Design of Multi Output DC-DC Boost Converters

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Abstract—**DC-DC converters are used as power electronic interfaces for renewable energy sources such as photovoltaic power system, fuel cells. To construct an efficient renewable energy system, they need to have the suitable converter. In this paper, we proposed triple output boost DC-DC converters which are used in such system to improve efficiency, performance and also to reduce cost and component count. Double outputs boost DC-DC converters is an existing converter. Double output boost dc-dc converter and Triple output boost dc-dc converter were designed through derivation by using Single pole Triple Throw (SPTT) switch and Single Pole Four Throw (SPFT) Switch as building block. Switch realization and operating characteristics of the existing and proposed converters were obtained with their voltage transfer ratios. The performances of the existing double output dc-dc boost converter and Triple output dc-dc boost converters were simulated with equal duty ratio for each switches using MATLAB/Simulink.**

Index Terms— **Double output dc-dc boost converter, Triple output dc-dc boost converter, Topologies, Voltage transfer ratio.**

I. INTRODUCTION

Nowadays, several structure of combining batteries and ultra-capacitors have been discussed by various researchers. Although there are different types of dc-dc converter belongs to buck, boost and buck-boost topologies have been developed to meet variety of application specific demands [1] & [2]. The conventional approach of connecting the energy storage unit is by using independent converter has many problems [5]. The independent converter with energy sources can be connected either in series or parallel in multiple input converters. If the sources are connected in series it has to conduct the same current and if the converters are connected in parallel it should have same Voltage levels [4]. Both the conditions are practically undesirable. Instead of this, multi input converter is used to connect multi Sources in a single system to give required load demand an also to improve efficiency [6], reduce overall cost, reduce component count, more stability and simple control. Similarly multi output dc-dc converter has the same procedure to design a converter.Multi output dc-dc converter used where we need to convert from single dc input voltage to multi dc output voltage.

The Output voltage of the converter can be varied independently by varying the duty cycle of the particular switch of the Converter [7]. Multi output dc-dc boost converter can be constructed using single pole triple throw switch as a building block [3]. Design of new converters from existing converters is complicated task [2]. Hence in this paper, a systematic approach to design a proposed triple output dc-dc boost converters were designed.Fig.1 shows the block diagram of multiple output dc-dc boost converter with single input voltage source.

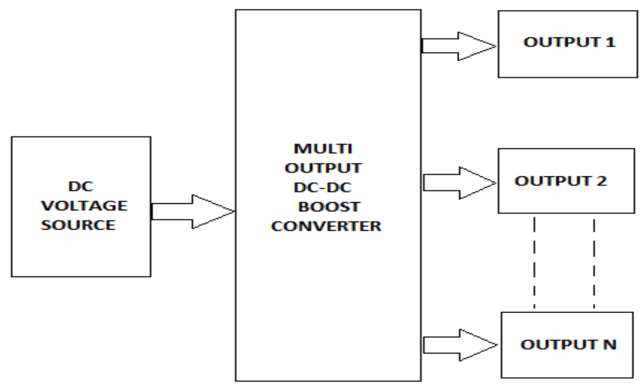

Fig.1.Block diagram of multi output dc-dc boost converter

Fig.2 shows the block diagram of multi output dc-dc boost converter for automobile applications.

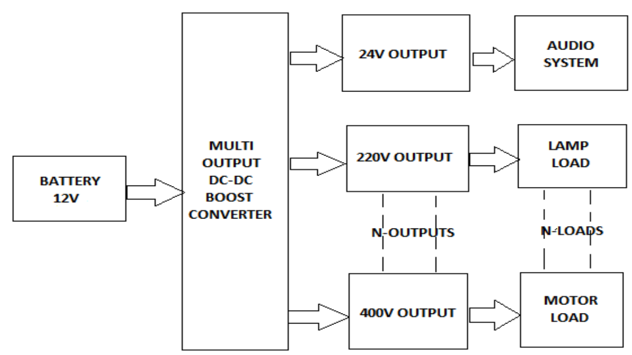

Fig.2.Block diagram of Multi output dc-dc boost converter for automobile applications.

