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Integrated Dual Output Buck Boost Converter for Industrial Application.

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***Abstract*— Modern world is seeking for reduced size, reliable and less cost equipment Single Input Multiple Output Converters (SIMO) and the research on them are worthy. This is because there may be auxiliary circuits in addition with the main power circuit. These auxiliary circuits and ICs work with reduced voltage level. The wide application of SIMO converters include telecommunications, industries, LED drivers, hybrid electric vehicles, dc based nano grids etc. The SIMO converters existing in the market faces some challenges because of its circuit and cost. So research work is progressive under this by the engineers. Integrated Dual Output Buck Boost Converter is a Single Input Multiple Output (SIMO) dc-dc converter topology is one such research work to meet the challenges that have been met by the conventional SIMO dc to dc converters. . It provides one step-up and one step-down output which can be achieved by replacing the switch in conventional boost converter by two series connected switches. In conventional SIMO topologies individual dc-dc converters are used for multiple outputs which require about 2N switches for N outputs that result in bulkier circuits. In the proposed topology, this drawback is overcome by including only N+1 switches for N outputs which make the system simpler, reliable and less cost. The selection of boost converter yields a good efficiency also. The analysis is similar to conventional buck and boost converters that makes the control system much simpler and easier. The type of closed loop feedback system used in this converter gives a better cross regulation and voltage regulations which are the common problems met by most of the SIMO dc-dc converters. Most attractive feature is that this converter does not require any other circuit components in order to achieve good cross regulation. The requirement of voltage regulators also is not needed with this converter. These all again reduces the cost of the product which will be an attractive feature in modern market. In order to check the behavior of the converter simulation is carried out in MATLAB environment. The simulation results validate the operation of the converter.**

Keywords*— DC-DC converters, Integrated Dual Output Converter (IDOC), Single Input Multiple Output (SIMO).

I. INTRODUCTION

Present day power electronic systems require multiple dc outputs at different voltage levels. This is because auxiliary circuits are often present in addition to the main power stage, and they should be powered at low voltages. For example, such requirement of multiple output can be seen in Hybrid electric vehicles [3], dc based nano grids [2], LED drivers, standby power supplies etc.

For example DC based nano grid Fig 1.a a dc distribution system generally met by local renewable energy sources like solar, wind etc. This low power distribution can be used for various applications and the power is taken from the common bus. Here the voltage requirement for different applications will be different

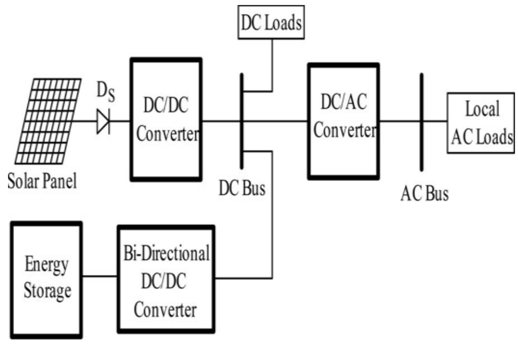

Fig 1

In industrial field the reduction in size, reliability and less cost are attractive features which lead to advanced research on SIMO dc to dc converters. This is because various ICs work on low voltages at different low voltage levels. So SIMO dc to dc converters have very good role in industrial field.

The field of power electronics has a very good role in designing a multioutput DC-DC converter. This is because the power electronic converters meet the required power by utilizing less space. Moreover with proper PWM method the switching loss can be reduced. So that system efficiency can be increased.

