ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization Vol. 5, Special Issue 3, March 2016

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

# Non-Isolated Multi-Input Multi-Output DC–DC Boost Converter with Current Mode Control

Swapna G [1], Deena George [2]

Assistant Professor, Dept. of EEE, Toc H Institute of Science &Technology, Arakkunnam, Kerala, India

PG Student [PE], Dept. of EEE, Toc H Institute of Science &Technology, Arakkunnam, Kerala, India

**ABSTRACT:** A new multi-input multi-output dc–dc boost converter with unified structure for hybridizing of input sources in electric vehicles is proposed in this paper. In fact, by hybridization of energy sources, advantages of different sources are achievable. The proposed converter has several outputs with different voltage levels which makes it suitable for interfacing to multilevel inverters. Using of a multilevel inverter leads to reduction of voltage harmonics which, consequently, reduces torque ripple of electric motor in electric vehicles. Also, electric vehicles which using dc motor have at least two different dc voltage levels, one for ventilation system and cabin lightening and other for supplying electric motor. The proposed converter has just one inductor. Introduction of current control mode results in better response as compared with usage of voltage mode control alone.

**KEYWORDS:** DC–DC converters, Electric vehicle, Battery, Fuel cell, multiple-input–multiple-output (MIMO), current mode control.

## I. INTRODUCTION

Electric vehicles are set to play a prominent role in addressing the energy and environmental impact of an increasing road transport population by offering a more energy efficient and less polluting drive-train alternative to conventional internal combustion engine (ICE) vehicles [1], [2]. Most electric and hybrid electric configurations use two energy storage devices, one with high energy storage capability and the other with high power capability. This input source may have different voltage levels. So to provide a specific voltage level for the load and to control power flow, usage of a dc-dc converter for each of the input source is essential, which results in higher cost, bulky system and increased energy losses. Consequently, multi-input dc-dc converters have been used. Multi-input converters are of two main types, isolated multi-input dc-dc converters and non isolated multi-input dc-dc converters. In isolated multi-input dc-dc converters, high-frequency transformer is used in order to attain electric isolation and impedance matching between two sides of converter [3]. Due to the usage of transformer, isolated dc-dc converters are heavy and massive. Furthermore, transformer has losses in its core and windings. Because of the above drawbacks, usage of non isolated multi-input dc-dc converters in electric vehicle applications seems to be more preferable. The non-isolated converters type is generally used where the voltage needs to be stepped up or down by a relatively small ratio. There are four main types of converter in this non-isolated group, usually called the buck, boost, buck-boost and Cuk. The buck converter is used for voltage step-down, while the boost converter is used for voltage step-up. The buck-boost and Cuk converters can be used for either step-down or step-up. Therefore, hybridization of different sources is essential. A new multi-input multi-output non isolated converter based on combination of a multi-input and a multi-output converter is proposed.

In [4], multiphase converter is introduced. The proposed converter has four input by different voltages. In this converter, each of the energy sources can deliver or absorb energy from load and other sources. Employment of a separate inductor for each input source is the drawback of this converter. In [5], a triple input converter for hybridization of battery, photovoltaic cells, and fuel cell is introduced by the author. By proper switching of converter, charge and discharge of battery by means of other sources and load is possible, respectively.

In [6] and [7], a single inductor multi-output dc-dc converter is proposed which can generate several different voltage levels in its outputs. The converter is controlled to regulate the output voltages at their desired values despite of the load power variation or input voltage variation. In [8], a new control method is proposed which provides

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*An ISO 3297: 2007 Certified Organization* *Vol. 5, Special Issue 3, March 2016*

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

satisfactory dynamic performance for multi-output buck converter. But the shortcoming of these converters is their single input source. In other words, in applications such as electric vehicles that several input energy sources like fuel cell and battery are employed, this converter is not utilizable. One way to solve this problem is to employ a multi-input multi-output converters.

In [9] and [10], a non-isolated multi-input multi-output converter with single inductor is proposed. Usage of large number of switches is the drawback of converter which results in low efficiency. Impossibility of energy transfer between input sources is other disadvantage of the proposed converter. In this paper, a new multi-input multi-output non-isolated converter based on combination of a multi-input and a multi-output converter is proposed. The proposed converter as compared to similar cases has less number of elements. This converter can control power flow between sources and between the source and load. Also, proposed converter has several outputs different voltage level.

