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A novel approach to step-up three input DC to DC Converter for Hybrid Electric Vehicles

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ABSTRACT

*In this paperthree-input DC to DC converter has been proposed, **Neural Network** has been used to control switches and studied for **Hybrid Electric Vehicles**. Compared withtraditional works and output gain is increased. **Energy storage system**, **Fuel cell** and **photovoltaic panel** are the input sources. The Fuel cell is considering as the main power supply and photovoltaic cell (PV cell) is used to charge battery, increases the efficiencyand reduce fuel cost. The converter has the ability of providing the required power by load in absence of one or two input sources. Power management strategy is explained and applied in control method. A prototype simulation of converter has been done and tested.*

1. INTRODUCTION

The world needs to dramatically reduce its greenhouse gas emissions and fast, if there's any hope of preventing worse and more frequent extreme weather events. That means shifting to renewable sources of energy and, importantly, decarbonizing transportation, a sector that is now responsible for about a quarter of the world's carbon dioxide emissions. Global warming and lack of crude oil/fossil fuels are main fault of vehicles running on oil or diesel. So that to overcome the precedent problems, car designers have shown keen interest in hybrid electric vehicles and plug-in hybrid electric vehicles. Fig.1 shows, the overall structural design of hybrid electric vehicle powered by renewable resources. Electrical vehicles have also been studied. Electrical Vehicles depend on energy stored in energy storage system. Limited driving range and battery takes long time to charge theseare main limitation.However, by using bidirectional on and off board charger, electrical vehicles could have the vehicle to grid (V2G) capability. Solar-assisted Electrical Vehicles (EVs) have also been studied. At present it looks like impractical causes are as mentioned ahead, Desired location and more size of PV panels. As the Main power source of HEVs is considered Fuel cell, as the result of many more years of research and advancement on HEVs. Emissions of fuel cells are only water and heat.Furthermore, FCs have other advantages like Reduced

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greenhouse gas emissions, High Reliability, Flexibility in installation and operation, Development of renewable energy resources, Reduced demand for foreign oil, Improve environmental Quality. However, poor conversion and high cost performance are the main problems of Fuel Cells. Hereit is considerable point to note that vehicle mainly driven by FCs, are hybridized by ESSs. The main benefits of hybridizing are increasing fuel economy, providing a flexible operating strategy, beaten fuel cell cold-start and problems of transient and reducing the cost per unit power.

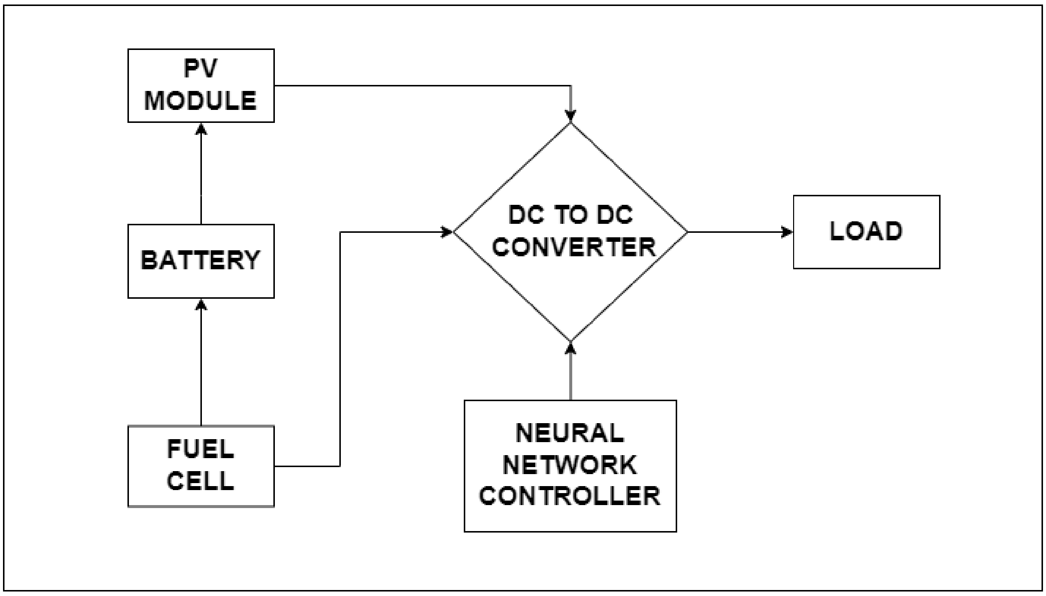

Fig.1.Generalstructureofthree-poweredHEV

In the literature, few numbers of analysis have been reported on E-Vehicles' and Hybrid E-Vehicles' electronic interfaces. The system is primarily powered by FC and second battery unit. V2Gisoneofthe main advantages of proposed converter. Even though, the great number of power switches can reduce the reliability as well as increase the cost.Three-input DC to DC boost converter for hybrid PV, FC, Battery is proposed. The proposed converterdoes not work properly because a battery can be only discharged by Photo Voltaic and only charged by Fuel Cell. Two-input DC to DC converter is proposed to interface two different power sources with a DC bus or load. The converter has higher efficiency so that achieving turn-on zero voltage switching toall switches. However,itlacks a bidirectional port. So that, in applications in need of Energy Storage System, it can't be used. Compact two- input convertersis proposed for standalone PV systems. Moreover, high voltage gain of the converter makes the converter suitable to low input voltage applications. However, the greater number of semiconductors and passive elements reduces the efficiency.

Control method predefined in the vehicle's controller should be control the power flowbetween given input resources, battery set and electrical motor.Maximum usage of power resources, operating fuel cell and PV panel, providing demand power permanentlyin their optimal region are the prime duties of control scheme. Some converters have been proposed recently for Photo Voltaic systems. But the required converter for Hybrid EV applications should extract power from Photo Voltaic and Fuel Cell. Besides, in consideration supply Back-up power from the battery device, a bidirectional port is needed to discharge and charge the battery according to discrepancy between demanded energy and produced power. A multi input converter (MIC) can provide power to the connected load from different energy sources individually or simultaneously.

