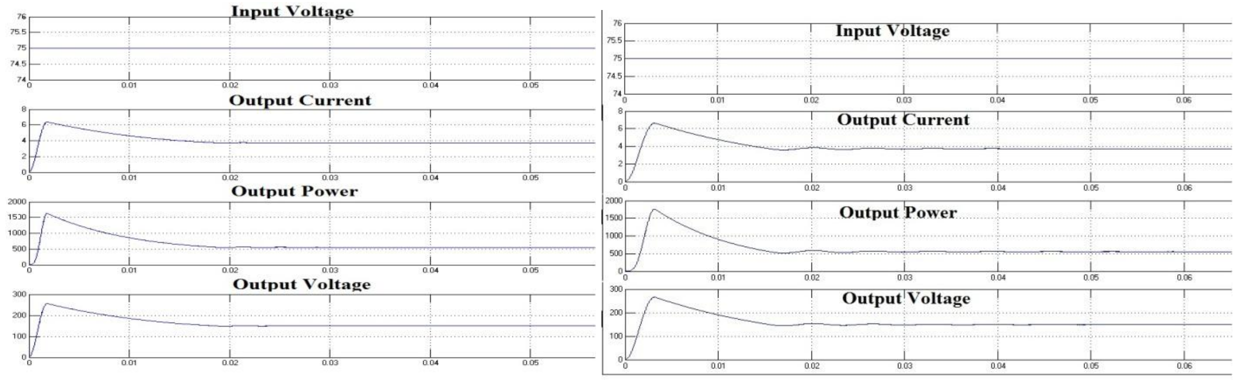
capacitor (*C*) discharges the energy as shown. When Q_1 turns off, the inductor energy continuously transfers to a battery through the body diode of Q_2.

III. SIMULATION RESULTS

A. *Converter with different Inductors without using the controller*

Boost Mode

The simulation is carried out, and it shows the result for inductor current, input voltage, duty ratio, and output voltage when L_1=548 µH and L_2=180 µH inductor are used for a boost operation. Both inductor currents are continuous. But a current ripple of 180 µH inductor is higher than that of 548 µH inductor. It is a matter of course because of different inductance values. During the boost mode, if an inductor is designed larger than an optimal inductance value, the current ripple will be reduced, however, it will decrease a fast response characteristic to load variations.



(a) (b)

Fig 8 Simulation output for open loop control of boost converter for (a)L=180 μH , (b)L=548 µH

Comparison of Inductance Values for Boost Converter :

Tabulation 4.1

S. No	INDUCTANCE L = 180 µH	INDUCTANCE L = 548 µH
1	Input Voltage =54.7V	Input Voltage =54.2V
2	Input Current =7.54 A	Input Current =7.69 A
3	Input Power =412.43W	Input Power = 416.9 W
4	Output Voltage=123.3V	Output Voltage=116.8V
5	Output Current =3.08 A	Output Current =2.92 A
6	Output Power=380.2 W	Output Power =341.3W
7	Efficiency (%)= 92.1%	Efficiency (%) = 81.8 %

When compared the performance of these two different values of Inductances 180µH and 548µH, the Inductance value of 180µH is most suitable and optimal value for Boost operation because both inductor currents are continuous, But a current ripple of 180µH inductor is higher. If an inductor is designed larger than an optimal inductance value, the current ripple will be reduced.

Buck Mode

The simulation is carried out, and the result shows the inductor current, input voltage , duty ratio, and output voltage when 548 µH and 180 µH inductor are used for a buck operation.