## II. THE PROPOSED CONVERTER

In this paper a multi input multi output non-isolated dc-dc converter is proposed. The circuit diagram of the proposed converter is presented in Fig.1. The converter has m input sources Vin1, Vin2, Vin3, ....Vinm. and the magnitude of the input voltages are like that order, Vin1<Vin< Vin3 < ....... < Vinm. The proposed converter has n number of outputs with n capacitors, only one inductor and m+n switches. The load resistances are R1, R2, R3, R4, R5....Rn equivalent to power feeding to multilevel inverter. The MIMO converter output can be boosted up properly by controlling the switching pulses.

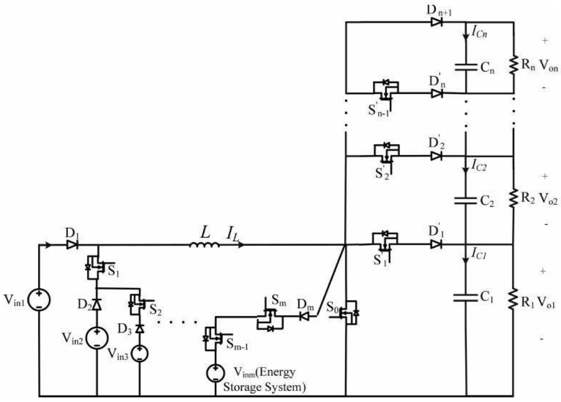

Fig.1. MIMO Converter.

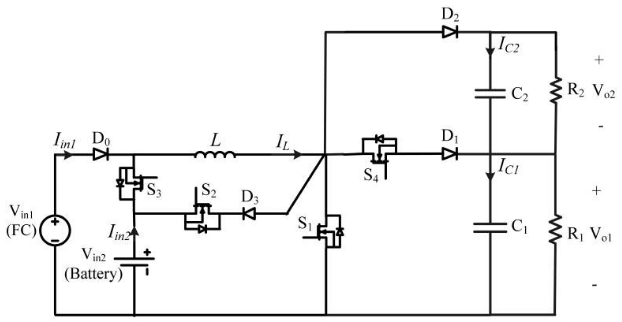


Fig.2. Converter with two-input and two-output.

In this paper MIMO converter with two-output and two-input is analysed and is shown in Fig. 2. In Fig. 2, $R_1$ and $R_2$ are the load resistances and the voltage level across this two load also differ so that multilevel inverter can be possible to connect with this converter. A diode placed in between $Vin_1$ and $Vin_2$ so $Vin_1$ can deliver power to the $Vin_1$ but $Vin_2$ cannot deliver power to Vin1. If this converter used in Electric Vehicle applications then Fuel Cell or PV which cannot be charged must have to place where Vin1 placed in the circuit and battery is located where $Vin_2$ placed in the circuit. In this converter four power switches $S_1$, $S_2$, $S_3$, $S_4$ are controlled for power flow and output voltage control.

Depending on the battery charging and discharging mode there is two power operation modes are discussed for proposed converter. When the load power requirement is high then two input sources together deliver power to the load. In each mode only three switches are active and one switch is not active. When battery operate in discharging mode, in such condition, S2 is not active and switches S1, S3, S4, are active and at battery charging mode, in such condition, S3 is not active and switches S1 ,S2 , S4, are active.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization Vol. 5, Special Issue 3, March 2016