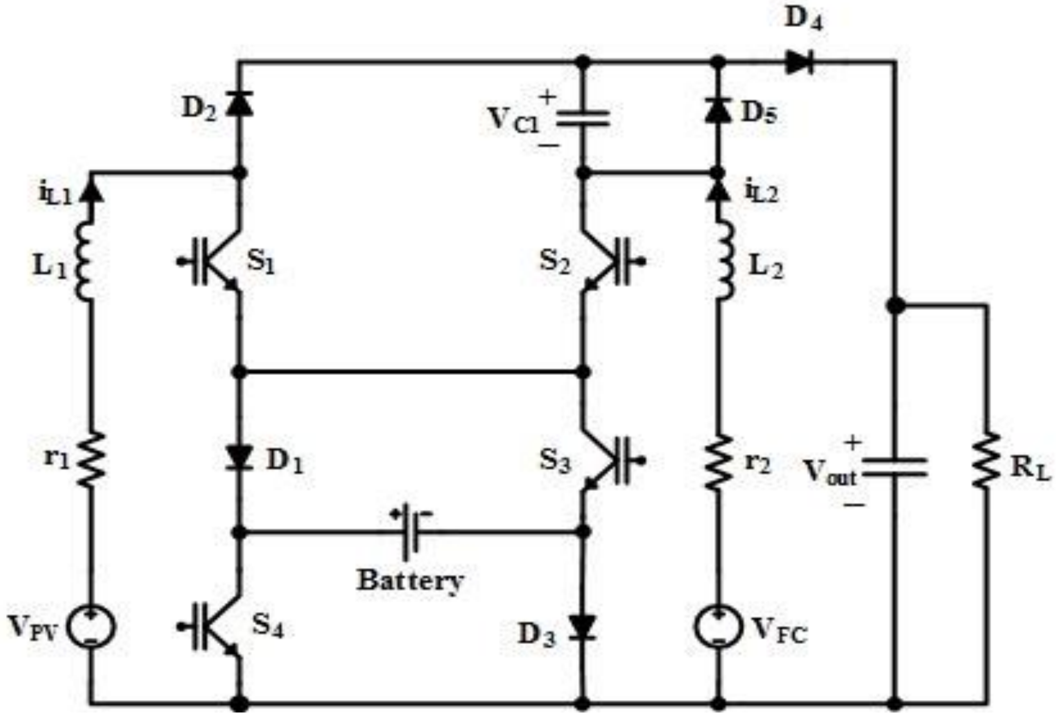

Fig.2.Three-input DC-DC boost converter

In this study, three-input DC to DC converter is proposed to merge a Photo Voltaic, a fuel cell and battery connect them together. Furthermore, DC gain is enhanced in respect of traditional converters. The battery can be discharged and charged to achieve power management. In section (II)the proposed structure is studied, and different operation modes are discussed in section (III). In section (IV) additional advantages have been explained. Section (V) shows simulation diagram. Experimental results have beendiscussed in section (VI). Section (VII) concludes the whole paper.

2. PROPOSED CONVERTER TOPOLOGY

Structure of three-input DC-DC boost converter is shown in Fig. 2. The converter is made of twoconventional boost converters, replacing extra capacitor in one of the converters, and a battery to store the electric energy. Characteristic of the converter is acceptable for hybrid vehicle systems. In paper, action of the converter in perspective of managing and controlling the inputpower source. Then outputsof V_{PV} and $V_{FC}$are based on characteristic of independent power sources. L1and L2 this are two inductances input filters of PV panel and fuel cell. Using L1 and L2 are connected in series with input sources change PV and FC modules to current sources. r1 and r2 are equivalent resistance ofV_{PV}'s and V_{FC}'s, respectively. $R_L$would be equivalentresistance of loads connected to the DC bus. S4, S3, S2 and S1 are power switches(IGBT). Diodes D4, D3, D2 and D1 are used to

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establish modes, which will be described. Output Capacitor Co is performed as output voltage filter and Capacitor C1 is used to increase output gain. Systemoperation would be in continuous conduct mode (CCM) to produce smooth current with minimal possible amount of current ripple.

3. MODES OF OPERATION

In this part, proposed converters have been discussed. Converter operationsare divided into three states.
States:

1- The load is supplied by Photo Voltaic panel and Fuel Cell and battery is not used.
2- The load is supplied by Photo Voltaic panel, Fuel Cell, and battery, in this state battery is in discharging mode.
3- The load is supplied by Photo Voltaic panel and Fuel Cell and battery is in charging mode.

3.1 Operation in First state (The load is supplied by Photo Voltaic panel and Fuel Cell and battery is not used)

In this first state, as it is shown in Fig. 3, there are three modes of operation. During this state, the system performing operation without charging or discharging of battery. So that, there are two current paths to flow through(S3 and D3 orD1 and S4). In this paper D3 and S3 is considered as common path. However, D1 and S4 could be selected as an alternative path. During this state, switch S3 would be permanently ON and switch S4would be OFF.

Mode 1 (0< t <d1T): Inductors*L1* and *L2* are chargedvia power sources *vPV*and *vFC*, respectively.In this defined interval, diode *D3*andswitches S1, *S2*, *S3*are turned ON. [see Fig. 3.2(a)].