In this paper, design and Switch realization of Double output dc-dc boost converter using single pole triple throw switch as a building block using with various modes of operation is presented in part II, design and Switch realization of triple output dc-dc boost converter using single pole triple throw switch as a building block using with various modes of operation is presented in part III. Voltage transfer ratios of double output and proposed triple output dc-dc boost converter converters are presented in part IV. Simulation models and results of performances of the converter are presented in part V.

II. Design Of Double Output Dc-Dc Boost Converter Using Single Pole Triple Throw Switch

The basic circuit diagram of the Double output dc-dc boost converter using single pole triple throw switch as a building block is shown in Fig.3.

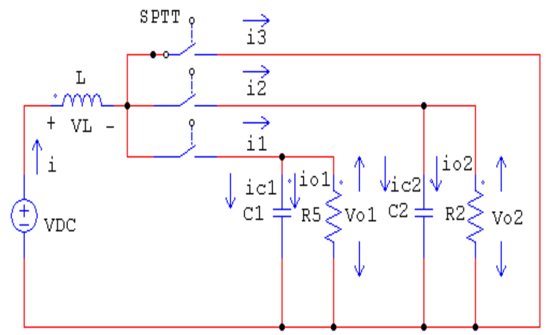

Fig.3.Circuit diagram of Double output dc-dc boost converter using single pole triple throw switch as a building block.

The circuit diagram of Double output dc-dc boost converter is shown in fig.4. In double output converters, it uses only one inductor. Load R1 consumes power when the switch S1 is ON condition. Load R2 consumes power when the switch S2 is ON condition. Switch S3 is used for freewheeling purposes.

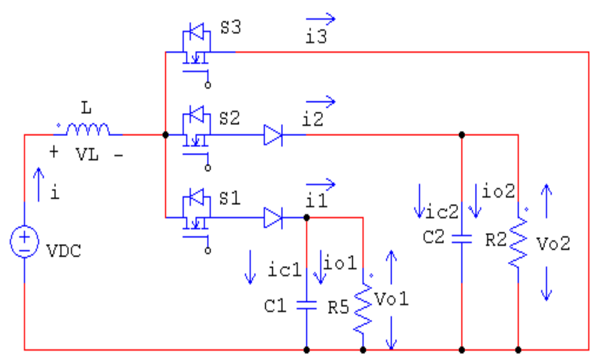

Fig.4 The final circuit diagram of Double output dc-dc boost converter

The voltage across inductor for different modes of operation of the converter is shown in the Table. I.

According to the modes of operation given in Table I. Switches are replaced by semiconductor switch or Diode [3]. Voltage drop across the inductor depends on the switches which are in ON condition.S1 conducts positive current and opposes either positive or negative voltage depending on the magnitude of output voltages.

TABLE I
VOLTAGE ACROSS THE INDUCTOR IN DOUBLE OUTPUT DC-DC BOOST CONVERTER USING SINGLE POLE TRIPLE THROW SWITCH FOR DIFFERENT MODES OF OPERATION

Mode	ON condition switches	V_L	Description
1	S1	V_{DC}-V_{01}	V_{DC} gives energy to the inductor and load resistor R1
2	S2	V_{DC}-V_{02}	V_{DC} gives energy to the inductor and load resistor R2
3	S3	V_{DC}	Inductor is being charged and both loads R1&R2 are disconnected from the circuit and inductor

For this purpose, diode is connected series with MOSFET. Similarly; S2 is replaced by MOSFET with series diode. Switch S3 conducts positive current and opposes positive voltage so it can be replaced by MOSFET. It is necessary to commutate the switch S1 by turning ON S3 and then turning ON S2 , instead of turning ON the sequence as S1 and S2.Because of continuous inductor current,S2 cannot be turned ON by turning OFF S1.If S2 is turned ON by turning OFF S1, it will produces discontinuous inductor current.