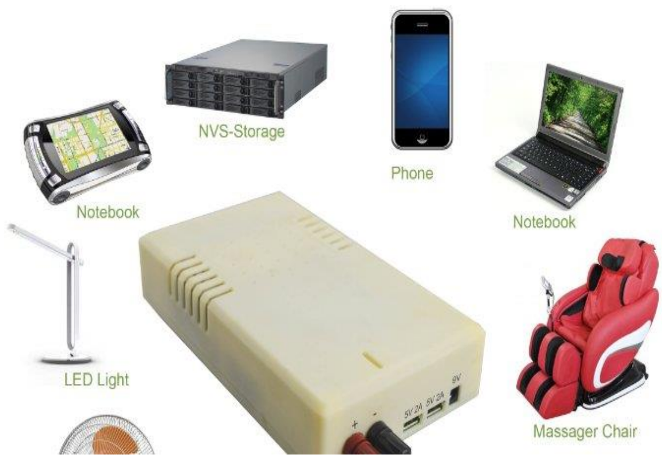

Fig 2 various industrial applications

In conventional multi output dc-dc converters individual dc-dc converters are used for different outputs. Fig 3.a shows conventional architecture for single input multiple output dc-dc converters.

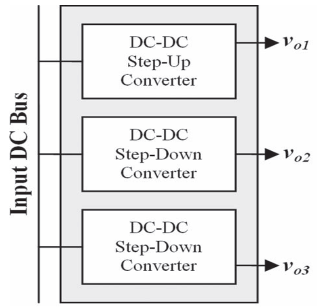

Fig 3.a

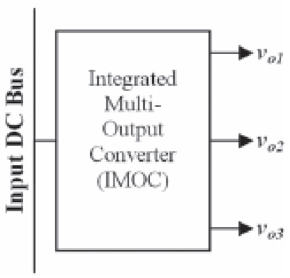

Fig 3.b

Fig 3.a conventional Fig 3.b proposed

The following section discusses the problems met by different multiple output dc-dc converters.

In some conventional multioutput dc-dc converters, individual dc-dc converters are used for output having different voltage requirement. An individual dc-dc converter is of two types, an isolated dc-dc converter and a non-isolated dc-dc converter.

An isolated dc-dc converter requires at least two switches at the front end, a transformer and at least two switches at the back end. So four switches, control drive circuitry and the transformer make the system more bulky and complex. For each and every dc-dc converter require the above mentioned components. Hence the whole system becomes complex. In some isolated multi output dc-dc converter, secondary is interleaved so as to get multiple output. Having the occurrence of more switches and transformer, the power density decreases. Moreover the leakage inductance of the transformer decreases the efficiency also.

In some isolated SIMO converters, secondary windings are interleaved for multiple outputs [6]. The step up or step down outputs depend on the turns ratio of the transformer. But in such converters precise regulation of each outputs is difficult due to the magnetic coupling. For precise regulation on each secondaries additional linear regulators, synchronous switch post regulators etc are required [12], [14].

In special connected two transformer (SCTTs) [16], to attain better cross regulation at load conditions a Complementary Pulse Width Modulation technique (CPWM) is used. So that it requires a bulky LLC resonant tank at the secondary, a snubber circuit to decrease the voltage stress of the rectifier. So that the system becomes bulky.

In [17] a full bridge dual output dc-dc converter, even if the LLC tank can be eliminated but each converter share the common leg.

In resonant based isolated multiple output converters [18], due to the presence of inductance of the resonant tank there will be cross regulation problem. In order to reduce cross regulation various approaches such as magnetic coupling between several secondary windings, secondary side post regulator ect should be included.. With magnetic coupling, only the master output voltage can be regulated. Other slave outputs cannot be regulated. If Secondary Side Post Regulator SSPR is connected it makes high cost of production, bulky system, poor efficiency and poor EMI performance.

From the literature discussed above, generally most of the isolated multiple output dc-dc converters are bulky, have complex control system and less reliable.

A non-isolated multiple output dc-dc converters are of two types, DC-DC converters with cascaded dc-dc stages [4], [19] or time-multiplexed and current- channelized multiple-output converters. In converters with cascaded dc-dc stages, the impedance interaction between individually designed converters may make the cascaded system unstable. To attain stability circuits such as adaptive active capacitor converter circuits should be connected. The presence of capacitance and inductance in such circuits make poor voltage regulation. Moreover it needs to design separate dc bus voltage controller and unbalanced loads can induce low-frequency oscillations on the current of the sources. In time multiplexed and current channelized multiple output converters, practically it becomes more difficult to generate switching functions that can share a fixed switching period. So the control system of the converters is very complicated. Hence the whole system becomes unreliable.

