Fuzzy Logic Control Based MIMO DC-DC Boost Converter for Electric Vehicle Application

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Abstract— Nowadays the usages of electric vehicles are increased than the fossil fuel vehicles. In the case of electric vehicle which using dc motor has at least two different voltage levels one for ventilation system and cabin lightening and other for supplying electric motor. Here a fuzzy logic based multi input multi output (MIMO) DC-DC boost converter for electric vehicle application is presented, and is compared with the PI based hardware. In this converter the load power can be flexibly distributed between the input sources. The proposed converter has only one inductor with different inputs and outputs. The charging and discharging of energy storages by other input sources can be controlled properly. Depending on the charging and discharging state of the energy storage system two power operating modes are defined for the converter. The validity of the converter and its performance are verified by simulation by using MATLAB/SIMULINK and the results also presented.

Key words: DC-DC converter, electric vehicle, multi input multi output (MIMO)

I. Introduction

Electric vehicles (EV) are becoming more popular compared to fossil-fuel vehicles due to increasing energy consumption in the world, increasing oil and natural gas prices, and the depletion of fossil fuels and also provide environment friendly operation [1] . Due to this developing EVs as a replacement of fossil fuel vehicle has steadily increased. In electric vehicle it use clean and renewable energy source. Here fuel cell stacks are usually used as the clean energy source. The fuel cells are the energy sources that convert the chemical energy reaction into electrical energy[2]. But the fuel cells are not enough to meet the load demand in EVs because of slow power transfer rate during transitory situations and also high cost per watt. So fuel cells are not used alone in EVs. Due to this multi input is needed. A combination of different energy sources such as battery stacks, ultra capacitors, and recently solar panels can be used to achieve high power and energy dense source in EVs. So fuel cells are used with energy storage system like battery, super capacitors. But the battery and fuel cells voltage levels are different so in order to get the specified voltage level dc-dc converter is needed for each input. Usage of dc-dc converter for each input is not economical and also high losses. Multiinput dc-dc converters are one among the best solution to this problem. The multi input converters can be isolated or nonisolated multiinput dc-dc converter. In[3] isolated multiinput converters even though it provide electrical isolation and also impedance matching between two sides of converter there are some drawbacks. They are, in addition to high frequency transformers it use high frequency inverter and rectifier and also it is heavy and massive.

In nonisolated multiinput dc–dc converter which is derived from H-bridge structure[4]. By cascading two H-bridge with different dc-link voltages, different voltages due to addition or subtraction of H-bridges outputs are accessible. Less number of passive elements is the advantage of this converter and its drawback is unsuitable control on the power which is drawn from input sources.

In [5], a multioutput converter is presented. This converter is a single input converter. On the other hand, use of just one input energy source in electric vehicles cannot provide load requirements because the load is dynamic and its power has variation. Therfore, hybridization of different sources is essential. In [6], a nonisolated multiinput dc–dc converter for hybridization of energy sources is proposed which has just one inductor. In [7] and [8], a nonisolated multiinput multioutput converter is introduced which has just one inductor. Using of large number of switches is drawback of this converter which caused low efficiency.

In this paper, a converter based on the combination of these two converters is presented. This converter has less number of elements compared to similar cases. This converter can control power flow between sources with each other and load. Also, proposed converter has several outputs that each one can have different voltage level.

This paper is organized as follows. Section II deals with the converter structure. The different operation modes of the converter are explained in Section III. Section IV represents the simulations and experimental results, respectively, and Section V concludes this paper.

II. Converter structure

The structure of the nonisolated multiinput multioutput dc–dc boost converter is presented in Fig. 1. As seen from the figure, it consists of m input power sources Vin1 , Vin2 , Vin3 , Vin4 ,…….. Vinm ,such that Vin1 < Vin2 < Vin3 ,…….< Vinm and only one inductor, n capacitors(C1, C2, C3, …. Cn) and n number of load resistance (R1, R2, R3,…… Rn,) and m + n switches. For convenience the converter with two input two output is analysed. Fig. 2 shows converter with two input and two output. It consists of two power inputs, Vin1 as fuel cell and Vin2 as battery, four switches S1, S2, S3, S4, four diodes D0, D1, D2, D3, only one inductor and two output capacitors as C1 and C2 and two load resistors R1 and R2. In this converter, source Vin1 can deliver power to source Vin2 but not vice versa. Here, FC is used as a generating power source and the battery is used as an ESS.