The basic idea in the synthesis of double output dc-dc boost converter is to bring a new switching circuit which can be able to connect or disconnect two output loads individually or simultaneously. Inductor is used as an energy storage element in this circuit [2]. In mode 1 the V_{DC} gives energy to the inductor and load resistor R1.In mode 2, V_{DC} gives energy to the inductor and load resistor R2, In mode 3, Inductor is being charged and both loads R1&R2 are disconnected from the circuit and inductor. The final designed circuit has only three MOSFET and two diodes.

III. Design Of Proposed Triple Output Dc-Dc Boost Converter Using Single Pole Four Throw Switch

The basic circuit diagram of the Proposed Triple output dc-dc boost converter using single pole four throw switch as a building block is shown in Fig.5.

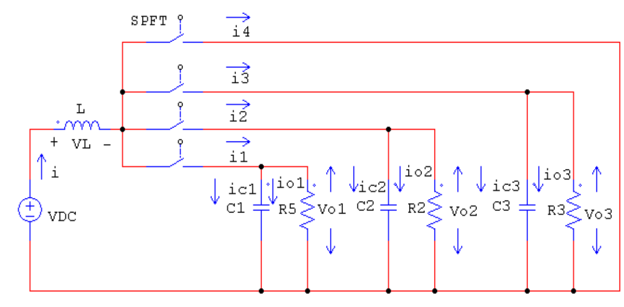

Fig.5.Circuit diagram of Proposed Triple output dc-dc boost converter using single pole four throw switch as a building block.

The circuit diagram of Triple output dc-dc boost converter is shown in Fig.6. In double output converters, it uses only one inductor. Load R1 consumes power when the switch S1 is ON condition. Load R2 consumes power when the switch S2 is ON condition. Load R3 consumes power when the switch S3 is ON condition. Switch S4 is used for freewheeling purposes.

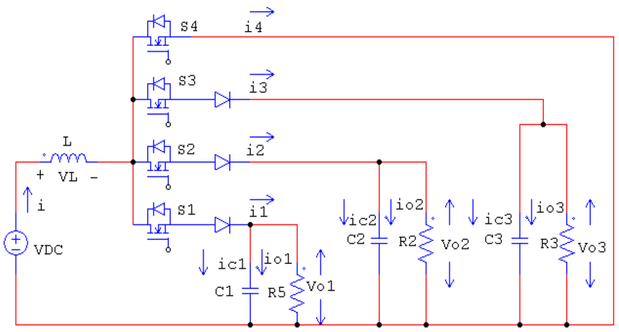

Fig.6 The final circuit diagram of Proposed Triple output dc-dc boost converter

The voltage across inductor for different modes of operation of the Proposed Triple output dc-dc boost converter is shown in Table. II. According to the modes of operation given in Table II, Switches are replaced by semiconductor switch or Diode [1].Voltage drop across the inductor depends on the switches which are in ON condition.S1 conducts positive current and opposes either positive or negative voltage depending on the magnitude of output voltages.

TABLE II

VOLTAGE ACROSS THE INDUCTOR IN PROPOSED TRIPLE OUTPUT DC-DC BOOST CONVERTER USING SINGLE POLE FOUR THROW SWITCH FOR DIFFERENT MODES OF OPERATION

Mode	ON condition switches	V_L	Description
1	S1	V_{DC}-V_{01}	V_{DC} gives energy to the inductor and load resistor R1
2	S2	V_{DC}-V_{02}	V_{DC} gives energy to the inductor and load resistor R2
3	S3	V_{DC}-V_{03}	V_{DC} gives energy to the inductor and load resistor R3
4	S4	V_{DC}	Inductor is being charged and both loads R1&R2 are disconnected from the circuit and inductor

For this purpose, diode is connected series with MOSFET.Similarly; S2, S3 are replaced by MOSFET with series diode. Switch S3 conducts positive current and opposes positive voltage so it can be replaced by MOSFET.It is necessary to commutate the switch S1 by turning ON S4 and then turning ON S3 and S2 instead of turning ON the sequence as S1, S2 and S3.