A multiple output converter has to meet many challenges. They are its ability to regulate each of the individual outputs precisely, to have better cross-regulation behaviour due to changes in the other output and to devise a suitable control system to coordinate the power flow between the different outputs.

For a multiple output converter, cross regulation [6], [23], [28] is the change in voltage on one output (expressed as a percent) caused by the load change on another output. This may be due to conduction loss of diodes, magnetic windings of the transformer, ESR of the capacitor, external inductors included in the circuit. Cross regulation problems leads to the use of additional linear and non-linear switching. But in this converter a better closed loop feedback control system is employed for the reduction of cross regulation.

In order to mitigate the above problems associated with SIMO converter a new version having an integrated architecture with a step up output and multiple step down outputs it replaces all the individual dc-dc converters be a series connected switches in a conventional boost circuit. The integrated multiple-output converters (IMOCs) Fig 2.b in this paper, utilize a reduced number of switches ($(N + 1)$ switches for N outputs) compared with separate converters. In conventional converters with separate dc-dc converters 2N switches are required. The use of a lower number of switches reduces the cost of the switch and its associated drivers. In addition, due to its integrated architecture, all the outputs of the system are regulated using the same set of switches, and hence, the coordination control is easier.

The circuit analysis and the control system requirement are exactly similar to that of conventional buck and boost converters. But compared with conventional buck or buck-boost converter, the input filter requirement is lower as the input and output current of this proposed converter are linear.

By the implantation of proper feedback control system which will be discussed in the following section, the regulation of outputs can be done individually. Hence good voltage regulation and cross regulation can be achieved. The cross regulation again can be decreased by replacing the diode by a switch. The switching pattern of this switch is just the complementary of the second switch in Integrated Dual Output Buck Boost Converter.

This paper is organized as follows: This paper studies the integrated dual-output converter (IDOC), which has two dc outputs—a step-up and a step-down. Proposed topology circuit and extended version circuit are discussed in section II. The analysis of proposed topology and design of passive components are discussed in section III. The simulation of proposed topology with D_1=0.33 and D_2=0.33 is shown in section IV. Cross regulation reduction and voltage regulation are shown in that section. Section V concludes the paper.

II. PROPOSED TOPOLOGY

A. *Circuit diagram*

In the proposed topology the switch in the conventional boost converter is replaced by two series switches. For Integrated Dual output Buck Boost converter two switches S_1 and S_2 which are two Mosfets. L_1, L_2 are two inductors, $C_1$and C_2 are two capacitors.

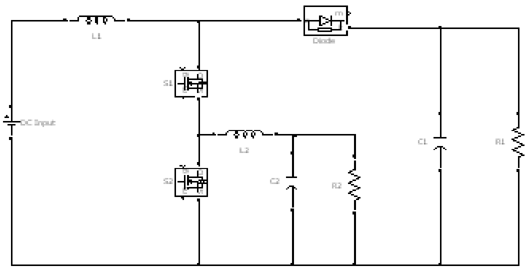

Fig 4 Proposed topology

For outputs greater than two can be formed by connecting a series of switches as shown in the Fig 5. There are N+1 switches for N outputs which give one step up output and multiple step down outputs.

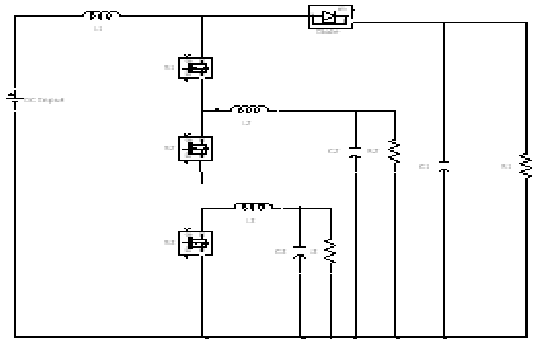

Fig 5 Integrated multi output dc-dc converter.