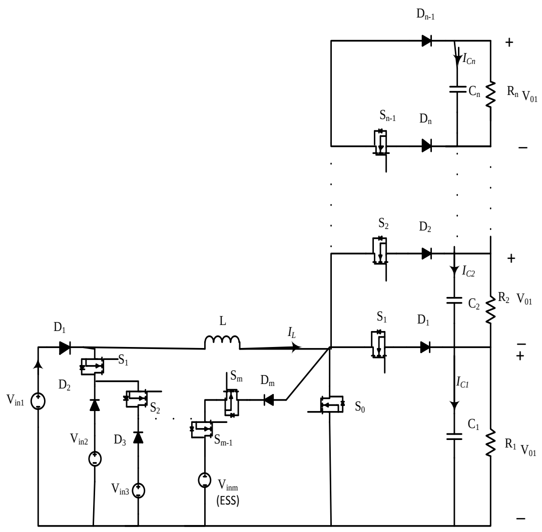

Fig. 1: MIMO converter structure

Depending on the utilization state of the battery, two power operation modes are defined for converter. In each mode, just three of the four switches are active, while one switch is inactive.

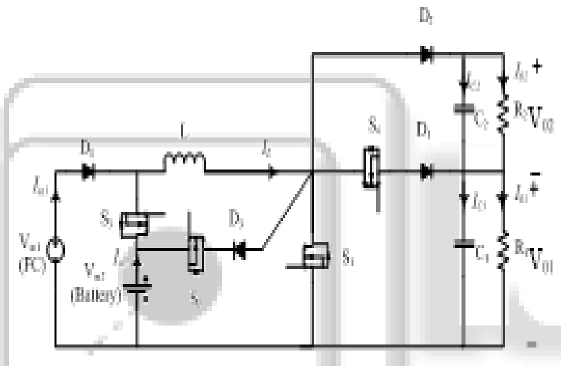

Fig. 2: converter with two input and two output

It should be noted that each of input sources can be used separately. In other words, the converter can work as a single input dc–dc. Two main operation modes of the converter are battery discharging mode and battery charging mode.

III. Operation Modes

A. *Battery discharging mode*

When load power is high, both input sources deliver power to load, in such a condition, S2 is inactive and switches S1, S3 , and S4 are active. Here, S1 is active to regulate source 2 (battery) current to desired value. In fact, S1 regulates battery current to desired value by controlling inductor current. Regulation of total output voltage VT = V01 + V02 to desired value is duty of the switch S3 . Also, output voltage V01 is controlled by S4 . It is obvious that by regulation of VT and V01 , the output voltage V02 is regulated too. Gate signals of switches and also voltage and current waveforms of inductor are shown in Fig. 7. According to switches states, there are four different operation modes in one switching period as follows:

1) Switching State 1 (0 < T < T1)

In this state, switches S1 and S3 are turned ON. Because S1 is ON, diodes D1 and D2 are reversely biased, so switch S4 is turned OFF. Since S3 is ON and Vin1 < Vin2 , diode D0 is reversely biased. Equivalent circuit of the converter in this state is shown in Fig. 3. In this state, Vin2 charges inductor L, so inductor current increases. Also, in this mode, capacitors C1 and C2 are discharged and deliver their stored energy to load resistances R1 and R2 , respectively.

2) Switching State 2 (T1 < T < T2)

In this state, switch S1 is still ON and S3 is turned OFF. Because S1 is ON, diodes D1 and D2 is reversely biased, so switch S4 is still OFF. Equivalent circuit of the converter in this state is shown in Fig. 4 In this state, Vin1 charges inductor L, so inductor current increases. In addition, capacitors C1 and C2 are discharged and deliver their stored energy to load resistances R1 and R2 respectively.