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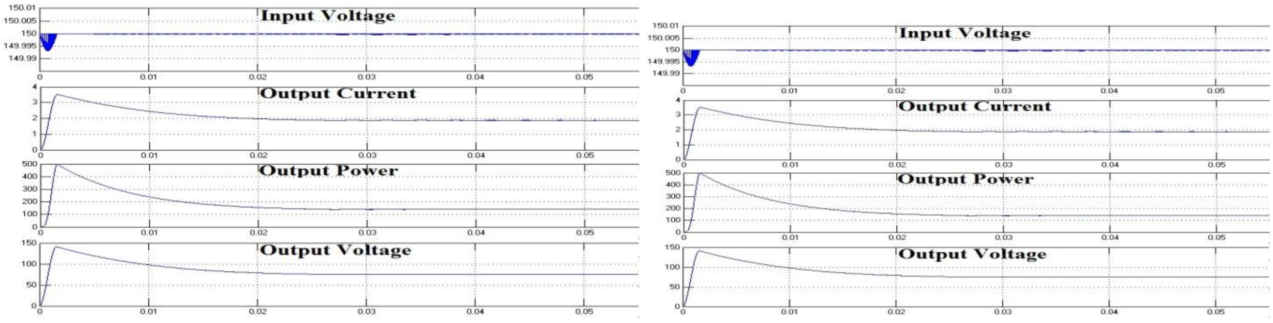

(a) **(b)**

Fig 9 Simulation output for open loop control of buck converter for (a) L=180 μH , (b) L=548 µH

Comparison of Inductance values for Buck converter

Tabulation 4.2

S. No	INDUCTANCE L = 180 µH	INDUCTANCE L = 548 µH
1	Input Voltage=122.3V	Input Voltage =123.5V
2	Input Current=0.76 A	Input Current=0.79 A
3	Input Power= 93.68 W	Input Power = 97.5 W
4	Output Voltage =65.4 V	Output Voltage=56.72V
5	Output Current = 1.30 A	Output Current =1.42 A
6	Output Power =93.02 W	Output Power=80.54 W
7	Efficiency (%) = 91.37%	Efficiency (%) =84.12 %

When compared the performance of inductance values for buck converter, the inductance 548 µH is selected as an optimal value because, an inductor current is continuous when it operates with a 548µH inductor, but when it operates with a 180µH inductor, the inductor current is discontinuous. The inductor 180 µH also seems to be suitable for buck mode because the efficiency is 7.25% higher than that of 548 µH, however the current peak will be higher due to DCM operation of inductor current. So the optimal inductance value of a buck mode is 548 µH.

B. ***Converter with a Common Inductor (L=10 mH) with and without using the controller***

Boost Mode

The open loop control of the modified boost converter is simulated with the inductor value as L = 2mH for boost converter with the load capacity of 500W as shown

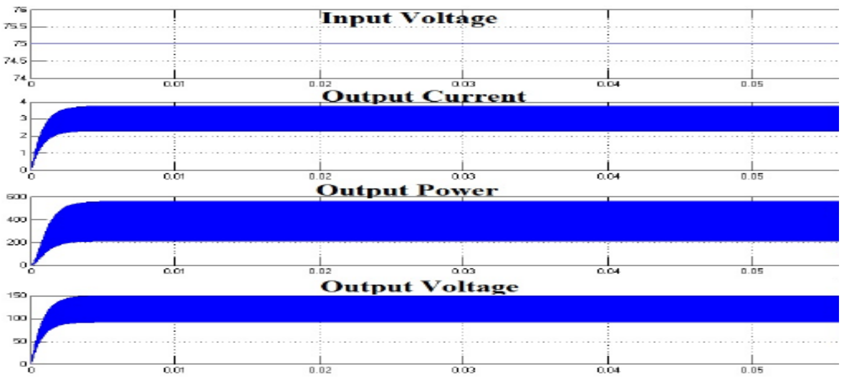

Fig 10 Simulation output for open loop control of boost converter for L=2 mH

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The closed loop control of the modified boost converter is simulated by using the PI controller. The output voltage and the reference voltage is compared by using the comparator and is given to the PI controller to eliminates the error and to produce the pulse strain which is given to the gate pulse of the switch. The inductor value as L = 2mH is designed for boost converter with the load capacity of 500W as shown