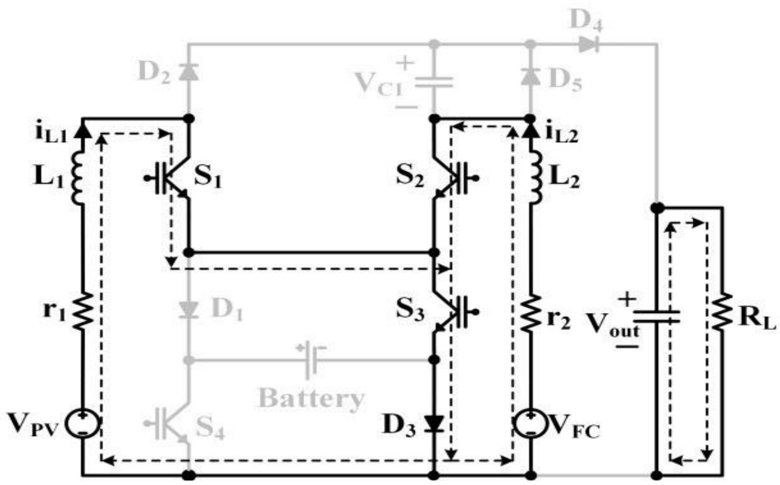

Fig.3.1Current-flow path of operating modes in first operating state. (a) Mode1.

Mode 2 (d1T < t < d2T): Inductor*L2* still charged and *L1*inductoris being discharged via *vPV–vC1*. In this interval, switch*S1* would be turned OFF and *D2* would be turned ON and *S2*, *S3* and *D3* are stillON. [see Fig. 3.2(b)].

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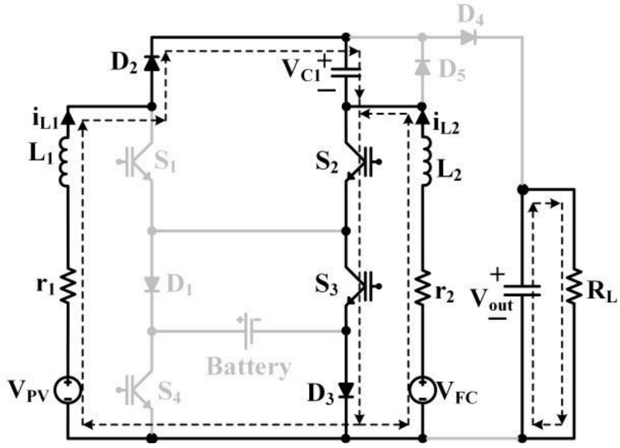

Fig. 3.2 Current-flow path of operating modes in first operating state.(b) Mode 2.

Mode 3 (d2T < t < T):*L1*Inductoris charged with *vPV*and *L2*inductoris discharged via *vPV+ vC1 – vo.*In this mode interval, *S2* is turned OFF and *S1* is turned ON and *S3* and *D3* are still ON. [see Fig. 3.3(c)].

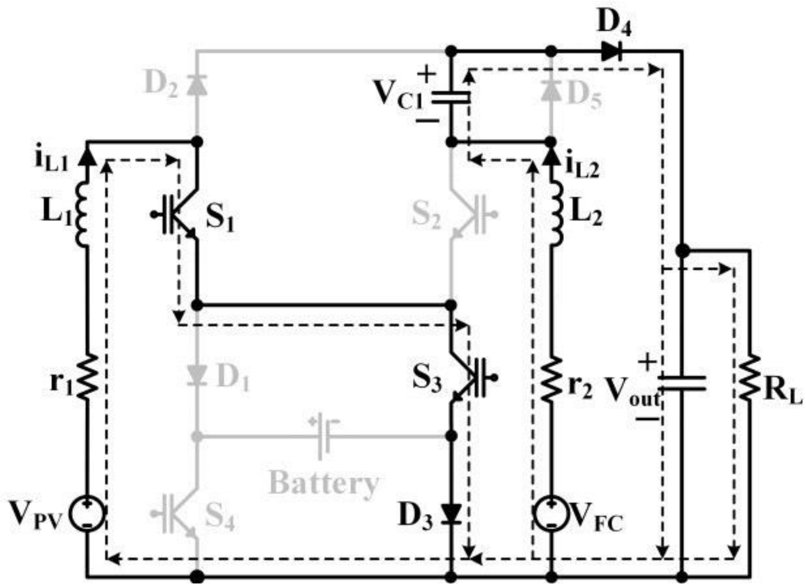

Fig.3.3 Current-flow path of operating modes in first operating state. (c) Mode 3.

3.2 Operation in Secondstate (The load is supplied by Photo Voltaic panel, Fuel Cell, battery, in this state battery is in discharging mode)

In this state, there are four operation modes. The load is supplied by allthree input sources (PV, FC and battery). Only one current pathin first mode. However, in other remaining three modes, there are two current paths (through *D3* and *S3* or *S4*and *D1*). In this state, current passes through *D1* and *S4*. Switch *S4* would be permanently ON during this state.

Mode 1 (0 < t < d1T):*L1* and *L2* are the Inductors, charged by *vPV* + *vBattery*and *vFC* + *vBattery*respectively.
In this interval, *S4*, *S3*, *S2*and *S1*are turned ON.

Mode 2 (d1T < t < d2T):*L1* and *L2* are the Inductors charged by *vPV*and *vFC*respectively.
In this interval, *S4*, *S2*, *S1*and *D1* are turned ON.

Mode 3 (d2 T < t < d3T):*L1* Inductoris discharged to capacitor *C1* and *L2* is charged by *vFC*.
In this interval, *S4*, *S2*, *D2*and *D1*are turned ON.

Mode 4 (d3T < t < d4T):In this interval, *S4*, *S1*, *D4*and *D1*are turned ON. *L1* Inductor is charged by *vPV*and *L2 inductor* discharges *C1* to the output capacitor.

3.3 Operation in Third state (The load is supplied by Photo Voltaic panel and Fuel Cell and battery is in charging mode)

In this state, as it is shown in Fig. 4, there are four different modes. During this state, Photo Voltaic panel and Fuel Cell charges the battery andsupply the energy to load. In the first and second operation modes, there are two feasible current paths through (D*3* and *S3* or *D4*and *D1)*. Here we have considered path *D1* and *S4* is to flow the current in this state. Switch *S3* would be permanently OFF, during this state and diode *D1* conducts.

Mode 1 (0 < t < d1T):In this duration, *S4*, *S2, S1*and *D1* are turned ON. *L1* and *L2* are inductors charged by *vPV*and *vFC*,respectively [see Fig. 4.1(a)].