In mode 1 the V_{DC} gives energy to the inductor and load resistor R1.In mode 2, V_{DC} gives energy to the inductor and load resistor R2, In mode 3, V_{DC} gives energy to the inductor and load resistor R3.In mode 4 Inductor is being charged and both loads R1&R2 are disconnected from the circuit and inductor. The final designed circuit has only four MOSFET and three diodes.

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In this paper until the power sources V_{DC} is assumed to be power source, which need not be charged. However if the sources is an energy storage unit, then it needs to be charged regularly. For this purpose the converter need to have bidirectional power capability this circuit can be used for bidirectional dc-dc converter by connecting a diode in parallel connection [2]. The final designed circuit has only three MOSFET and two diodes. From the above designed circuit, we can conclude that the numbers of switches are reduced and the circuit has only one inductor. In this analysis, similar to the conventional single output dc-dc boost converter parasitic components will be neglected [3].

IV. VOLTAGE TRANSFER RATIO OF THE DOUBLE OUTPUT AND PROPOSED TRIPLE OUTPUT DC-DC CONVERTER

The voltage transfer ratio gives the relation between the input voltages, output voltage of double output and triple output dc-dc boost converters. Corresponding to their duty ratios; the switching pattern has three modes for double output dc-dc boost converter as shown in Fig.7.

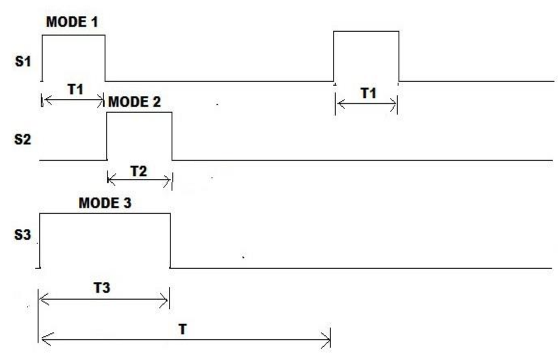

Fig.7.Switching pattern of double output dc-dc boost converter.

Corresponding to their duty ratios; the switching pattern has four modes for triple output dc-dc boost converter as shown in Fig.8.

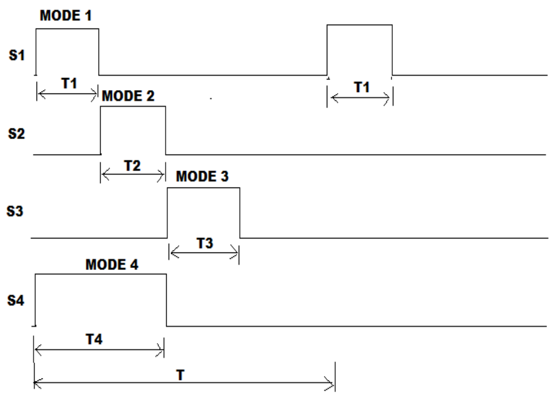

Fig.8.Switching pattern of proposed triple output dc-dc boost converter

Voltage second balance equation can be formed by taking the product of individual switch duty ratios and total time from the switching patterns.

$$T_1=d_1*T \quad (1)$$

$$T_2=d_2*T \quad (2)$$

$$T_3=d_3*T \quad (3)$$

$$T_4=d_4*T \quad (4)$$

$$T_1+T_2+T_3+T_4=T \quad (5)$$

Where,

T is the total time period of the switching patterns.

d_1, d_2 ,d_3 and d_4 are the duty cycles of the switches S_1 ,S_2 ,$S_3$and S_4 respectively.

V_{DC} is the input voltage of the converter.

V_{01} V_{02} V_{03} are the output voltages of the converter.

T_1 T_2 T_3 T_4 are the On time of the switches S_1 ,S_2 ,S_3 and S_4 respectively.