III. ANALYSIS OF PROPOSED TOPOLOGY

The Integrated Dual Output Buck boost converter is developed using two bidirectional switches S_1 and S_2. These are connected in series in a conventional boost circuit. There are three distinct modes of operations which are discussed in the following sections.

A. *Switching intervals*

- *Interval 1- Both switches S_1 and S_2 On*

When both switches are turned on, the diode D will be reverse biased and that circuit will be open circuited. The input current flows through L_1, S_1 and S_2. The inductor current i_{L1} builds up to its maximum value. While L_2 discharges the charge that was stored in the previous mode. This mode of operation is defined by duty ratio $D1$.

$$V_{L1} = v_{in}$$
$$i_{C1} = -\frac{v_{01}}{R_{01}}$$
$$V_{L2} = -v_{02}$$
$$i_{C2} = i_{L2} - \frac{v_{02}}{R_{02}}$$

- *Interval 2- S_1 is On and S_2 is Off*

When S1 is on and S2 is off, the inductor L1 discharges and the inductor current is distributed into two components. One i_D is flowing through diode *D*, and the other portion i_{L2} which builds as in conventional buck converter. The step-down converter draws energy from the source during this interval. The diode current i_D is equal to the difference between the inductor currents $iL1$ and $iL2$. The time duration for mode 2 operation is defined to have a duty cycle of $D2$.

$$v_{L1} = v_{in} - v_{01}$$
$$i_{C1} = i_{L1} - i_{L2} - \frac{v_{01}}{R_{01}}$$
$$v_{L2} = v_{01} - v_{02}$$
$$i_{C2} = i_{L2} - \frac{v_{02}}{R_{02}}$$

- *Interval- 3 S_1 is off S_2 is on*

  When S_1 is off and S_2 is on, the inductor L_2 discharges through the antiparallel diode of switch S_2. This interval is similar to the freewheel period of conventional buck converter. The inductor L_1 discharges aniL_1 falls to a minimum value. The diode current i_D and i_{L1} are similar in this mode. Hence during this interval, both inductors L_1 and L_2 give out their energy to their respective outputs.

$$v_{L1} = v_{in} - v_{01}$$
$$i_{C1} = i_{L1} - \frac{v_{01}}{R_{01}}$$
$$v_{L2} = -v_{02}$$
$$i_{C2} = i_{L2} - \frac{v_{02}}{R_{02}}$$

The switching strategy makes the converter operate in the interval sequence (III), (II), (I), (II), (III) during each period.

B. Steady state behaviour

1) Voltage gain

For inductor L_1,

$$v_{in} * D_1 + (v_{in} - V_{01}) * (1 - D_1) = 0 \quad (1)$$

Solving,

$$\frac{V_{01}}{V_{in}} = \frac{1}{(1 - D_1)} \quad (2)$$

This is the expression for the conventional boost converter. So V_{01} yields step up output voltage.

For inductor L_2,

$$(V_{01} - V_{02}) * D_2 + -V_{02}(1 - D_2) = 0 \quad (3)$$

Solving,

$$\frac{V_{02}}{V_{01}} = D_2 \quad (4)$$

Substituting (2) in (4),

$$\frac{V_{02}}{V_{01}} = \frac{D_2}{(1 - D_1)} \quad (5)$$

2)Range of input voltage

Because both duty cycle D_1 and D_2 share the same switching period, duty cycles $D1$ and $D2$ should satisfy

$$D1 + D2 \leq 1.$$

For any particular value of the duty cycle $D1$, the step-down gain varies within the range

$$0 \leq \frac{v_{02}}{v_{in}} \leq 1$$

This converter can provide step-down output ranges varying from zero to the input voltage. Compared with a conventional buck converter, the IDOC can provide wide step-down outputs at acceptable duty ratios of switches. This is because the step down output depends upon both $D1$ and$D2$, instead of only one duty cycle as in the case of a buck converter.

