Bidirectional DC-DC Converter For Electric Vehicle Application Using FLC Controller

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Abstract: In this, A design of bidirectional DC-DC converter is proposed which is suitable for electric and hybrid vehicles applications. The main advantages of the proposed structure are that it can utilize different energy sources with different voltage-current characteristics. Moreover, the proposed structure is bidirectional, and battery could be charged in braking mode too. These features along with high voltage gain make this converter an excellent alternative for DC-DC converters in electric vehicles. A speed control structure is added to this in order to control the speed of the motor using Fuzzy Logic Control (FLC) and the performance of the proposed controller with conventional Proportional Integral (PI) controller under steady state and transient conditions are compared in terms of peak overshoot, settling time, torque ripples, etc. the simulation is carried out in MATLAB/Simulink software.

1 INTRODUCTION

Due to significant challenges including contaminants in the air, global warming, and increasing demand for fossil fuels, the electric vehicle (EV) sector is expanding quickly nowadays. The primary components of EVs are power converters and drive systems, and several research initiatives are carried out to increase the density and efficiency of these converters. There are several different varieties of EVs, including fuel cell-electric vehicles (FCEVs), hybrid electric vehicles (HEVs), and pure electric vehicles (PEVs). Each of these cars has an electric motor that operates using batteries that are wired through voltage source converters (VSCs) to the motor. On the contrary, a large DC voltage is necessary at the motor side with regard to the direct link among the power supply of the electrical drive and its voltage. As a result, a DC-DC converter should be used to transform the weak voltage from the battery side into a high voltage DC-link. Indeed, the battery's output voltage drops as the level of charge, or SOC, of the battery increases. The DC-DC converters used in electric vehicles (EVs) should be able to function in a bidirectional mode. The converter can send power from the battery side to the motor side and the other way around thanks to this characteristic. As a result, the battery is able to be charged while the vehicle is in braking mode. High efficiency, compact size, little battery current ripples, and light weight are some of the most crucial factors that should be taken into account while designing these converters. The two types of bidirectional DC-DC converters are isolated and non-isolated architectures. A lightweight, highly reliable 3kW standalone DC-DC converter with bidirectional operation is presented for electric cars (Ansari, P. Cheng et al,2016). With this converter, there are fewer switching components needed for power transfer in both directions. Contrary to other isolated converters, this converter is less efficient. For fuel cell cars, a clamp separated, bidirectional DC-DC converter is shown that does not employ a snubber circuit. Zero switching is employed on the converter's primary side and secondary side, respectively. Regarding bipolar DC micro grids, a brand-new reversible step-up DC/DC converter with high voltage gain and bipolar DC outputs is described.

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However, the lack of an isolating transformer places restrictions on this converter's voltage conversion factor. A boost-powered converter with multiple inputs and outputs that offers both gentle switching and a high voltage gain is offered. This converter is a good contender for fuel-cell systems because to these properties.

This paper proposes a bidirectional converter capable of handling multiple inputs and multiple outputs for electric vehicle applications. Various types of sources is used in the proposed converter with different VI characteristics. Due to the switched capacitor cell, the proposed converter is capable of high voltage conversion ratio. And also due to the bidirectional property, the regenerative braking can be applied and increase the running time of the vehicle. A speed control loop controls the speed of the pmdc motor of the electric vehicle using Fuzzy Logic Control (FLC).

2.SYSTEM DESCRIPTION

The block diagram of the proposed inverter is given below in Fig 1.

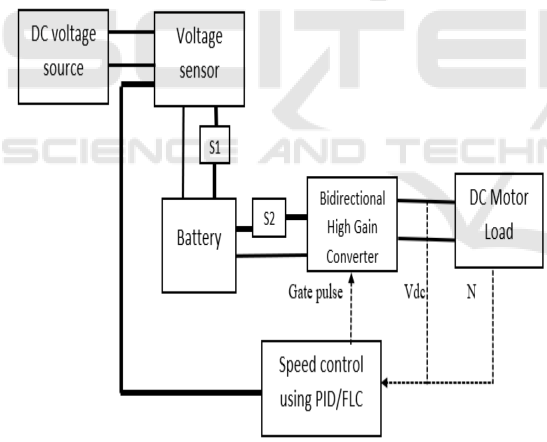

Fig 1.