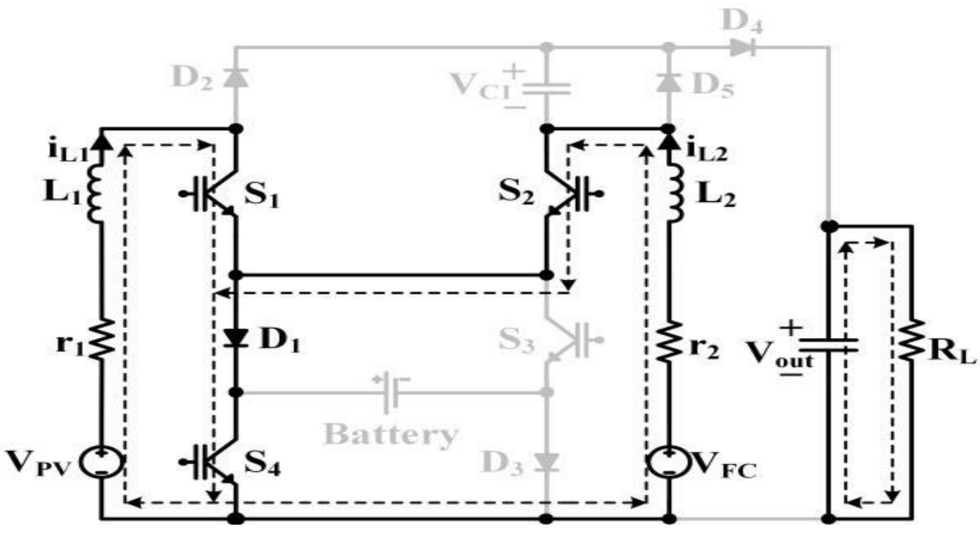

Fig.4.1Current-flow path of operating modes in third operating state. (a) Mode 1.

Mode 2 (d1T < t < d2T):*S4*, *S2*and *D1* areturned ON, in this interval. *L1*Inductor is discharged to capacitor *C1* and *L2*inductorischarged by *vFC*[see Fig. 4.2(b)].

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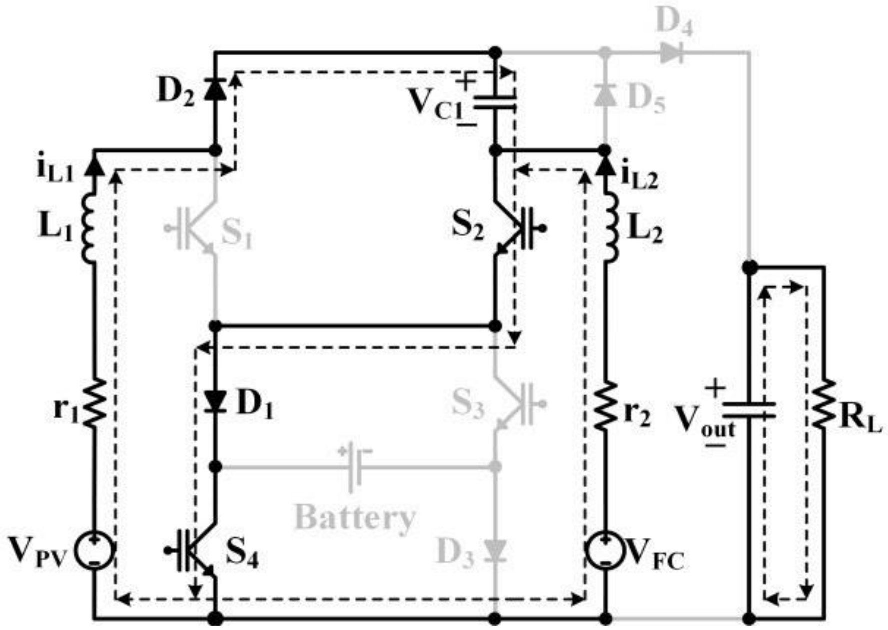

Fig.4.2Current-flow path of operating modes in third operating state. (b) Mode 2.

Mode 3 (d2 T < t < d3 T):In this interval, *S2*, *S1*, *D1* and *D3* are turned ON. *L1*and *L2* inductors are charged by *vPV –vBattery*and *vFC – vBattery*, respectively [see Fig. 4.3(c)].

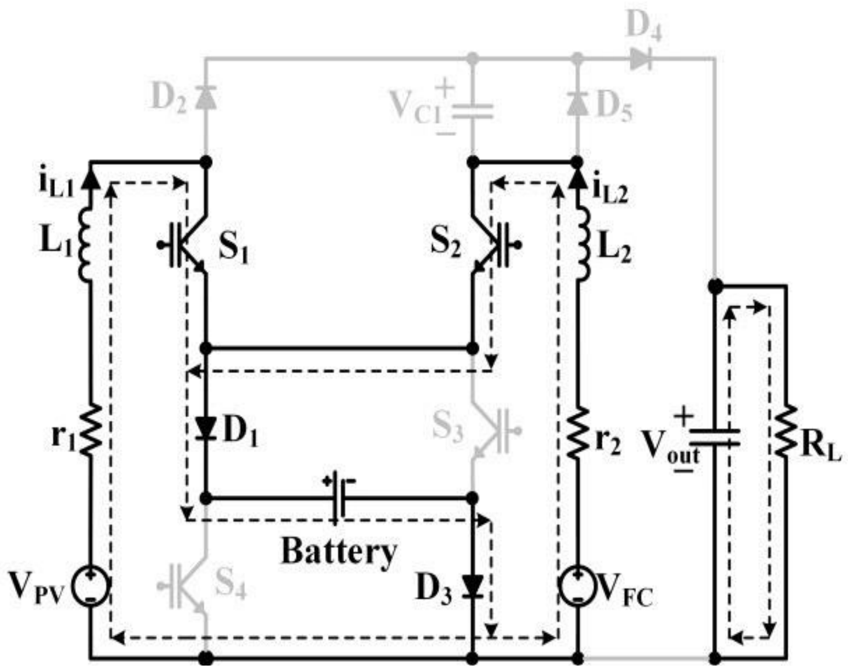

Fig.4.3Current-flow path of operating modes in third operating state. (c) Mode 3.