Similarly, the step-up gain varies between

$$1 \leq \frac{V_{01}}{V_{in}} \leq \frac{1}{1 - D_1}$$

Thus, the Integrated Dual Output Buck Boost Converter preserves the qualities of both buck and boost converters in an integrated architecture.

C. Design of passive components

Design of passive components in this converter is same as that of the conventional buck and boost converters.

- .Inductance L_1

$$L_1 = \frac{D_1(1 - D_1)^2 R_{01}}{f_{sw}\delta_i} \quad (6)$$

Assume 35% current ripple.

- Capacitor C_1

$$C_1 = \frac{V_{01} D_1 T_s}{R_{01}\delta_v} \quad (7)$$

Assume 3% ripple.

- Inductor L_2

$$L_2 = \frac{(1 - D_2) R_{02}}{f_{sw}\delta_i} \quad (8)$$

Assume 35% ripple

- Capacitor C_2

$$C_2 = \frac{(1 - D_2 T_s^2}{8 L_2 \delta_{v02}} \quad (9)$$

Assume 3% ripple

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TABLE I. DESIGN SPECIFICATION

Sl No	*Parameter*	*attributes*
1	Input voltage V_{in}	12V
2	Output voltage V_{01}	18V
3	Output voltage V_{02}	6V
4	Step up dc load I_{01}	5A
5	Step down dc load I_{02}	5A
6	Switching frequency	100kHz

TABLE IIDESIGN VALUES OF PASSIVE COMPONENTS

Sl No	*Components*	*attributes*
1	Inductor L_1	15μH
2	Inductor L_2	20μH
3	Capacitor C_1	500μF
4	Capacitor C_2	200μF

IV CLOSED LOOP SIMULATION

A closed loop feedback control system is implemented in this converter to provide better cross regulation which is already explained in the above section. The subsections of this section refers the simulated waveforms at D1=0.33 and D2=0.33.

A Waveforms

1) When D_1=0.33 and D_2=0.33

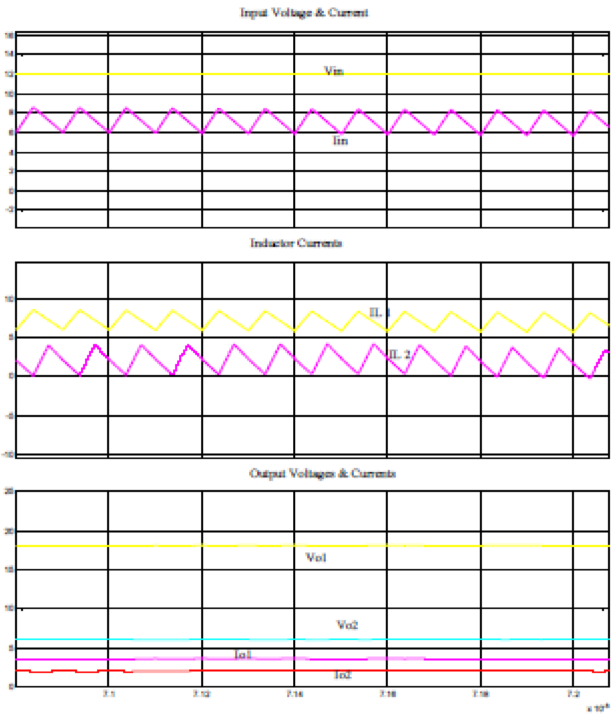

Fig 6

With D_1=0.33 and `D2=0.33 obtained both step up output-voltage of 17.6V and step down output of 6V. The load resistance used are R_{01}=5Ω and R_{02}=3Ω.The inductor currents are also obtained.