Voltage second balance equation of the inductor is given by

$$T_1*(V_{DC}-V_{01}) +T_2*(V_{DC}-V_{02}) +T_3*(-V_{DC}) =0 \quad (7)$$

$$T_1*(V_{DC}-V_{01}) +T_2*(V_{DC}-V_{02}) +T_3*(V_{DC}-V_{03}) +T_4*(-V_{DC})=0 \quad (8)$$

By combining the equations (1),(2),(3),(5) and (7),we can get the following equation (9) which gives the relation between the input and output of double output dc-dc boost converter.

$$V_{O1} *d_1+ V_{O2} *d_2= V_{DC} \quad (9)$$

By combining the equations (1),(2),(3),(4),(5) and (8),we can get the following equation (10)which gives the relation between the input and output of triple output dc-dc boost converter.

$$. V_{O1} *d_1+ V_{O2} *d_2+ V_{O3} *d_3= V_{DC} \quad (10)$$

From the above equations (9) and (10) we can conclude that output voltages of the converter are independent of each other. It is applicable only if the duty ratios are equal for S1 and S2 for the double output dc-dc boost converter and if the duty ratios are equal for S1, S2 and S3 for the triple output dc-dc boost converter [3]. In this paper, 0.5 constant duty ratio is selected for switching commands for S3 for both of the converters. Effective value for d_1 is the non overlapping part of S1 and S3 gate commands which is 0.25.Similarly effective value for d_2 is 0.25.This is reason that sum of the voltage cannot be directly found from the equations(9) and (10).

V. Simulation And Results

The simulation model and the output results are verified using MATLAB/Simulink. The simulation model of double output dc-dc boost converter using MATLAB/Simulink is shown in the Fig.9.

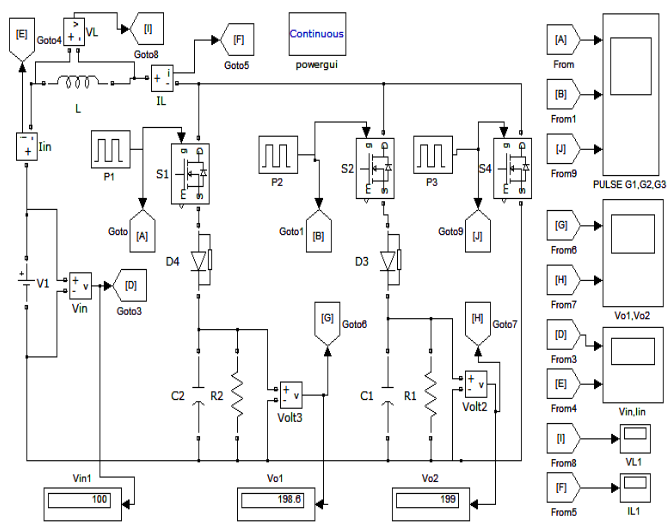

Fig.9.Simulation model of double output dc-dc boost converter using MATLAB

The values of inductance and capacitance are L=200 mH and C=80 µF were used for both of the converters. The converter operates in continuous conduction mode (CCM).The switching signals for Switches S_1,S_2 ,S_3 of double output dc-dc boost converter are shown in the Fig.10. Switching signal of switches S1 and S2 has same duty ratio but phase shifted by an angle 180 degrees at a switching frequency of 10 kHz. But switch S3 has constant 0.5 duty ratio at a switching frequency of 100 kHz. Pulse width modulation technique is used in this converter.

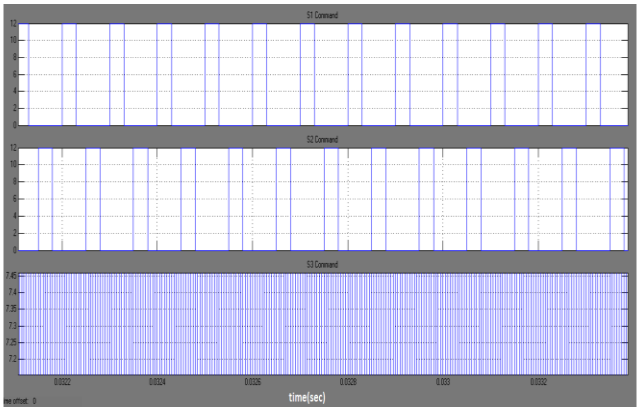

Fig.10.Switching signals of double output dc-dc boost converter

The simulation result of inductor voltage and current of double output dc-dc boost converter are shown in the fig.11 and Fig.12 respectively.