Mode 4 (d3 T < t < d4 T):In this interval, *S4*, *S1*, *D1* and *D4* are turned ON. *L1* Inductor is charged by *vPV–vBattery andL2*inductor [see Fig. 4.4(d)].

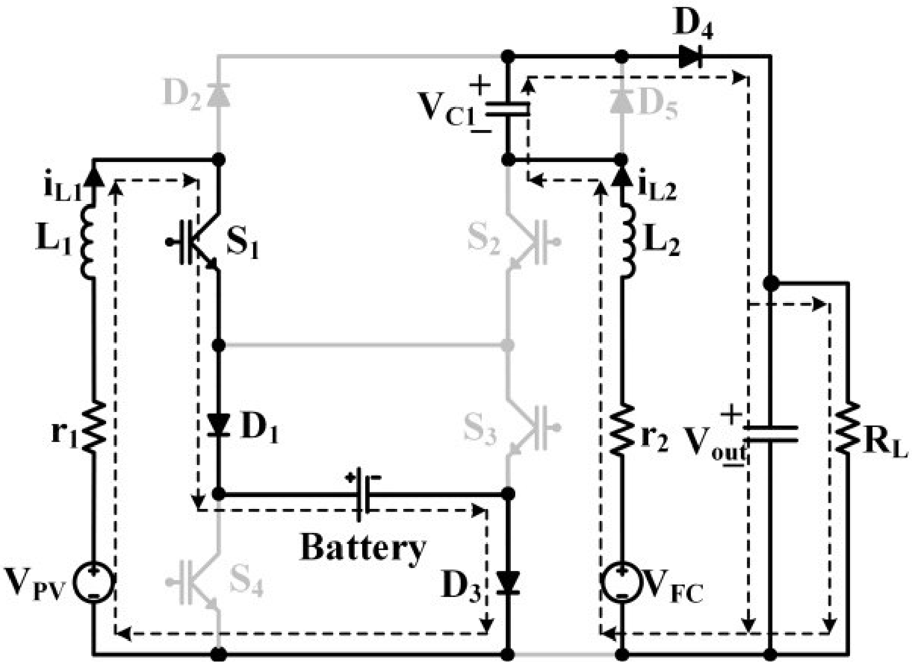

Fig.4.4Current-flow path of operating modes in third operating state. (d) Mode 4.

Fig.5 shows switching pattern for each mode and each state.To control state of power switches independently, a saw-tooth wave as a carrier is compared with signals *d1*, *d2*, *d3* and *d4*. Here we are not considering output voltage utilized power of each sources Photo Voltaic panel, Fuel Cell and battery can be controlled using *d1*, *d2*, *d3* and *d4* signals.

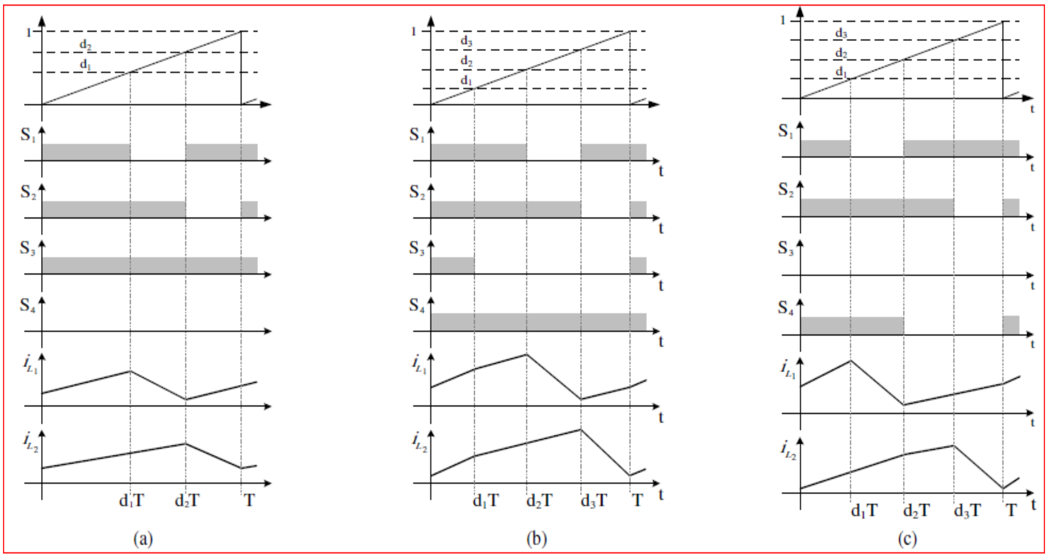

Fig.5. Switching pattern for three states. (a) First state. (b) Second state. (c) Third state.

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4. ADVANTAGES OF THE CONVERTER, MAKING CONVERTER SUITABLE FOR 'HYBRID ELECTRICAL VEHICALS'.

The proposed converter has designed in such a way that,only one of resource can be utilizing at a timeand rest other power sources can't provide energy. This ability enhances the reliability and safety of the proposed converter. Different other possible states have been described as follows:

4.1Photo Voltaic Panel ON and Fuel Cell OFF

Due to the large start-up time of used fuel cell, taking long time to start up a car or when the car is running out of fuel cell. In this state, battery can be discharged or charged by Photo Voltaic panel. Because of the facts that Fuel Cell is the prime power supply andenergy storage system has a limited capacity, this state cannot be so longer. So that consideration the Photo Voltaic panel operates individually, switch *S2* is turned off and instead of capacitor *C1*, the power of Photo Voltaic panel is transferred to the output capacitor *Co*. According to the proposed topology, battery can be discharged andcharged via Photo Voltaic panel and by controlling switches*S4*, *S3* and *S1*.