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

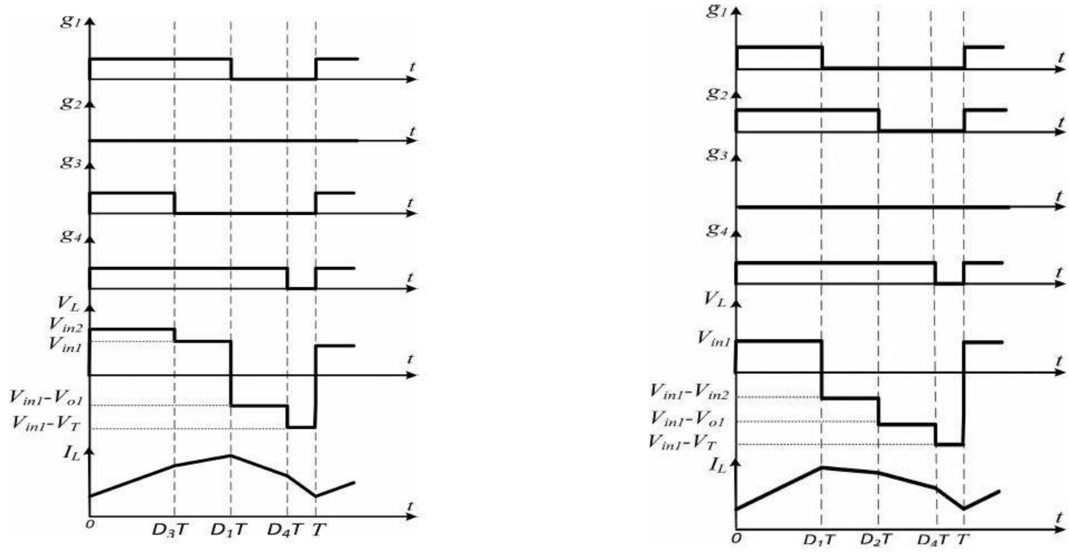


Fig.3. Steady state waveforms a) battery discharging mode b) battery charging mode

## III. MODES OF OPERATION

### A. FIRST OPERATION MODE( BATTERY DISCHARGING MODE)

In this mode, Vin1 and Vin2 supply power to the loads. Switch $S_3$ regulate the total output voltage $V_T = V_{01}+V_{02}$. In Fig. 3 a inductor voltage, Inductor current and gate signal of the switch waveforms are presented. In one switching period there are four different operation modes:

1. Switching State 1 ($0 < t < D_3T$): In this mode, Switches S1 and S3 are active and Vin1<Vin2 so diode D0 is reverse biased. So, inductor L charges by Vin2 and inductor current increases. Because S1 is active and diodes D1and D2 are reverse biased Also, in this mode, capacitors C1 and C2 supplies energy to the load resistances R1 and R2.
2. Switching State 2 ($D_3T < t < D_1T$):In this state only switch S1 is ON and S3 is OFF, diodes D2 and D1 is reverse biased, so S4 is OFF. So, inductor L charges by Vin1 and inductor current increases. In this mode also, capacitors C1 and C2 supplies stored energy to the load resistances R1 and R2.
3. Switching State 3 ($D_1$ T < t<$D_4$T): In this mode, switch S1 is OFF and S3 also OFF. Diode D2 reverse biased. In this mode inductor L is started discharging and inductor current decreases linearly and capacitor C1 and resistor R1 are charged by stored energy in inductor L. Capacitor C2 discharges its stored energy to the load resistance R2.
4. Switching State 4 ($D_4$ T < t<T): In this mode, all switches are OFF. Diode D2 is forward biased and inductor L is discharged through the diode D2 and delivers its stored energy to resistors R1, R2 and charges capacitors C1 and C2.

### B. SECOND OPERATION MODE (BATTERY CHARGING MODE)

In this mode, Vin1 supplies load as well as supplies Vin2 battery also. This condition occurs when load requirement is low and battery has to be charge. Switch S1 regulate the total output voltage $V_T=V_{01}+V_{02}$ . In Fig.5 inductor voltage, Inductor current and gate signal of the switch waveforms are presented. In one switching period there are four different operation modes:

1. Switching State 1 ($0 < t < D_1$ T)*:* In this mode S1 is active, so S4 and S2 reverse biased by reverse voltage and diode D2 also reversely biased. So, inductor L charges by Vin2 and inductor current increases. In this mode, capacitors C1 and C2 supplies energy to the load resistances R1 and R2.
2. Switching State 2 (D1 T < t<D2 T)*:* In this mode, switch S1 is OFF and switch S2 is active. Diode D1 and D2 are OFF because of reversely biased.Vin1<Vin2, for this reason in this mode inductor

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization Vol. 5, Special Issue 3, March 2016

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

current decreases and delivered energy to the battery (Vin2). In this mode, capacitors C1 and C2 get discharged and supplies energy to the load resistances R1 and R2.