2) Voltage Regulation

A cross regulation

In order to check the effect of sudden change in any of the outputs, two step loads are applied. In the first case a step load of 0 to 2A and in the second case a step load of 0 to 5A as loads in the step down circuit. The duty cycles D1 and D2 are taken as 0.33.

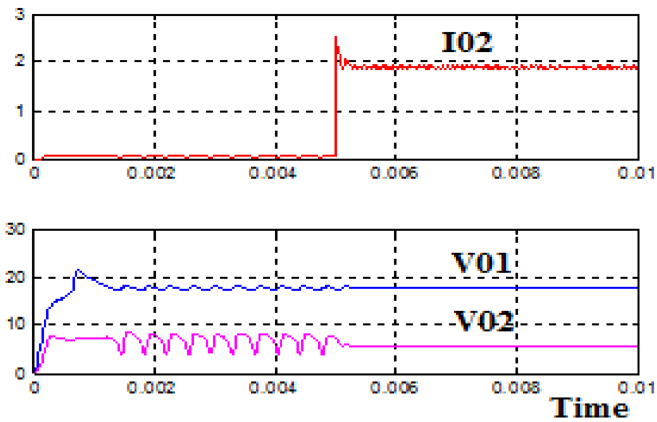

Fig 7.a

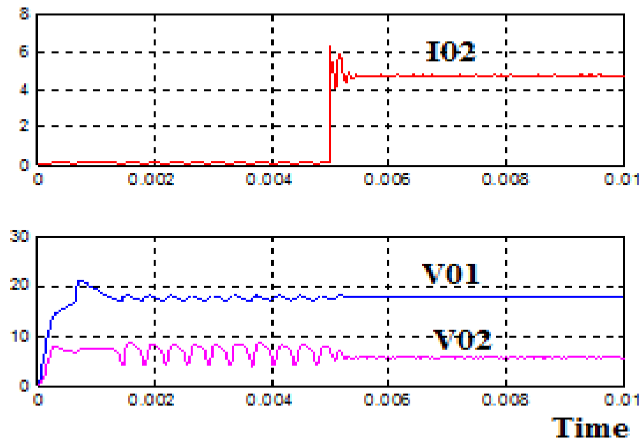

Fig 7.b

Fig 6 Cross Regulation a). step load of 0 to 2A b). step load of 0 to 5A

When both the step load changes were applied, the step up output and the step down output remained constant. At no load, there were more ripples than at the loaded condition. But the average value remained as the reference values. .

B Step change in the reference

In order to check the performance of the converter a step change of 4V to 6V is applied as the reference in the control circuit.

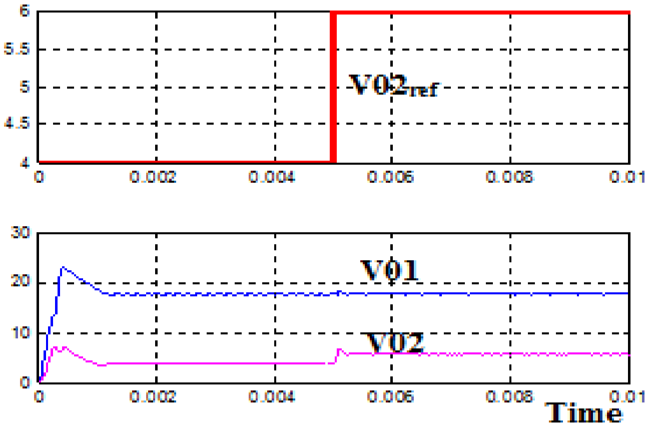

Fig 8 Step change of 4V to 6V in the reference of step down voltage

When the reference voltage at the step down circuit is changed from 4V to 6V, the step up voltage remained constant at 18V. There was a step change in V_{02} (4V to 6V) as per the reference given.

The below table show the range of step up and step down outputs that can be obtained with converter. It also give an idea about the favorable value of duty cycles.