4.2Photo Voltaic Panel OFF and Fuel Cell ON

As said above, Energy of Photo Voltaic panel is less than Fuel Cell and completely depends on climate condition. So, Fuel Cell would be the main input power source to provides the required power to HEV. Therefore, an extra diode (D5) is connected paralleled withcapacitor C1. When capacitor C1 will charge then diode D5 is off. When the Fuel Cell is utilized individually, then capacitor C1will discharges until its voltage goes to zero. Diode D5will be turned on and clamps the voltage of capacitor C1, when the voltage across capacitor C1 is goes to negative.

5. SIMULATION DIAGRAM

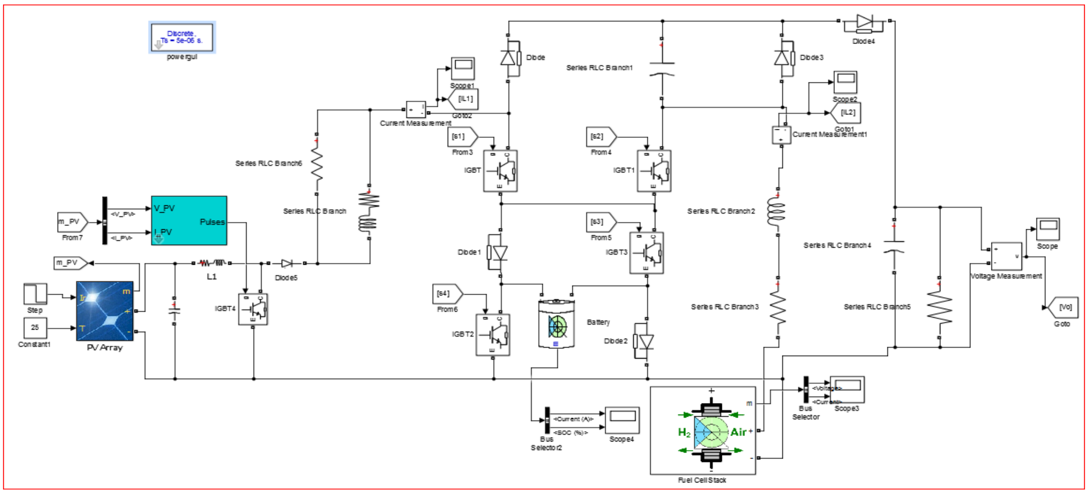

Fig. 6. Main Simulation Diagram.

6. EXPERIMENTAL RESULTS

An 80 W prototype version of the simulation circuit has been built,to verify the performance of the proposed converter. Tested in presented three states. About 30 KHz would beswitching frequency. A Neural Network is employed to control power switches.The given proposed converter has the ability of being used for different domestic and industrial applications such as smart homes, HEV and DGs interface. Power sources are mainly fuel cells, arrays, and so on. Transient time of the power sources need to ignore, they canbe replace with DC power supplies to obtain experimental results. 24V have been set to give both input sources. A Li-ion, 24-V, 7Ahbattery has been used as energy storage element. Due to excellent performance of Li-ion type batterie they are widely used in portable electronic gadgets. High energy density, high reliability, high temperature performance and being recyclable are features of Li-ion batteries. However, drawback is high cost. The value of the inductor L2 is 650 μH and the inductor L1 is 550 (μH). Capacitors have been utilized in the converter are 470 μF.

First states operation results. Fig.7(a) shows SOC of battery. Fig.7(b) and Fig.7(c) shows current through IL1 and IL2. Fig.7(d) shows output voltage.

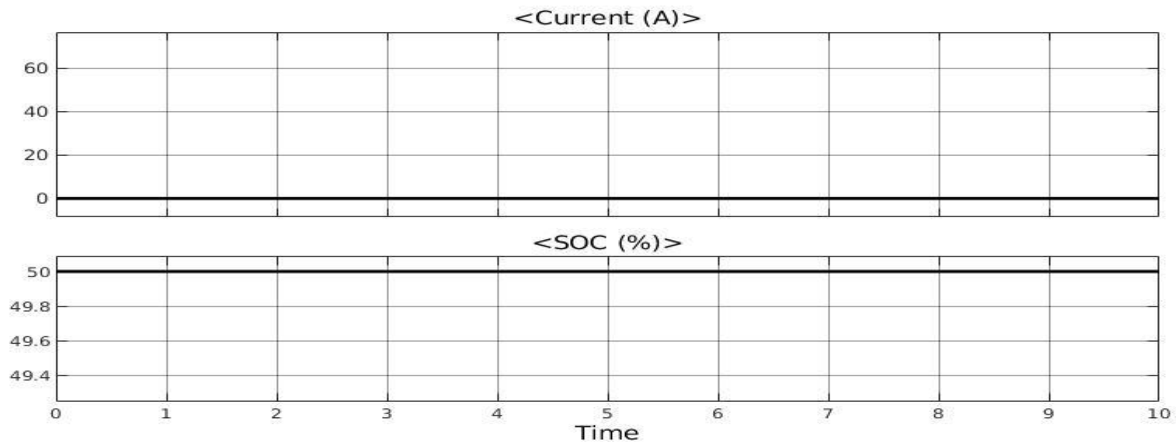

Fig.7 (a). First states operation, SOC of battery.

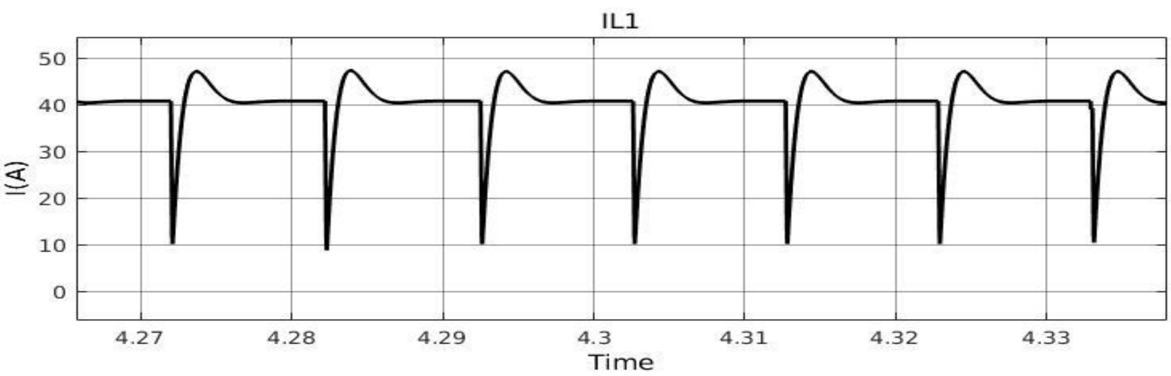

Fig.7 (b). First states operation, Current through IL1.