3. Switching State 3 (D2 T < t<D4 T): In this mode, Switch S1 and S2 is turned OFF and S4 is turned ON. So, diode D2 is reversely biased. In this mode inductor L is started discharging and inductor current decreases linearly and capacitor C1 and resistor R1 are charged by stored energy in inductor L. Capacitor C2 discharges its stored energy to the load resistance R2.
4. *Switching State 3 (D4 T < t<T):* In this mode, all switches are OFF. Diode *D2* is forward biased and inductor L is discharged through the diode *D2* and delivers its stored energy to resistors *R1*, *R2* and charges capacitors *C1* and *C2*.

## IV.DESIGN

In order to verify the performance of the proposed converter, simulations have been done in battery discharging and charging modes by MATLAB software. Input voltage sources are considered $Vin_1$ = 35V, $Vin_2$ = 48V. The output voltages of the converter are desired to be regulated on $V_{01}$ref = 80V and$V_{02}$ ref = 40V. Consequently, total output voltage is desired to be regulated on $V_T$ ref = 120V.

$$L\frac{di_L}{dt} = Vin2$$

$$L\frac{di_L}{dt} = Vin1$$

Adding above equations

$$LdI = D3TVin2 + D1TVin1$$

Assuming D3=40 %, D1=60%
Vin1=35v, Vin2=48v
L=2.5 mH
dV =DI/fC
Assuming D=30%,dv =10 mV
C= 1000 $\mu$F.

## V. SIMULATION & RESULTS

The various circuit parameters are specified in the table below

TABLE 1
**SIMULATION PARAMETERS**

| Symbols | Simulation Parameters |
|---|---|
| L | 2.5 mH |
| $f_s$ | 10 kHz |
| $C_1$ | 1000 $\mu$F |
| $C_2$ | 1000 $\mu$F |
| $Vin_1$ | 35 Vs |
| $Vin_2$ | 48 V |

A) Simulation Model For Multiple Input Multiple Output Dc-Dc Converter In Battery Discharging

The circuit was simulated in MATLAB/SIMULINK. The closed loop simulation diagram of the converter in battery discharging is shown in Fig.6. By controlling the duty ratio of switch $s_3$ the output voltage is regulated to 120 V.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*An ISO 3297: 2007 Certified Organization* *Vol. 5, Special Issue 3, March 2016*