Here DC supply is given in order to charge the battery, as switch S1 is ON and switch S2 is OFF. In this battery acts as a load. When the supply is not sufficient, the battery starts to discharge, as switch S1 is OFF and switch S2 is ON. In this battery acts as source. The speed of the motor and dc voltage is provided to the speed control loop which control the bidirectional converter output voltage so that the measured speed follows the reference speed. We are using PI & FLC in the speed control loop. The proposed dc-dc converter operates in three operational modes of power supply with battery to load, Power supply to battery mode, and regenerative braking mode.

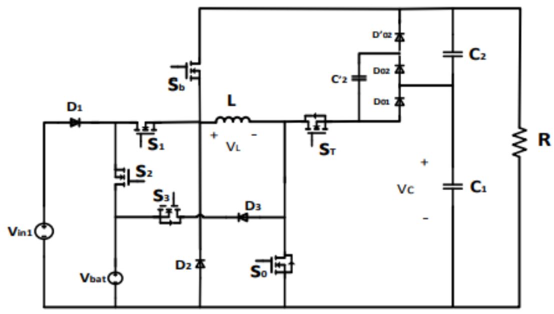

Fig 2

A. Power supply with battery discharging to load

In this state, the converter's linked load is powered concurrently by the battery and other input sources, as well as by the connected loads itself. Switch ST (the transfer switch), Power electronic switch S3 and Sb (the braking switch), and the remaining switches are all ON in this mode. In this mode, the switches regulate the output voltage (VO). The switching pulses of the proposed converter for this mode is provided below:

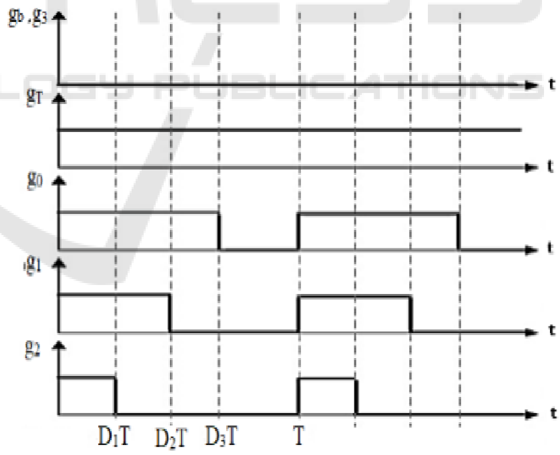

Fig 3

1) Time interval 0<t<D1T:

In this mode, the battery is utilised along with energy sources are used to power the load attached to the converter. Switch ST continues to be ON, power electronic switch S3 & Sb was continuously OFF, and the remaining switches are all ON in this and the battery is providing supply to the load. The equivalent circuit of the proposed converter for this mode is provided below:

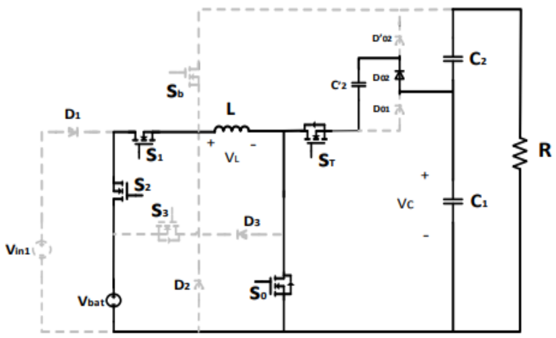

Fig 4

2) Time interval D1T <tVin1).