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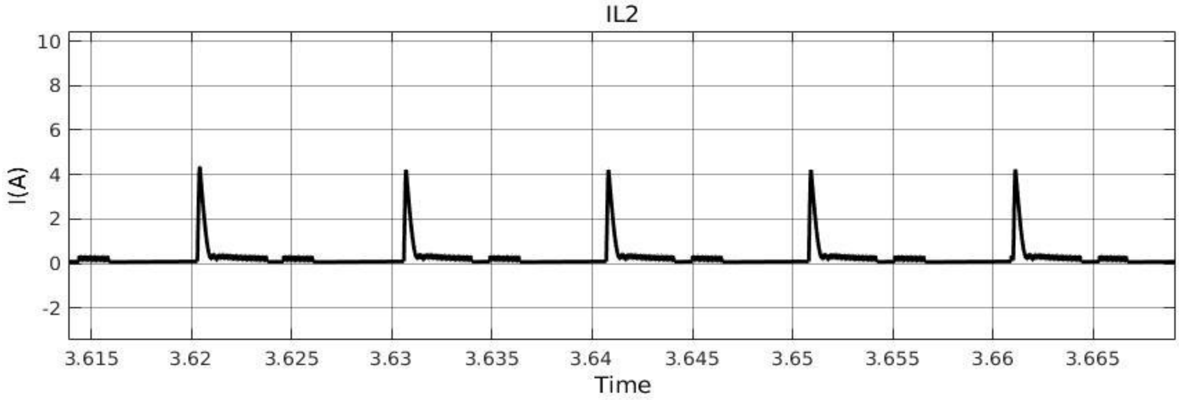

Fig.7 (c). First states operation, Current through IL2.

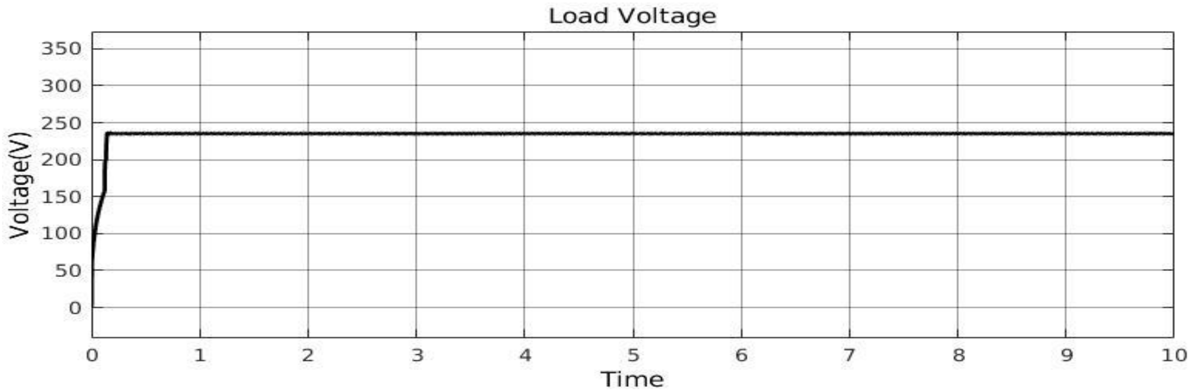

Fig.7 (d).First states operation, Output Voltage V.

Second state's operation results are shows in Fig. 8(a) shows SOC of battery. Fig. 8(b) and Fig. 8(c) shows current through IL1 and IL2. Fig. 8(d) shows output voltage.

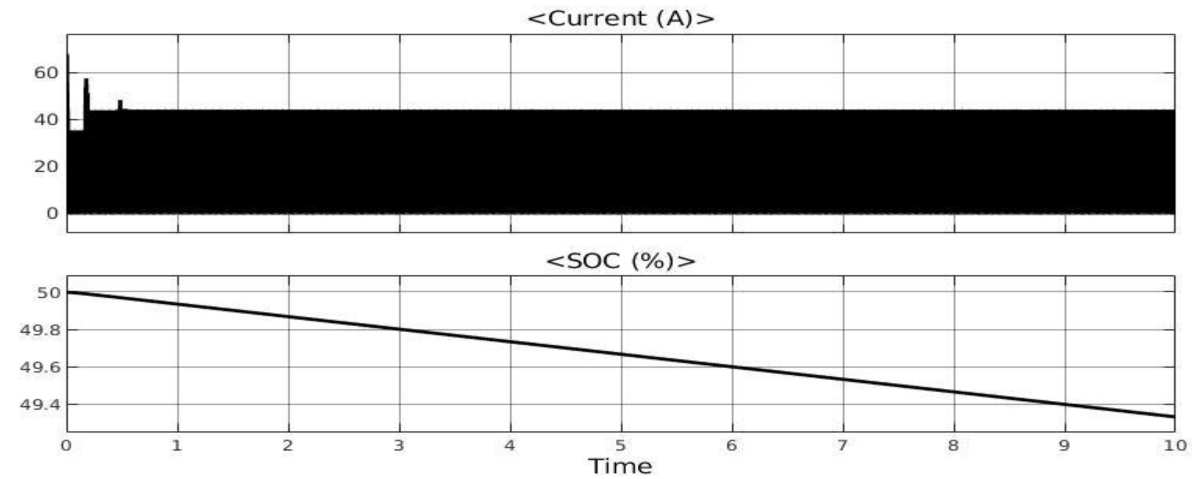

Fig.8 (a) Second states operation, SOC of battery.