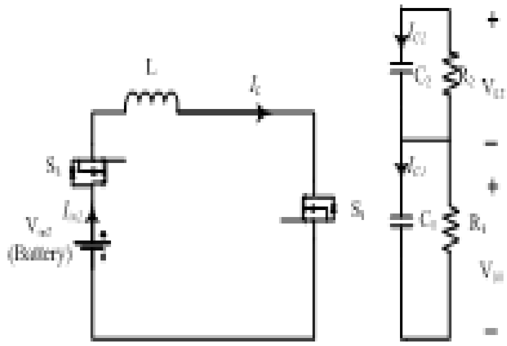

Fig. 3: Equivalent circuit of battery discharging mode, switching state 1

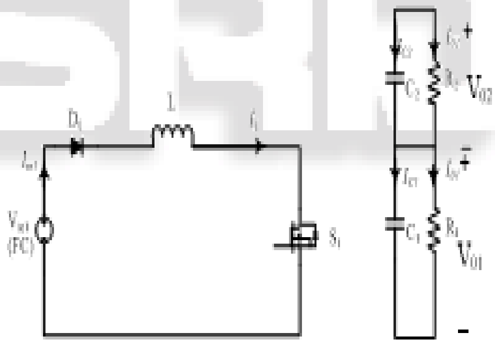

Fig. 4: Equivalent circuit of battery discharging mode, switching state 2

3) Switching State 3 (t2 < t<t3)

In this mode, switch S1 is turned OFF and switch S3 is still OFF. Also, switch S4 is turned ON. Diode D2 is reversely biased. Equivalent circuit of the converter in this state is shown in Fig 5 In this state, inductor L is discharged and delivers its stored energy to C1 and R1 , so inductor current is decreased. In this state, C1 is charged and C2 is discharged and delivers its stored energy to load resistance R2 .

4) Switching State 4 (T3 < T<T4)

In this mode, all of three switches are OFF. So, diode D2 is forward biased. In this state, inductor L is discharged and delivers its stored energy to capacitors C1 , C2 , and load resistances R1 and R2. Also, in this mode, capacitors C1 and C2 are charged. Equivalent circuit of proposed converter in this state is shown in Fig.6.

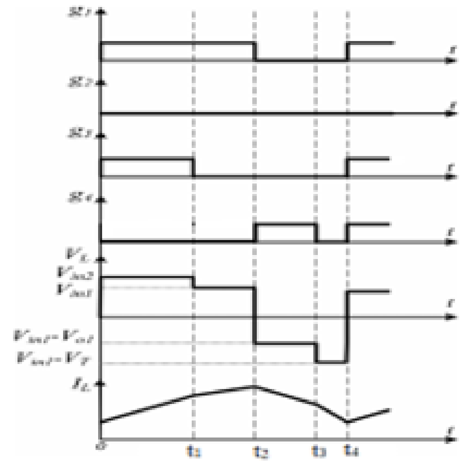

Fig. 7: Waveforms of the converter in battery discharging mode

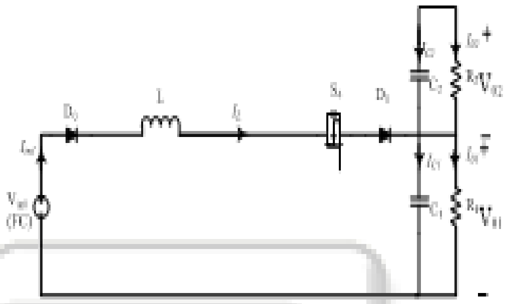

Fig. 5: Equivalent circuit of battery discharging mode, switching state 3

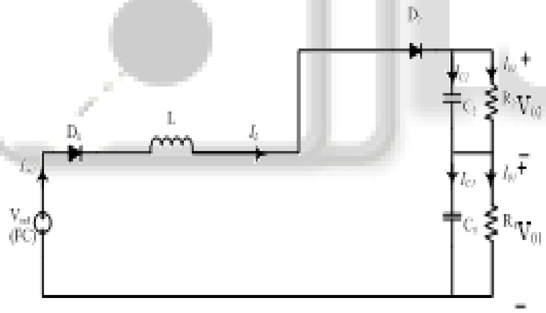

Fig. 6: Equivalent circuit of battery discharging mode switching state 4

B. *Battery Charging Mode*

When load power is low and Vin2 is needed to be charged, Vin1 not only supplies loads but also can charge Vin2. In this condition, switches S1 , S2 , and S4 are active and S3 is inactive. In this operation mode, switches S1, S2, and S4 are active and switch S3 is entirely OFF. Like previous operation mode of the converter in this mode, for each switch, a specific duty is considered. S1 is switched to regulate total output voltage VT = V01 + V02 to desired value. Regulation of the battery charging current (Ib) to desired value is the duty of switch S2 . Also, output voltage VO1 is controlled by switch S4 . It is clear that by regulation of VT and VO1, the output voltage VO2 is regulated too. In Fig. 12, gate signals of switches and voltage and current waveforms of inductor are shown. According to different switches states, there are four different operation modes in one switching period which is discussed as follows:

1) *Switching State 1 (0 < T < T1)*

In this state, switch S1 is turned ON, so S2 and S4 are reverse biased and cannot be turned ON. Also, diode D2 is reversely biased and does not conduct. Equivalent circuit of the converter in this state is shown in Fig. 8 In this state, Vin1 charges inductor L, so inductor current is increased. Also, in this mode, capacitors C1 and C2 are discharged and deliver their stored energy to load resistancesR1 andR2.