S0 is operating, S1 is turned OFF, and the remaining circuit elements are equivalent to those in the preceding mode in this mode. The inductor is charged by the primary energy source, such a fuel cell. The inductor voltage is equal to the voltage that is generated of the main source, and the current through the inductor rises proportionally with a less steep slope. (Vbat>Vin1). The equivalent circuit of the proposed converter for this mode is provided below:

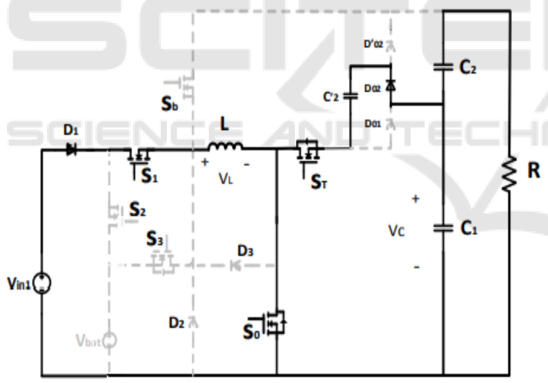

Fig 5

3) Time interval D2T <t<D3T:

So is operating in this mode and the power electronic switches S1 & S2 are turned OFF. D2 is in forward bias and the inductor current starts to flow and is maintained constant:

$i_{L1}=I_{LP12}$

where I_{LP12} is the inductor current of from previous interval D2T <t. The equivalent circuit of the proposed converter for this mode is provided below:

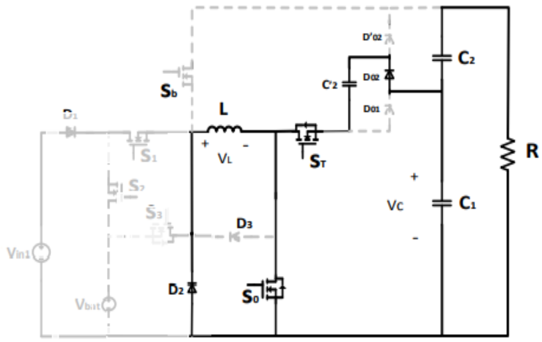

Fig.6

4) Time interval D3T <t

In this, S1, S2 and S0 are OFF and D2 is in forward bias.

VL1=-VC

VL1=Vi

VL1=Vi-VC

From the above relations the average input voltage is provided below

$V_i = V_{in\,l} \times D_1 + \sum_{i=2} V_{in\,l}\,(D_i - D_{i-1}) + V_{bat}\,(D_{n+1} - D_n)$

By simplifying, we get the voltage gain of the converter for one switching cycle is provided below:

$V_e/V_i = 1/1\text{-}D_0$

The equivalent circuit of the proposed converter for this mode is provided below:

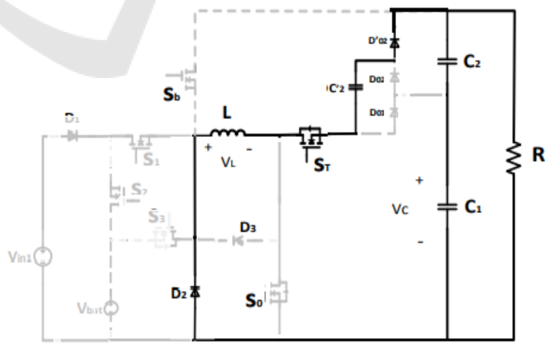

Fig 7

B. Battery charging mode by input sources

The battery is recharged in this mode by the input sources. While load is not connected and the battery has to be charged, this mode is active. Switches S1, ST, and Sb remain ON, whereas switch S2, ST, and

Sb remain continuously OFF. All other switches are ON. Each of the three stages for the converter , as illustrated below:

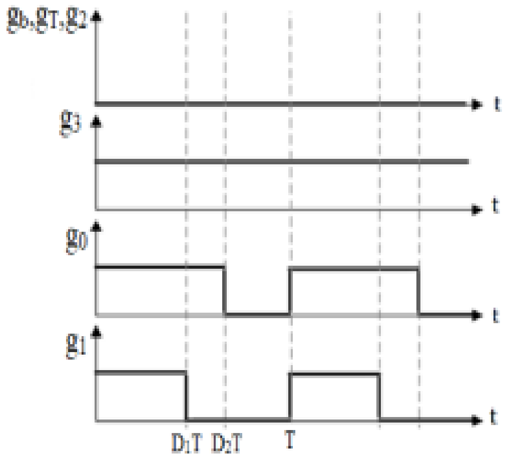

Fig 8

1) time interval 0 <t

S1 and S0 are both turned ON in this switching condition. As a result, the S3 and D3 are reverse biassed and have zero currents. The supply source (Vin1) charges the inductor L, increasing its current linearly. The equivalent circuit of the proposed converter for this mode is provided below:

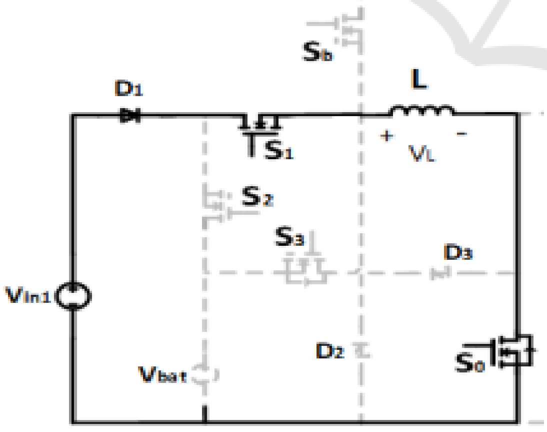

Fig 9

2) time interval D1T <t<D2T:

In this mode, the switch S0 starts operating, the S1 is OFF, the D2 is forward biased, and the inductor voltage is zero. The equivalent circuit of the proposed converter for this mode is provided below:

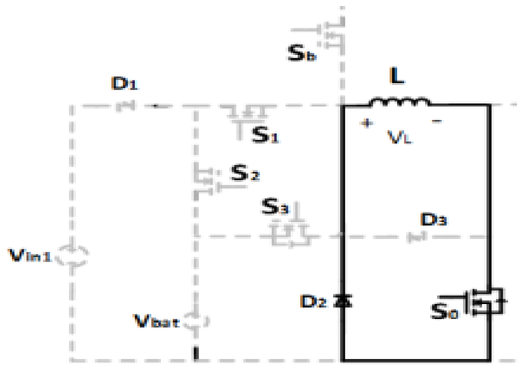

Fig 10

3) time interval D3T <t

So is turned OFF and the inductor starts discharging via S3 and charges the battery. The voltage across the inductor is given as

$$D_0VT+(1-D_1)(V_i-V_{bat})T=0$$

by simplifying the equation

$$V_{bat}/V_i=1/1-D_0$$

C. Regenerative Braking Operation

The vehicle itself can function as a power source and retain its energy in its batteries when it is braking or travelling downward. The transducer's effectiveness is increased by this mode of operation. So, to achieve this situation, a switch is placed on the rear route to provide a flickering mode for conversion, an elevated voltage for the voltage of the batteries, and battery energy conservation. The switches S1, ST and S0 remain perpetually OFF, S3 is perpetually ON, and the remaining switches are in operation. Sb regulates the battery's output voltage (Vbat.) in this mode. The converter functions as a straightforward buck converter while in the braking condition.

Time interval 0 <t<D1T:

Sb is activated in this mode. The voltage difference between Vo and Vbat equals the voltage level of the inductor.

$$V_L=V_O-V_{bat}$$

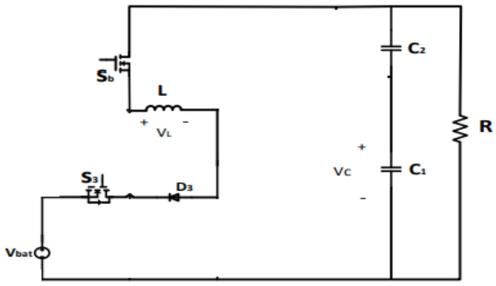

Fig 11

1) Time interval D1T <t<D2T:

In this state, Sb is off and the inductor's voltage is set to Vbat. The inductive energy is lost in the battery due to the opposing direction of the inductance and battery voltages, and the current flowing through the inductor decreases linearly as a result. The voltage across the inductance is:

$V_L=-V_{bat}$

The average voltage of the inductor in a period must be zero, so:

$D_0(V_0-V_{bat})T+(1-D_0)(-V_{bat})T=0$

$V_{bat}=D_0V_o$

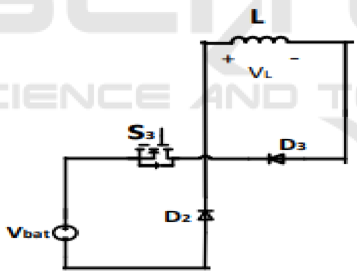

Fig 12

3.PROPOSED CONTROL STRATEGY

The DC reference voltage (V^*_{dc}) is provided below is calculated with the help of reference speed.