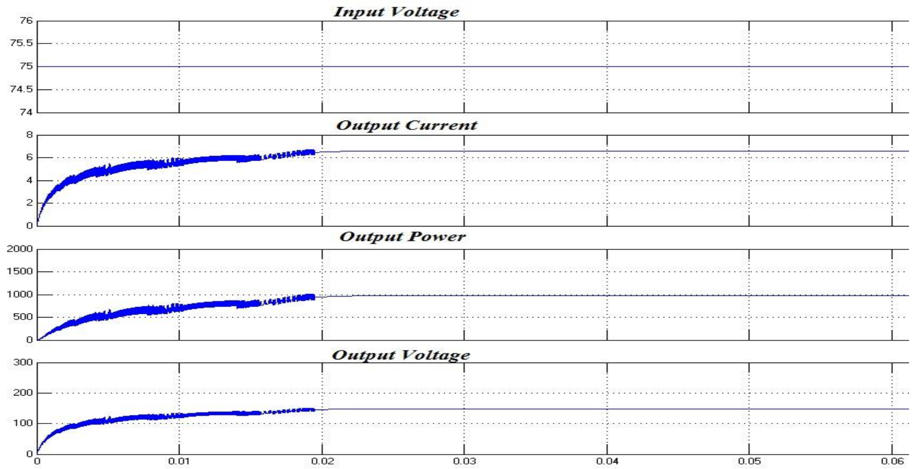

Fig 11 Simulation output for closed loop control of boost converter for L=2 mH

Buck Mode

The open loop control of the modified buck converter is simulated with the inductor value as L = 215 mH for buck converter with the load capacity of 125W as shown

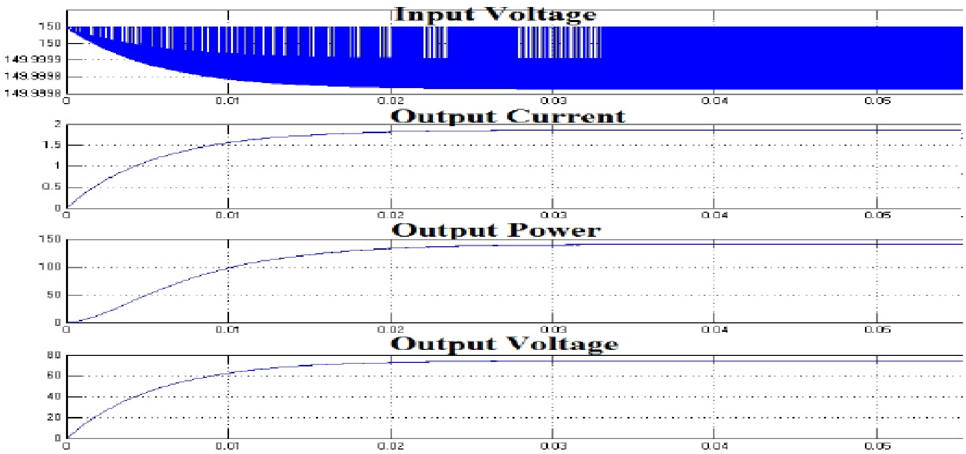

Fig 12 Simulation output for open loop control of buck converter for L=215 mH

The closed loop control of the modified buck converter is simulated by using the PI controller. The output voltage and the reference voltage is compared by using the comparator and is given to the PI controller to eliminates the error and to produce the pulse strain which is given to the gate pulse of the switch. The inductor value as L = 215mH is designed for buck converter with the load capacity of 125W as shown