The simulated input voltage and input current are shown in Fig.13. The simulated output voltages are shown in Fig.14.

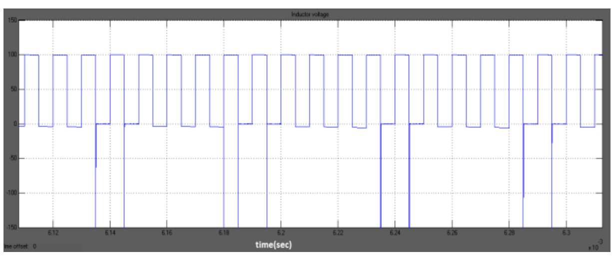

Fig.11.Simulation result of inductor voltage of double output dc-dc boost converter

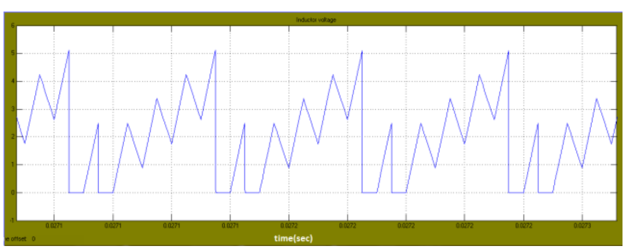

Fig.12.Simulation result of inductor current of double output dc-dc boost converter

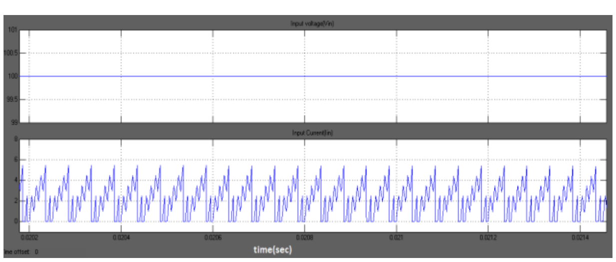

Fig.13.Simulation results of input voltage and input current of double output dc-dc boost converter

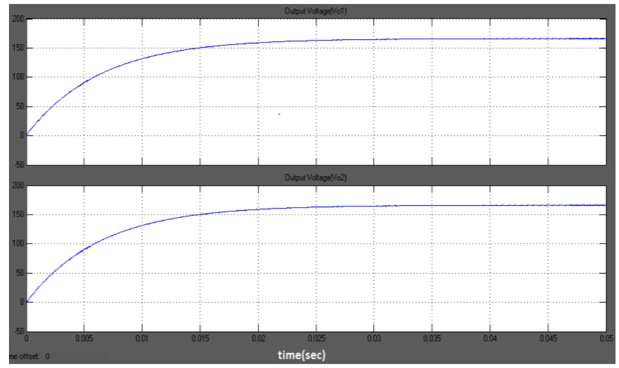

Fig.14.Simulation results of output voltages of double output dc-dc boost converter

It is observed that, duty ratio of 0.5 to 0.8 for switches S1 and S2 provides the same output voltage and input current of 0.669 amps, when the duty ratio of switch S3 kept as constant (0.5 duty ratio).so we can conclude this converter output voltage can be varied up to 0.4 duty ratio for S1 and S2 switches. In this range of duty cycle, converter consumes 0.02 amps input current. Output voltages of Double output dc-dc boost converter with equal duty ratio is shown in Table.III.