$V^*_{dc} = k_v w^*$

The reference voltage (V^*_{dc}) is compared with the actual load voltage (V_{dc}) and the error voltage (V_E) is provided below as

$V_E = V^*_{dc} - V_{dc}$

The generated error is given to proportional–integral (PI) control, which provides the reference voltage V_C as follows

$V_C(k) = V_C(k - 1) + K_P$
$\{V_E(k) – V_E(k – 1)\} + K_iV_E(k)$

The pulses generated for the boost converter is as follows

{If $M_C < V_C$ gating pulse is HIGH}
{If $M_C \geq V_C$ gating pulse is LOW}

Fuzzy Logic Controller

An approach to thinking that mirrors human reasoning is fuzzy logic. The strategy mimics how humans make decisions, which require considering all middle options between the digital signals YES and NO. Despite the fact that fuzzy logic (FL) may not produce accurate thinking, it is beneficial nonetheless. The FL's architecture is broken down by modules that convert system inputs into fuzzy sets. Another module that contains rules supplied by the user's IF-THEN statements. a fuzzy inference engine that uses IF-THEN rules and fuzzy interpretation on the inputs to emulate human reasoning.

Defuzzification is a different module that converts the fuzzy set acquired by the interfering engine into a crisp value. The membership function operates on sets of variables that are ambiguous. A fuzzy set can be graphically represented and linguistic terms can be quantified using membership functions. Simple model parameters can be utilised because complex functions do not increase output precision.

Table I. Knowledge based rules

E	Output
NVL	PS
NL	Ps
NM	PS
NS	PS
Zero	PM
PS	PM
PM	PM
PL	PL
PVL	PVL

When the error, is negative, the measured voltage is higher than reference voltage, then the fuzzy controller will provide Low as output and when the error is positive, the measured voltage is lower than the reference voltage, then the fuzzy controller increases the duty ratio (D).

4.SIMULATION SETUP & RESULTS

The simulation parameters for the proposed inverter are provided below in Table II:

TABLE II Simulation Parameters

Input Voltage	150 V
Input power	6KW
Switching Frequency	10 KHZ
Inductor	10µH
Coupling Capacitor	50µF
Output Capacitor	30µF
Battery voltage	180V
Battery capacity	100Ah
DC Motor parameters	600V, 6KW, 1500 rpm

The simulation circuit of the bidirectional converter with PI controller is provided below:

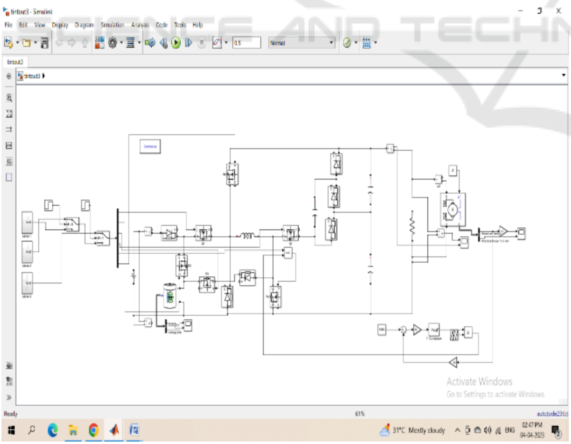

Fig 13 Simulation circuit of 3 leg 5 level inverter

The battery is discharging and provides supply to the motor load (mode 1) from t=0 to 0.2s. The dc voltage source is connected at t=0.2s and provides supply to both motor and battery (mode2). Regenerative braking is applied to the motor at t=0.4s and energy stored in motor windings is fed back to battery (mode 3). The battery voltage and %SOC is provided below:

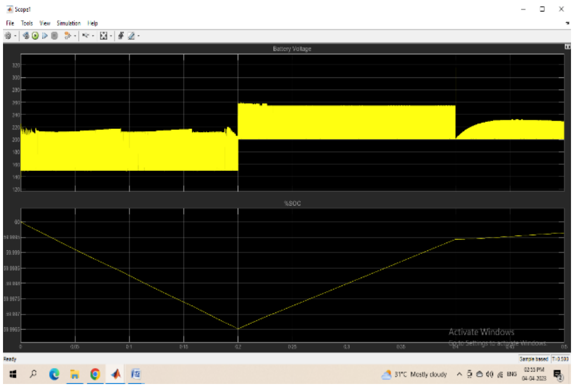

Fig 14

In this, battery is discharging in mode1 and the %SOC is reducing until t=0.2s and in mode 2, the battery is getting charged from dc voltage source and hence %SOC starts to increase and at t=0.4s, the regenerative braking is applied and the %SOC continues to increase. The load voltage and current is provided below:

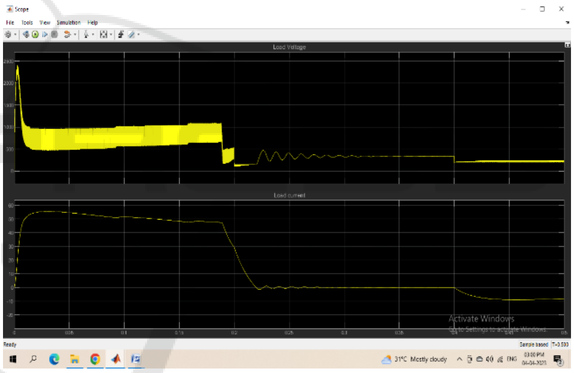

Fig 15

During modes 1 and 2, the current flow is positive i.e. in forward direction and in mode 3, the current flow is reversed due to regenerative braking. The motor speed and torque is provided below:

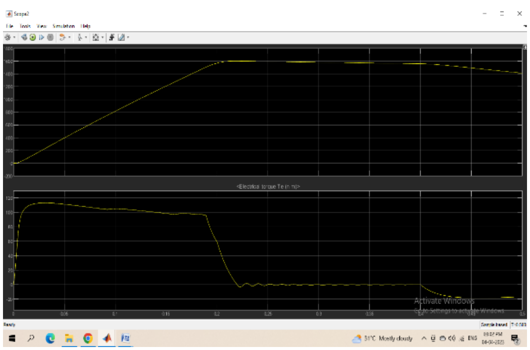

Fig 16

The speed is settled at t=0.2s in the set speed or reference speed with PI controller. The PI controller is replaced with fuzzy control and the speed and torque is as provided below:

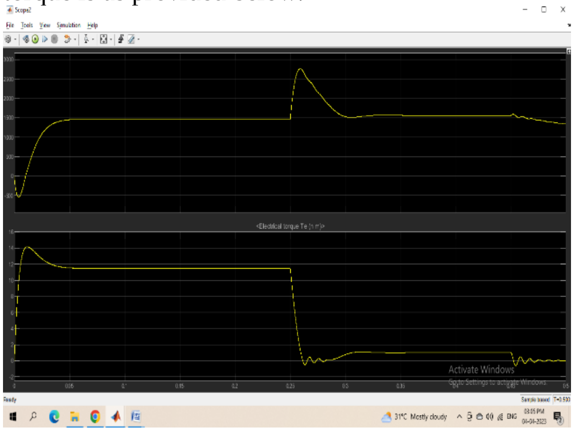

Fig 17

In this, the speed is settled at t=0.05s which is 4 times less than that of with PI controller.

A hardware prototype model of proposed converter with input voltage of 24V, 50 Hz is developed with 12V as battery voltage and output voltage of 64V with load resistance of 1KΩ. The hardware parameters is provided below in the following Table III.