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

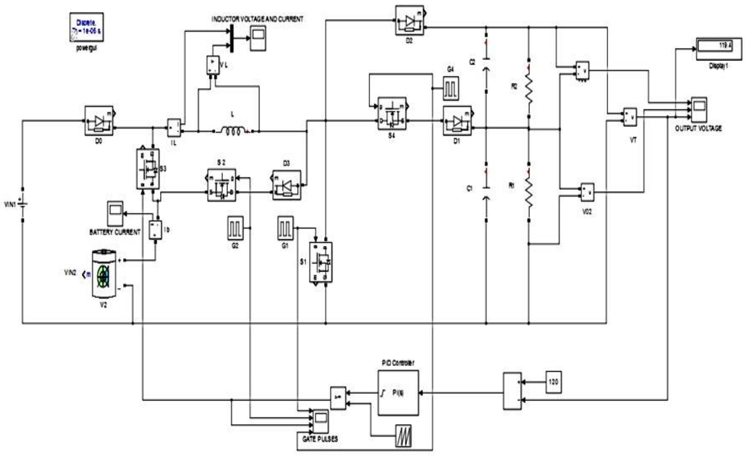

Fig.6.Simulation Block Of Closed Loop Battery Discharging Mode

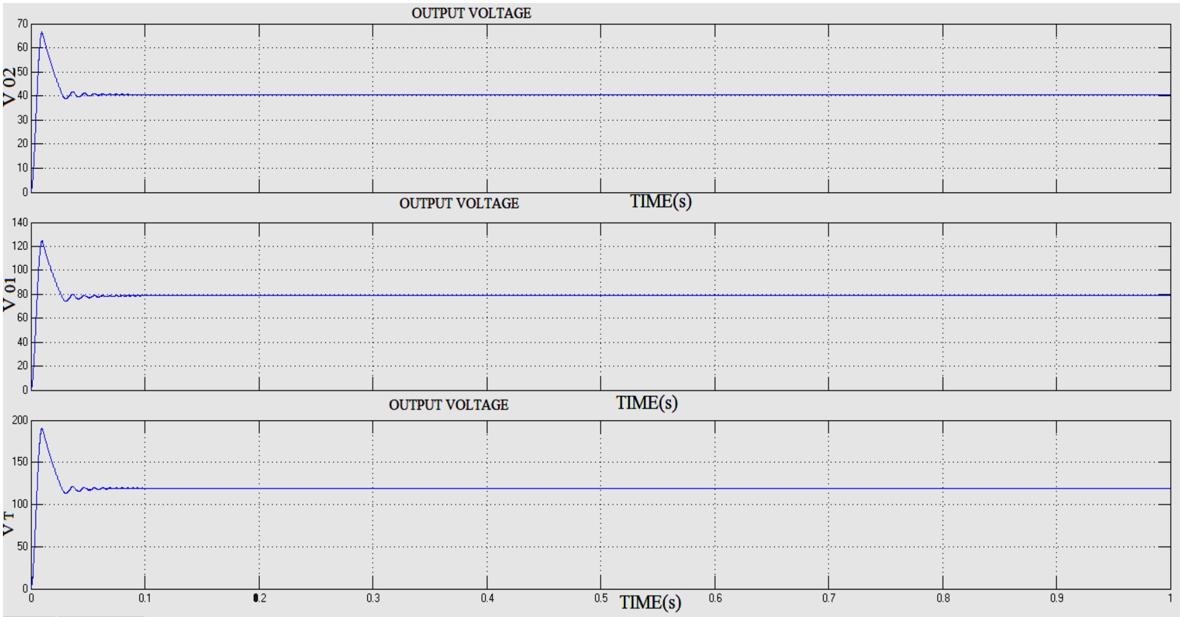


Fig .7 .Converter Output Voltage $V_{01}$ , $V_{02}$ and $V_T$

Closed loop simulation helps to maintain required output voltage with load variation.

B) Simulation Model For Multiple Input Multiple Output Dc-Dc Converter In Battery charging
The closed loop simulation diagram of the converter in battery charging is shown in Fig.9. By controlling the duty ratio of switch $s_1$ the output voltage is regulated to 120 V.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*An ISO 3297: 2007 Certified Organization* *Vol. 5, Special Issue 3, March 2016*