TABLE III

OUTPUT VOLTAGES OF DOUBLE OUTPUT DC-DC BOOST CONVERTER WITH EQUAL DUTY RATIO

Input voltage (V_{DC})	**Duty ratio (d_1)**	**Duty ratio (d_2)**	**Duty ratio (d_3)**	**Duty ratio (d_4)**	**V_{O1}**	**V_{O2}**	**V_{O3}**
100	0.25	0.25	0.25	0.5	131.8	230.9	149.7
100	0.3	0.3	0.3	0.5	164.3	189.9	222.1
100	0.4	0.4	0.4	0.5	178.3	179.1	223.8
100	0.5	0.5	0.5	0.5	198.1	198.5	199.4
100	0.6	0.6	0.6	0.5	198.3	198.6	199.2
100	0.7	0.7	0.7	0.5	198.4	198.7	199.0
100	0.8	0.8	0.8	0.5	198.5	198.8	198.8

The simulation model of triple output dc-dc boost converters using MATLAB/Simulink is shown in the fig.15.

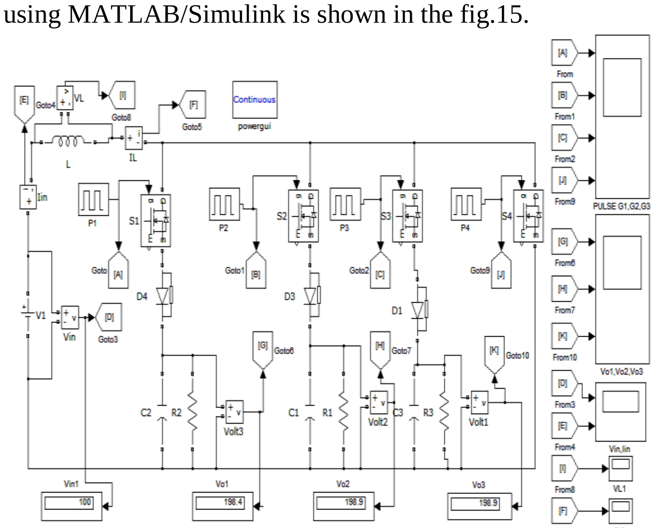

Fig.15.Simulation model of triple output dc-dc boost converter using MATLAB

The switching signals for Switches S_1,S_2 ,S_3 and S_4 of triple output dc-dc boost converter is shown in the fig.16. Switching signal of switches S1, S2 and S3 has same duty ratio but phase shifted by an angle 90 degrees between each switches at a switching frequency of 10 kHz. But switch S4 has constant 0.5 duty ratio at a switching frequency of 100 kHz.

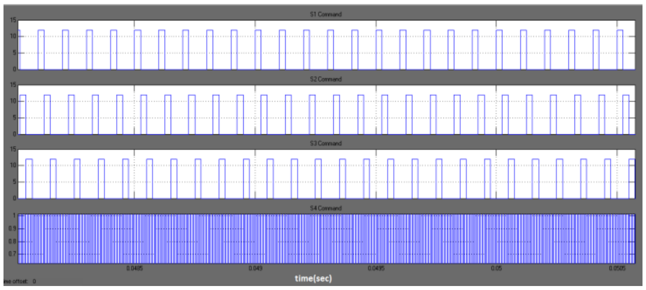

Fig.16.Switching signals of double output dc-dc boost converter

The simulation result of inductor voltage and current of triple output dc-dc boost converter are shown in the fig.17 and fig.18 respectively. The simulated input voltage and input current are shown in Fig.19. The simulated output voltages are shown in Fig.20.

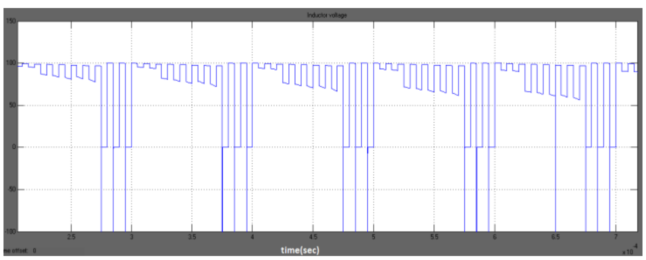

Fig.17.Simulation results of inductor voltage of double output dc-dc boost converter