TABLE III Hardware Parameters

IRF 250N MOSFET	200V,30A
U1560-DIODE	200-400-600V,15A
CAPACITOR	1000 µF, 25V
TRANSFORMER	12V,1A
TLP 250- DRIVER IC	12V,1.5A
CD 4050 BUFFER IC	3-18V,0.32mA
12V REGULATOR 7812	12V,1A
IN 4007 DIODE	700V,1A
ARDINO UNO CONTROLLER	7-12V,20mA

Arduino uno control is used for generating the pulses for the proposed converter and it is provided to driver circuit (TLP 250) in order to drive the mosfets IRF 250. The source voltage from the rectifier is provided in the following waveforms:

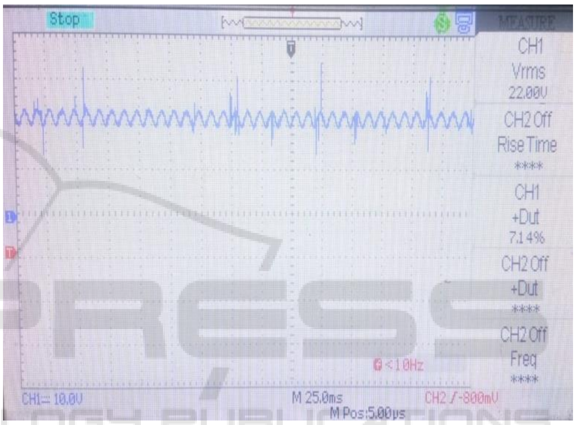

Fig 18

In this the source1 voltage is around 22V and the battery voltage is provided below:

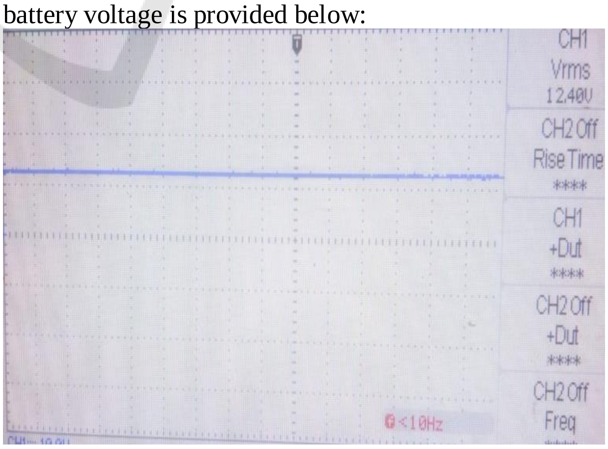

Fig 19

In this, the battery will be charging when source1 is available and when source1 is not available, the battery starts discharging and provides energy to the load. The load voltage is provided below:

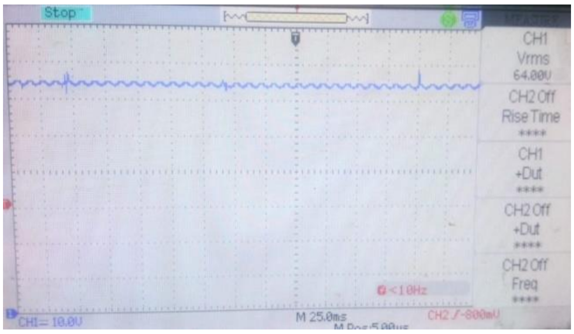

Fig 20

The load voltage of the proposed converter is around 64V.

5. CONCLUSION

In this, a bidirectional converter is designed with multiple input multiple output and the modes of operation of the proposed converter was analysed. A control structure is formulated to reduce the voltage distortions caused by varying loading conditions. A switched capacitor cell is used to increase the voltage conversion ratio. In my work we are compared Proportional Integral (PI) controller and Fuzzy Logic controller (FLC) in terms of speed of electric vehicle, peak overshoot, settling time and torque ripples. After comparing we come to know that Fuzzy Logic controller is better than Proportional Integral Controller, as the speed is 4 times increased than PI controller. The regenerative braking is applied and the energy from motor load is fed back to battery and charges the battery. A hardware prototype model was developed and the operation of the proposed converter is verified with the results.

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