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

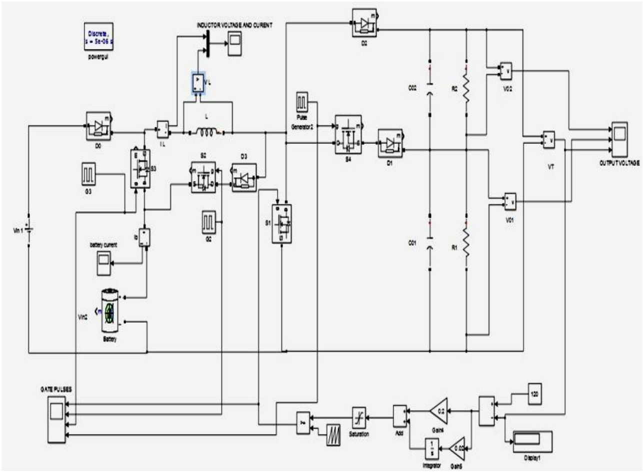

Fig.8. Simulation Block Of Closed Loop Battery Charging Mode

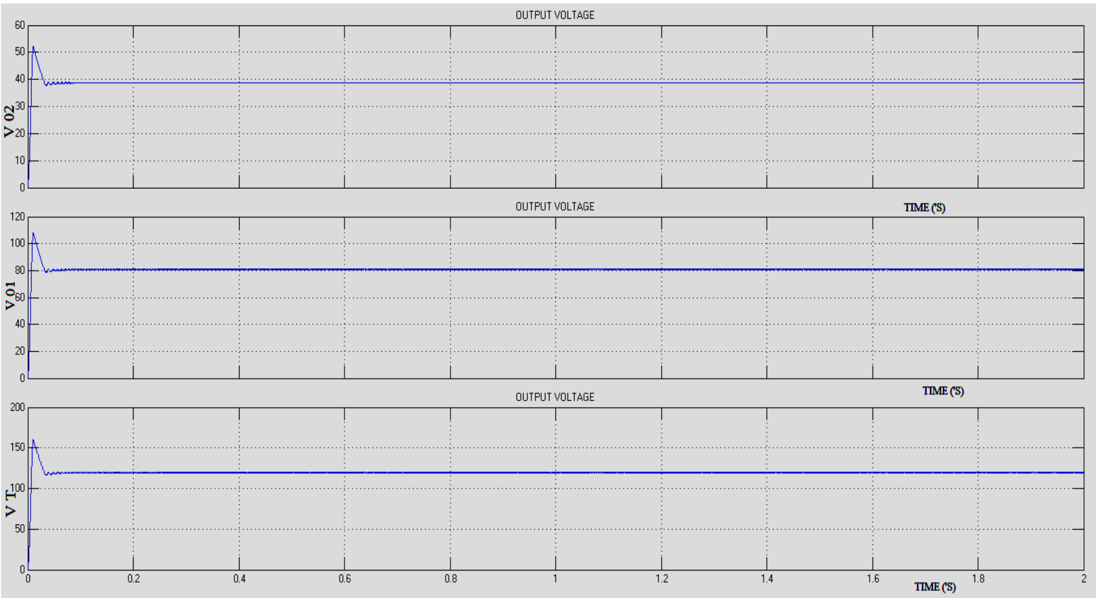


Fig.9. Output Voltage $V_{01} V_{02}$ and $V_T$

C) Simulation Model For MIMO Dc-Dc Converter with current mode control.

Voltage control mode and Current control mode are two commonly used control schemes to regulate the output voltage of dc-dc converters. Feedback loop method automatically maintains a precise output voltage regardless of variation in input voltage and load conditions. VMC only contains single feedback loop from the output voltage. Current-mode controlled dc-dc converters usually have two feedback loops: a current feedback loop and a voltage feedback loop. The inductor current is used as a feedback state. Converter processes that make use of inductor current sensing are termed current-mode controls. This control approach brings some additional advantages to a converter: Since the current is being measured directly, it is a simple matter to add overcurrent protection. The two-loop approach tends to have better dynamics than voltage-mode control alone.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization Vol. 5, Special Issue 3, March 2016

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

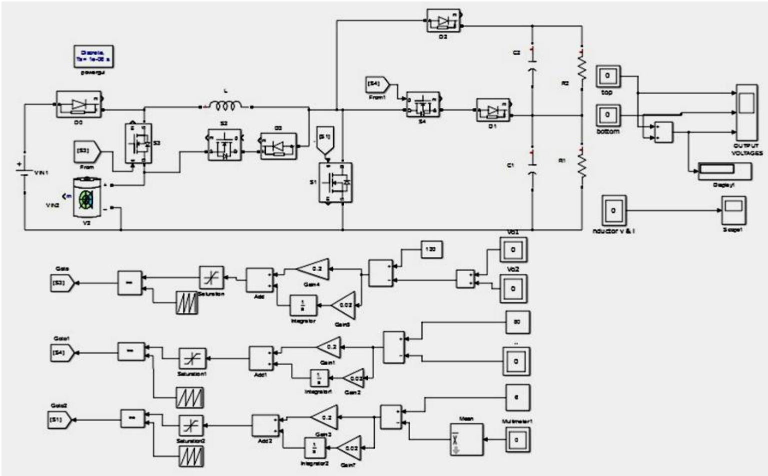

Fig.10. Simulation Block Of MIMO Dc-Dc Converter With Introduction of Current Mode Control

Simulation diagram of MIMO converter with current mode control is shown in Fig.12.There are three feedback loops, $V_T$ feedback is used to control the triggering of $S_3$ switch,$V_{01}$ feedback for $S_4$ switch and $I_L$ feedback control $S_1$ switch.