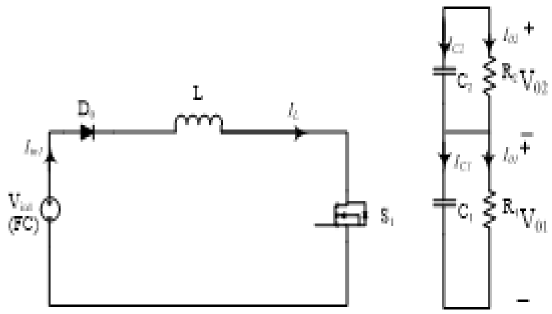

Fig. 8: Battery charging mode, switching state 1

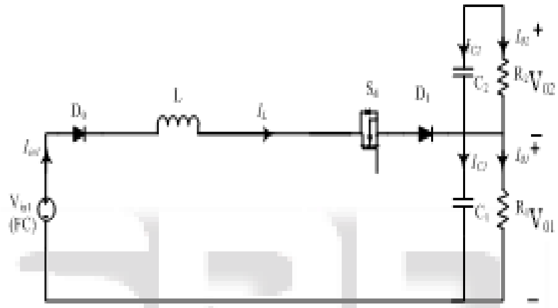

Fig. 10: Battery charging mode, switching state 3

2) *Switching State 2 (T1 < T<T2)*

In this mode, switch S1 is turned OFF and switch S2 is turned ON. Diode D1 and D2 are reversely biased, consequently, S4 is still OFF. Equivalent circuit of the converter in this state is shown in Fig.9 Since Vin1 < Vin2, therefore, in this period of time, inductor current decreases and inductor delivers its stored energy to battery (Vin2). Also, in this mode, capacitors C1 and C2 are discharged and deliver their stored energy to load resistances R1 and R2 respectively.

3) *Switching State 3 (T2 < T<T3)*

In this mode, switch S1 is still OFF and switch S2 is turned OFF and switch S4 is turned ON. Also, diodeD2 is reversely biased. In Fig.10 equivalent circuit of the converter in this state is shown. In this state, inductor L is discharged and delivers its stored energy to C1 and R1 , so inductor current is decreased. In this state, capacitors C1 is charged and capacitor C2 is discharged and delivers its stored energy to load resistance R2.

4) *Switching State 4 (T3 < T<T4)*

In this mode, all the three switches are OFF. Therefore, diode D2 is forward biased. In Fig.11, an equivalent circuit of the converter in this state is shown. In this state, inductor L is discharged and delivers its stored energy to capacitors C1, C2, and load resistances R1 and R2.

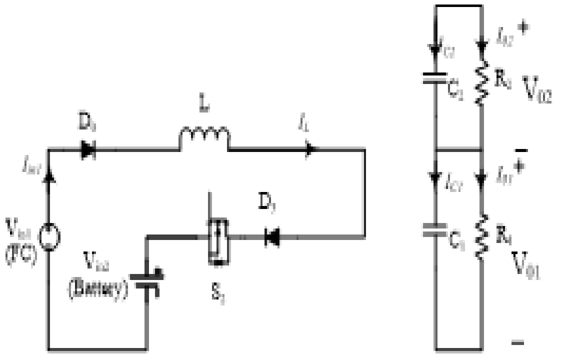

Fig. 9: Battery charging mode switching state 2

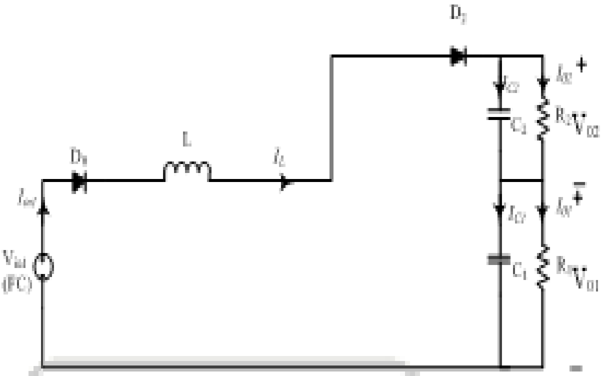

Fig. 11: Battery charging mode switching state 4.