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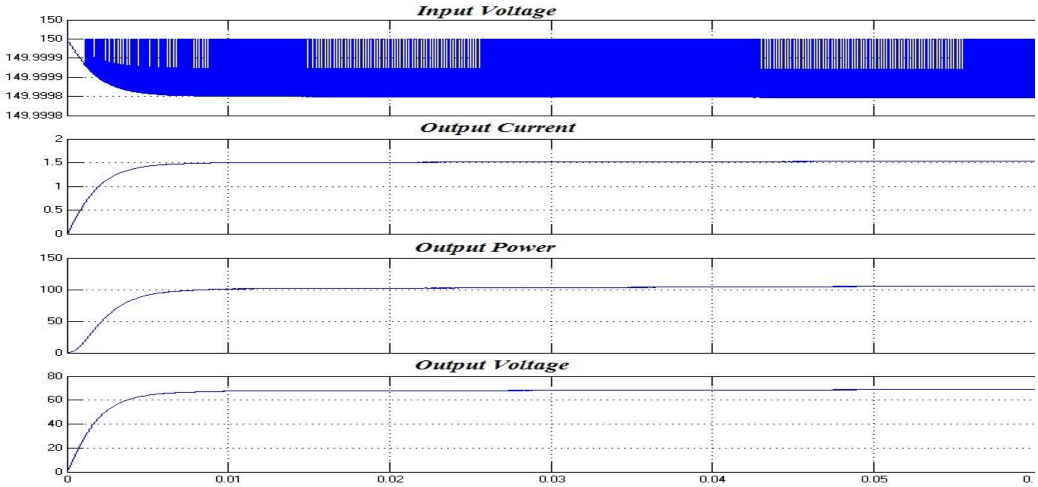

Fig 13 Simulation output for closed loop control of buck converter for L=215 mH

IV. COMPARISOM BETWEEN THE CONVERTER TOPOLOGIES

V.

Tabulation 4.3

SPECIFICATIONS	CONVERTER WITH SINGLE INDUCTOR		CONVERTER WITH SELECTIVE SWITCH		MODIFIED CONVERTER WITH COMMON INDUCTOR	
	Boost Mode	Buck Mode	Boost Mode	Buck Mode	Boost Mode	Buck Mode
Inductance	180 µH	548 µH	12 mH	225 mH	2mH	215Mh
Capacitance	470 µF	470 µF	1 µF	1 µF	1 µF	1 µF
Resistive Load	40 Ω	40 Ω	40 Ω	40 Ω	40 Ω	40 Ω
Switching Frequency	20kHz	20kHz	20kHz	20kHz	20kHz	20kHz
Input Voltage (V)	75	150	75	150	75	150
Output Voltage (V)	148.9	74.8	148.4	74.9	149.6	74.9
Load Capacity (W)	500	125	500	125	500	125
Duty Ratio (D)	0.5	0.5	0.4	0.4	0.4	0.4
Efficiency (%)	92.9	84.5	93.2	85.2	97.3	91.5

VI. CONCLUSION

In this paper a bidirectional dc-to-dc converter employing two different inductors with a common inductor is considered. One inductor is optimized for a buck mode, and the other inductor is optimized for a boost mode by designing each inductor with an optimal inductance value. The simulation is carried out using MATLAB/ Simulink

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model and from the simulation results the optimized value for boost mode is 2mH and for the buck mode is 215mH with the common inductance value of 10mH.

By using a switch, which can select an optimal inductor and it ensures higher efficiency compared to the conventional bidirectional converter working with a single inductor.

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REFERENCES

[1] J.G. Yang, and C.L. Kuo, "Isolated bidirectional full-bridge DC-DC converter with a flyback snubber," IEEE Trans. Power Electron., vol. 25.
[2] Le An and Dylan Dah-Chuan Lu " Design of a Single-Switch DC-DC Converter for PV-Battery Powered Pump System," School of Electrical and Information Engineering, The University of Sydney, NSW 2006 Australia.
[3] R. K. Singh, "A Magnetically Coupled Feedback-Clamped Optimal Bidirectional Battery Charger," IEEE Trans. on Magnetics, Vol. 60, No.2, Feb. 2013.
[4] S. Waffler and J.W. Kolar, "Efficiency Optimization of an Automotive Multi-Phase Bi-Directional DC-DC Converter," in Proc. 6th International Power Electronics and Motion Control Conference-ECCE Asia, May 2009.