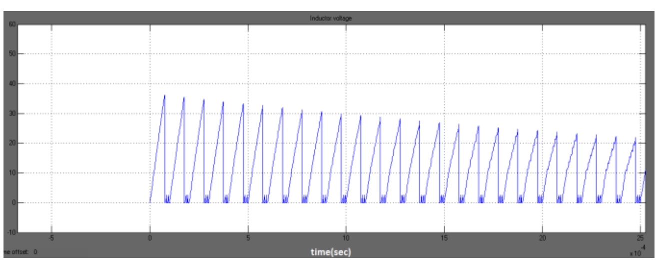

Fig.18.Simulation result of inductor current of triple output dc-dc boost converter

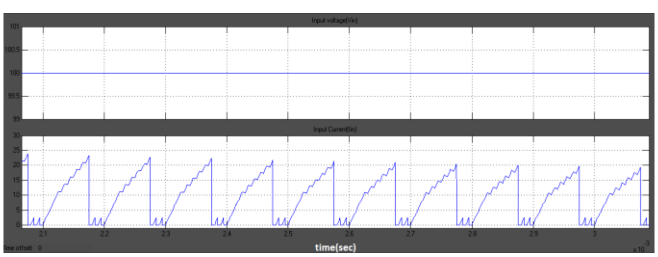

Fig.19.Simulation results of input voltage and input current of triple output dc-dc boost converter

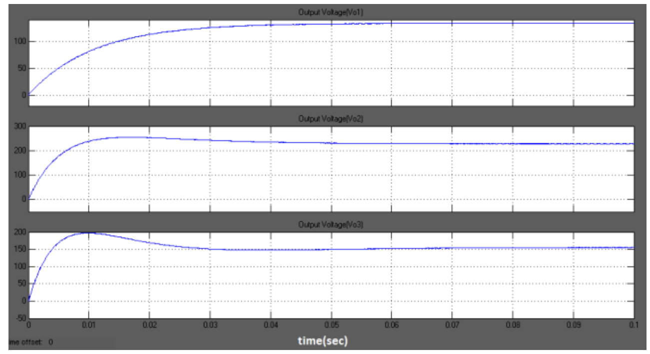

Fig.20.Simulation results of output voltages of triple output dc-dc boost converter

It is observed that, duty ratio of 0.5 to 0.8 for switches S1,S2 and S3 provides the same output voltage and input current of 1.512 amps, when the duty ratio of switch S4 kept as constant (0.5).so we can conclude this converter output voltage can be varied up to 0.4 duty ratio for S1,S2 and S3 switches. In this range of duty cycle, converter consumes 0.02 amps input current. Output voltages of triple output dc-dc boost converter with equal duty ratio is shown in Table.IV.

TABLE IV

OUTPUT VOLTAGES OF TRIPLE OUTPUT DC-DC BOOST CONVERTER WITH EQUAL DUTY RATIO

Input voltage (V_{DC})	**Duty ratio (d_1)**	**Duty ratio (d_2)**	**Duty ratio (d_3)**	**V_{O1}**	**V_{O2}**
100	0.25	0.25	0.5	131.8	132.1
100	0.3	0.3	0.5	166.0	166.3
100	0.4	0.4	0.5	182.0	182.4
100	0.5	0.5	0.5	198.6	199.0
100	0.6	0.6	0.5	198.6	199.0
100	0.7	0.7	0.5	198.6	199.0
100	0.8	0.8	0.5	198.6	199.0

VI. Conclusion

The double output and proposed triple output dc-dc boost converters topologies were designed through derivation by using single pole triple throw switch and single pole four throw switches as a building block. These two converters use only one inductor which reduces the converter size, component count and cost of the converters. The operating performance the double output and proposed triple output dc-dc boost converters of buck-buck dc-dc converters are verified using simulated results. The proposed converters can be used with Ultra Capacitor, Battery, Photovoltaic system, Fuel cell system for automobile applications such as Hybrid electric vehicle.

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