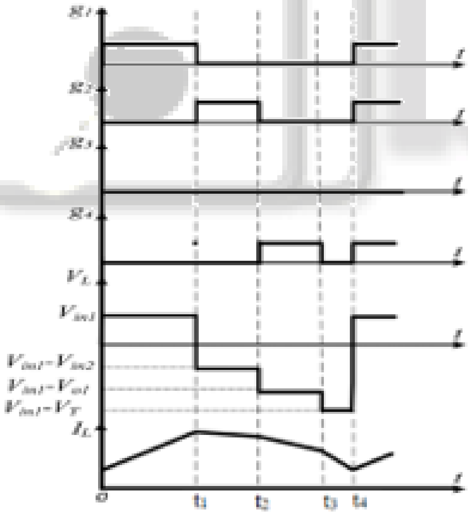

Fig. 12: Waveforms of the converter in battery charging mode

IV. SIMULATION RESULTS AND DISCUSSIONS

The new converter is modelled using MATLAB/SimPowerSystems.The interfaces and controllers are done using Simulink toolbox. The studied system is modelled in discrete-time mode. The Fig.13 shows the simulation diagram of converter with two input and two output and the simulation results are also showed. Here supply Vin1is given as 3.5V and the Vin2 is given as 6V. This simulation shows the battery discharging mode. Here it is designed to get equal voltage in the two sections so we get the V01 and V02 as 13V The total output voltage is 26V. The waveforms of V01 ,VT is showed in Fig.14.

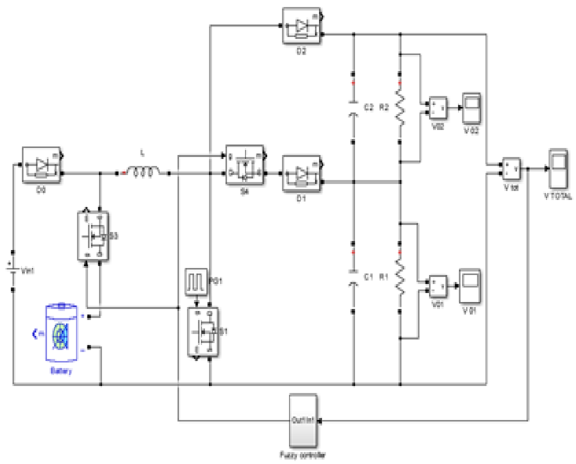

Fig. 13: simulation diagram of converter with two input and two output

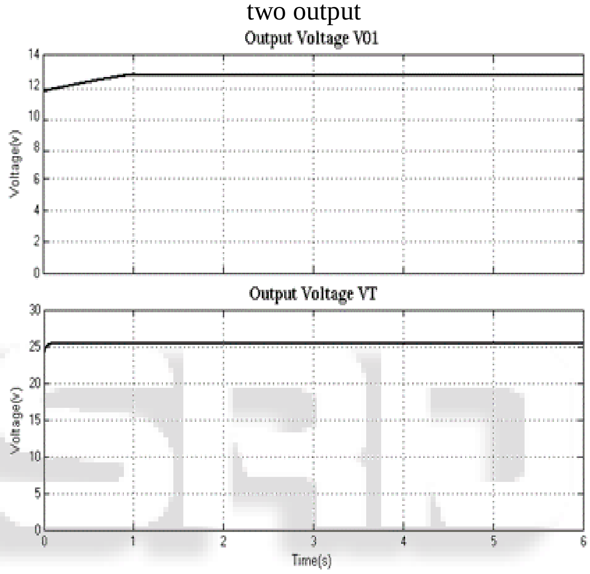

Fig. 14: wave form of voltage V01 ,VT

In this system, we have five rules for the fuzzy controller.

Rule 1: If E is Negative then U is Large Negative
Rule 2: If E is Small Negative then U is Small Negative
Rule 3: If E is Zero then U is Zero
Rule 4: If E is Small Positive then U is Small Positive
Rule 5: If E is Small Negative then U is Small Negative

V. HARDWARE IMPLEMENTATION

The hardware section fig.15 consist power circuit and a control circuit to control the power circuit and it is the battery discharging mode. The power circuit with components in the main circuit , and dsPIC30F2010 microcontroller ,LM317, LM324 op amp ,voltage follower L7805. Power supply is provided for the converter, driver circuit and the microcontroller according to their requirements. The main section of the system is dc-dc boost converter which is controlled by microcontroller DSPIC30F2010. The controller is programmed for closed loop control. Here PI control is used to control the converter. The switching frequency is selected as 8 khz . The hardware setup has mainly two parts control circuit and the power circuit both were implemented in separate PCB's. The output is analyzed with the help of DSO and is showed.