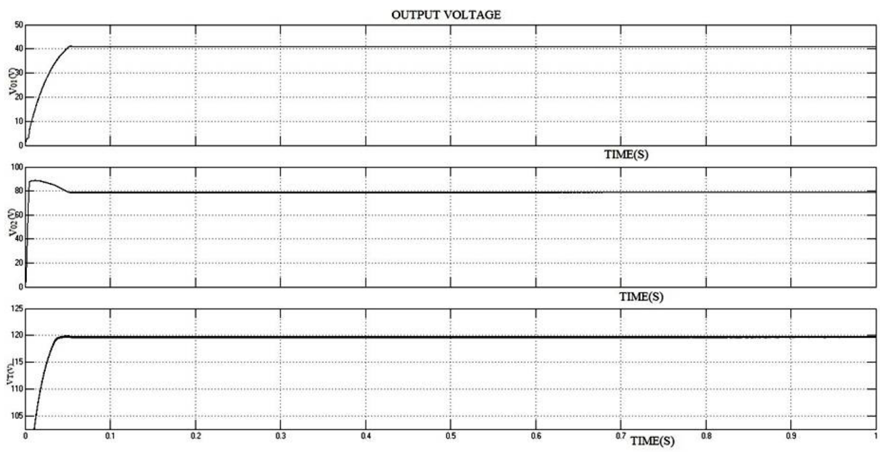


Fig.11 Output Voltage $V_{01}$ ,$V_{02}$ and $V_T$

From the simulation results, it is clear that with the introduction of current mode control, the peak overshoot and the settling time has been reduced to a greater extent.

## VI. CONCLUSION

A new multi-input multi-output dc–dc boost converter with unified structure for hybridizing of input sources in electric vehicles is proposed in this paper. The proposed converter has just one inductor. The proposed converter can be used for transferring energy between different energy resources such as FC, PV, and ESSs like battery and SC. In this paper, FC and battery are considered as power source and ESS, respectively. Also, the converter can be utilized as single input multi-output converter. It is possible to have several outputs with different voltage levels. The converter has two main operation modes which in battery discharging mode both of input sources deliver power to output and in battery charging mode one of the input sources not only supplies loads but also delivers power to the other source. Introduction of current mode control results in better response.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*An ISO 3297: 2007 Certified Organization* *Vol. 5, Special Issue 3, March 2016*

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

## REFERENCES

[1] X. Zhang and C. Mi, *Vehicle Power Management*, New York, NY, USA:Springer, 2011.

[2] M. Ehsani, Y. Gao, and A. Emadi, "Modern Electric, Hybrid Electric and Fuel Cell Vehicle Fundamentals, Theory and Design, "2nd ed., New York, NY, USA: CRC Press, 2010.

[3] J. L. Duarte, M. Hendrix, and M. G. Simoes, "Three-port bidirectional converter for hybrid fuel cell systems," *IEEE Trans. Power Electron.*, vol. 22, no. 2, pp. 480–487, Mar. 2007.

[4] T. Bhattacharya, V. S. Giri, K. Mathew, and L. Umanand, " Multiphase bidirectional flyback converter topology for hybrid electric vehicles," *IEEE Trans. Ind. Electron.*, vol. 56, no. 1, pp. 78–83, Jan. 2009.

[5] F. Nejabatkhah, S. Danyali, S. H. Hosseini, M. Sabahi, and S. A. Mozaffari Niapour, " Modeling and control of a new three-input DC–DC Boost converter for hybrid PV/FC/battery power system," *IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2309–2325, May 2012.

[6] A. Nami, F. Zare, A. Ghosh, and F. Blaabjerg,"Multi-output DC-DC converters based on diode-clamped converters configuration: Topology and control strategy," *IET Power Electron.*, vol. 3, pp. 197-208, 2010.

[7] A. A. Boora, A. Nami, F. Zare, A. Ghosh, and F. Blaabjerg,"Voltage sharing converter to supply single-phase asymmetrical four-level diode clamped inverter with high power factor load," *IEEE Trans. PowerElectron.*, vol. 25, no. 10, pp. 2507-2521, Oct. 2010.

[8] J. D. Dasika, B. Bahrani, M. Saeedifard, A. Karimi, and A. Rufer, "Multivariable control of single-inductor dual-output buck converters," *IEEE Trans. Power Electron.*, vol. 29, no.4, pp. 2061-2070, Apr. 2014.

[9] H. Behjati and A. Davoudi, "A MIMO topology with series outputs: An interface between diversifed energy sources and diode clamped multilevel inverter," *in Proc. Appl. Power Electron*. Conf. Expo., 2012.

[10] H. Behjati and A.Davoudi, " A multi-port DC-DC converter with independent outputs for vehicular applications," *in Proc. Vehicle Power Propulsion* Conf., 2011.