The same simulation is done with the step change in the V_{01ref} and the data is given in the table IV.

TABLE III Table D1 is kept constant at 0.33

D2	V01
0.139	17.65
0.167	17.64
0.222	17.69
0.33	17.7
0.389	17.64
0.444	17.54

TABLE IV D_2 IS KEPT CONSTANT AT 0.33

D1	V02
0.143	5.78
0.333	5.8
0.36	5.59

The range of step down output voltage is larger than the step up output voltage. From the table it is understood that the converter gives a better perfomance at D_1=0.33 and D_2=0.33.

3) Line regulation

In order to check the line regulation, 10% increase and decrease of input voltage is applied as step voltages

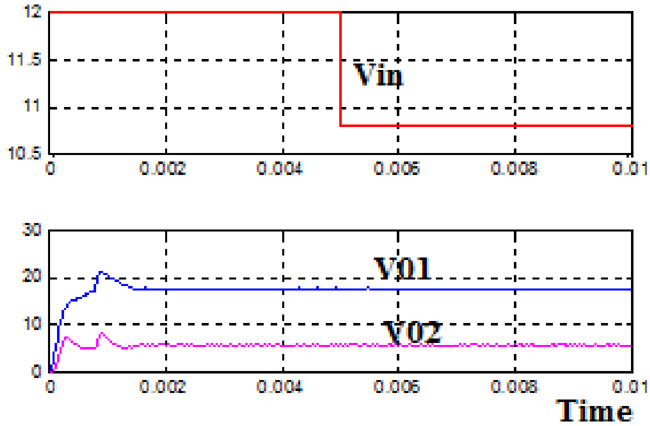

Fig 9.a

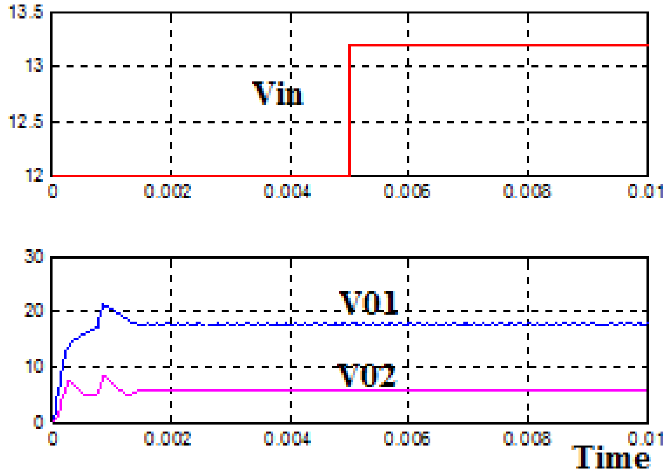

Fig 9.b
Fig 9 Line Regulation a) 10% decrease b). 10% increase

In both the cases the output voltage remained same as in the case of V_{in}=12V. A ± 15% line regulation limit is obtained by the simulation.

The circuit can be modified by replacing the diode by a controllable switch for attaining a wide range of step up loads. It can work even at zero loads at the step up circuit. The control signal applied to this switch will be the complementary of switch S_2. The simulation is done with duty cycles D_1=0.33 and D_2=0.33.

From the simulation result which is shown in Fig 9 is satisfactory. The output voltages V01 is reached up to 17.6V and V02 reached up to 5.8V.

From Fig 12 the no load operation can possible for the boost circuit. V_{01} remained at 17.6V while i_{01} was 0A. This shows the better cross regulation property even under the no load condition in the boost circuit.