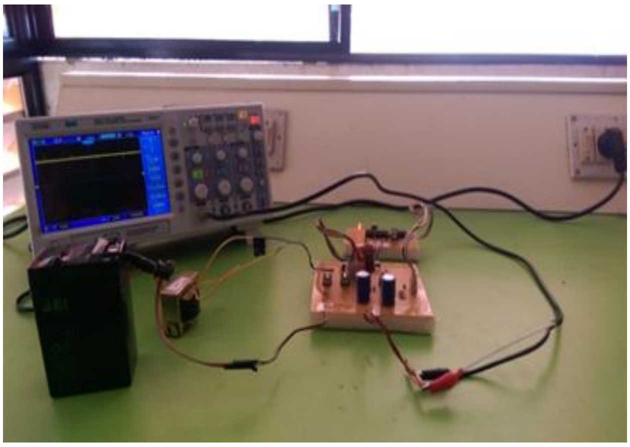

Fig. 15: Schematic of experimental setup.

Here the converter has two outputs i.e., V01, VT. In Fig.16.it shows Output voltage V01 and it is 12.4 V and in Fig.17. it shows Output voltage VT and it is 25.4 V.

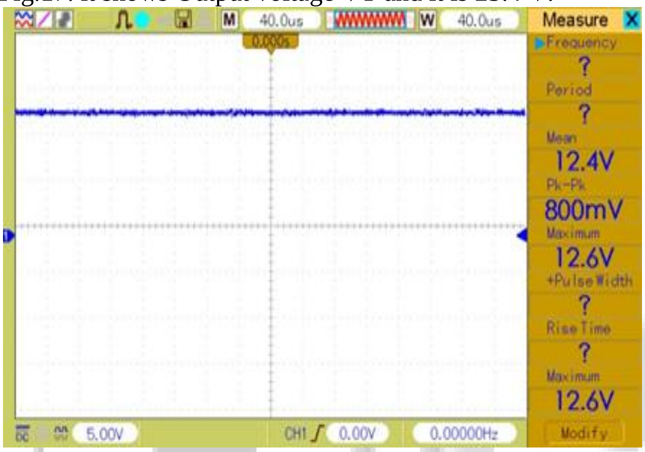

Fig. 16: Output voltage V01.

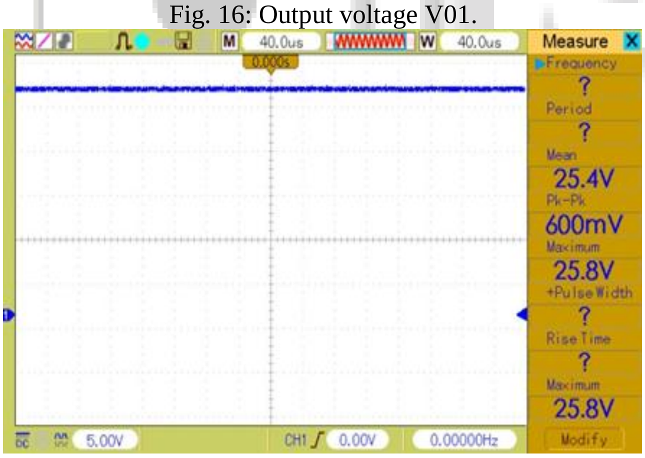

Fig. 17: Output Voltage VT

VI. Conclusion

A new nonisolated multiinput multioutput DC-DC boost converter for electric vehicle application is presented in this paper. In the case of electric vehicle which using dc motor has at least two different voltage levels one for ventilation system and cabin lightening and other for supplying electric motor. The converter has different inputs and different output voltage levels, this helps in the case of electric vehicle. Here nonisolated multiinput converter is used which overcomes the demerits of isolated multiinput converter. Due to its several outputs with different voltage levels which makes its suitable for interfacing to multilevel inverters. The validity of the converter and its performance are verified by simulation by using MATLAB/SIMULINK and the results also presented, the hardware also implemented. By using fuzzy logic controller instead of PI controller it is clear that the fuzzy provides better performance than PI in especially terms of accuracy, settling times.

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