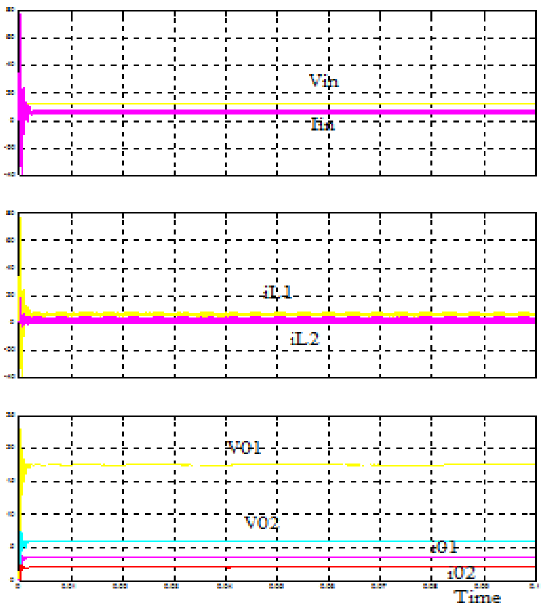

Fig 10 Modified topology

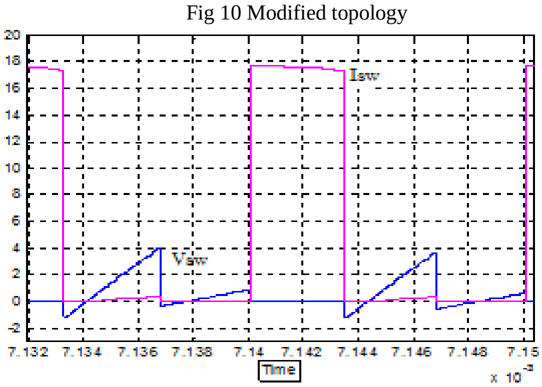

Fig 11 Current and voltage across $S_{3=}$

From the simulation the insertion of additional switch consumes only 0.232W.

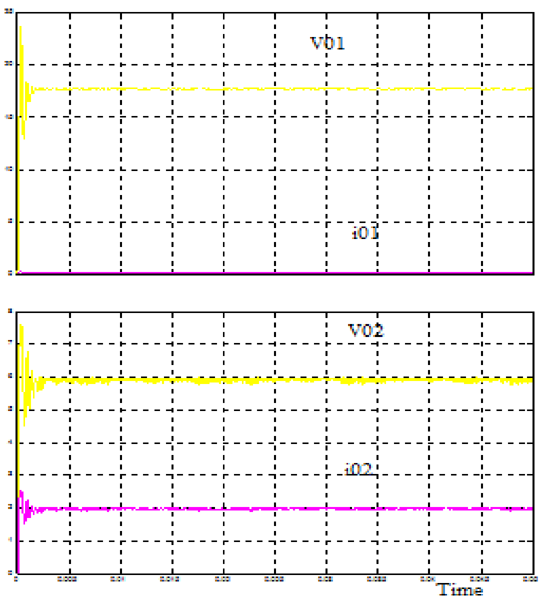

Fig 12 No load operation at the step up circuit that shows a better cross regulation.

4) *Efficiency calculation*

Power output for step up output= V01*I01=61.18W
Power output for step down output=V02*I02=11.53W
Power consumed by the switch S3=0.232W
Power input=Vin*Iin=72.71W
Power output=80.83W
Efficiency=(61.18+11.53)/80.83=89.95%

CONCLUSION

This paper has proposed an integrated dual output buck boost dc-dc converter with simultaneous step-up and step-down outputs. This topology can be extended for N outputs with one step up output and multiple step-down outputs. In contrast with conventional N output dc-dc converter, it requires only N+ 1 switch which reduces the cost and complexity. It has wider step-up voltage range and a better cross regulation. Two outputs can be separately regulated using a proper feedback control system. The cross regulation is well improved by this topology which could be illustrated by the simulation. The line regulation also could be verified by the simulation and that gave a ±15% of input voltage. The extended version gives the no load operation for the step up output circuit. This shows a better cross regulation and voltage regulation. The converter gives an efficiency of 89.95%. The converter behavior has been verified using the software MATLAB and the simulation results validate the behavior of the converter.

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