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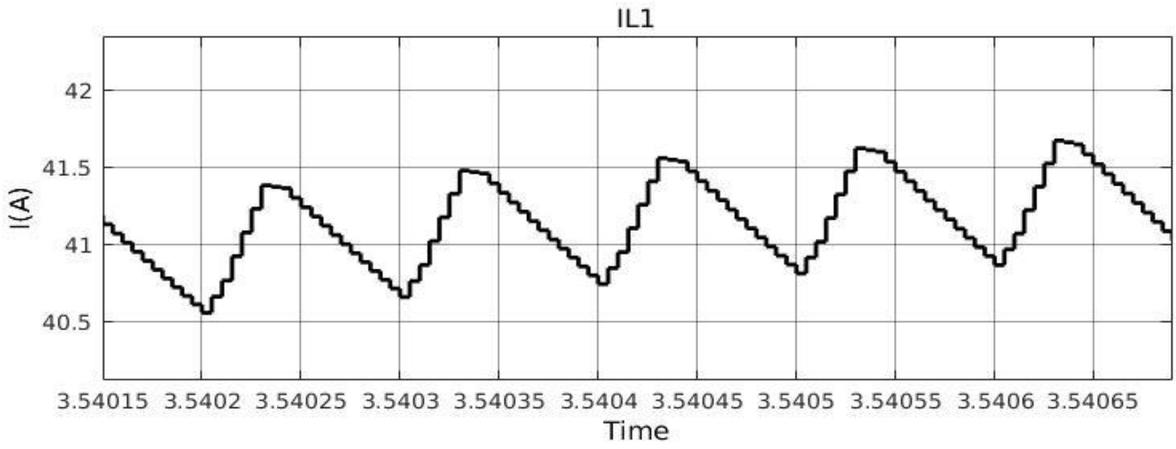

Fig.8 (b). Second states operation, Current through IL1.

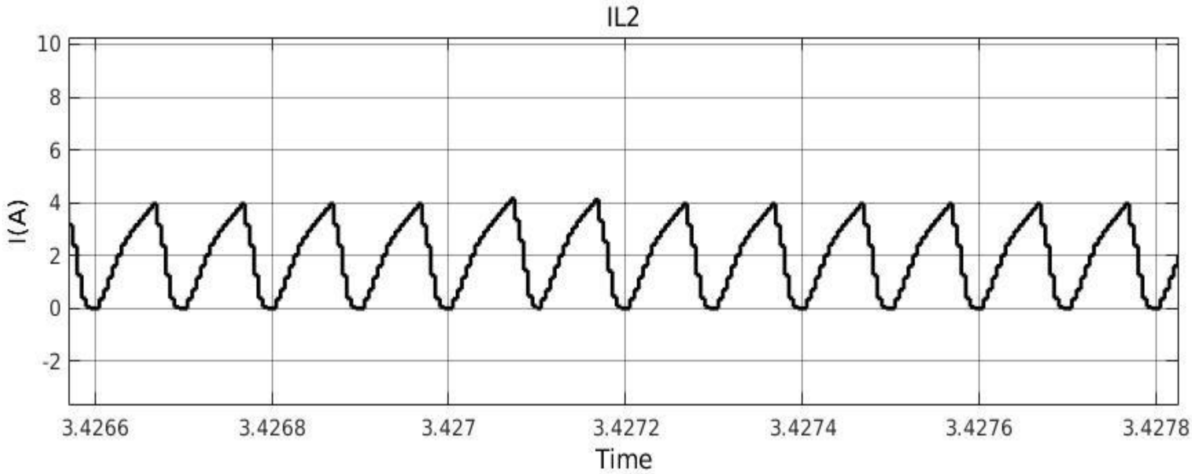

Fig.8 (c). Second states operation, Current through IL2.

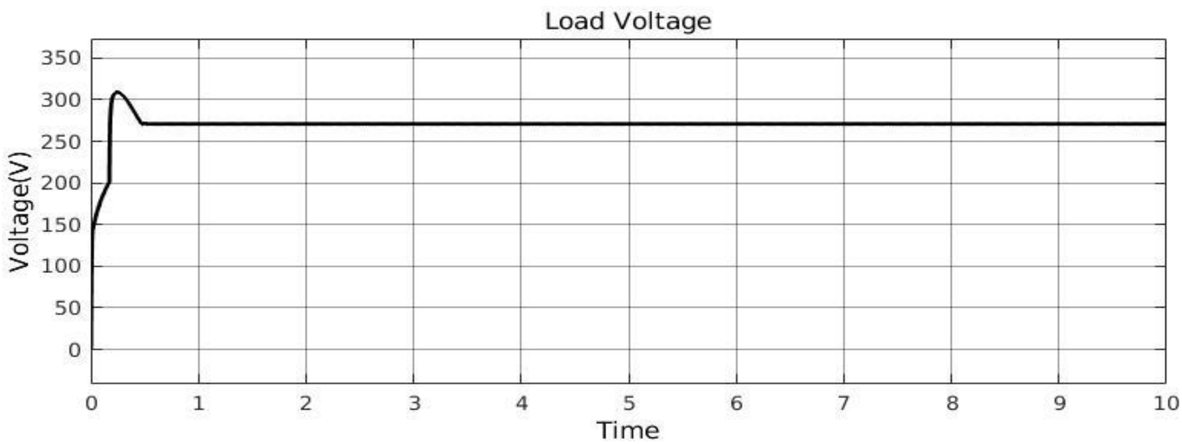

Fig.8 (d). Second states operation, Output Voltage V.

Third state's experimental results are shown in Fig.9(a) shows SOC of battery. Fig. 9(b) and Fig. 9(c) shows current through IL1 and IL2. Fig. 9(d) shows output voltage. 40 A current from PV array.

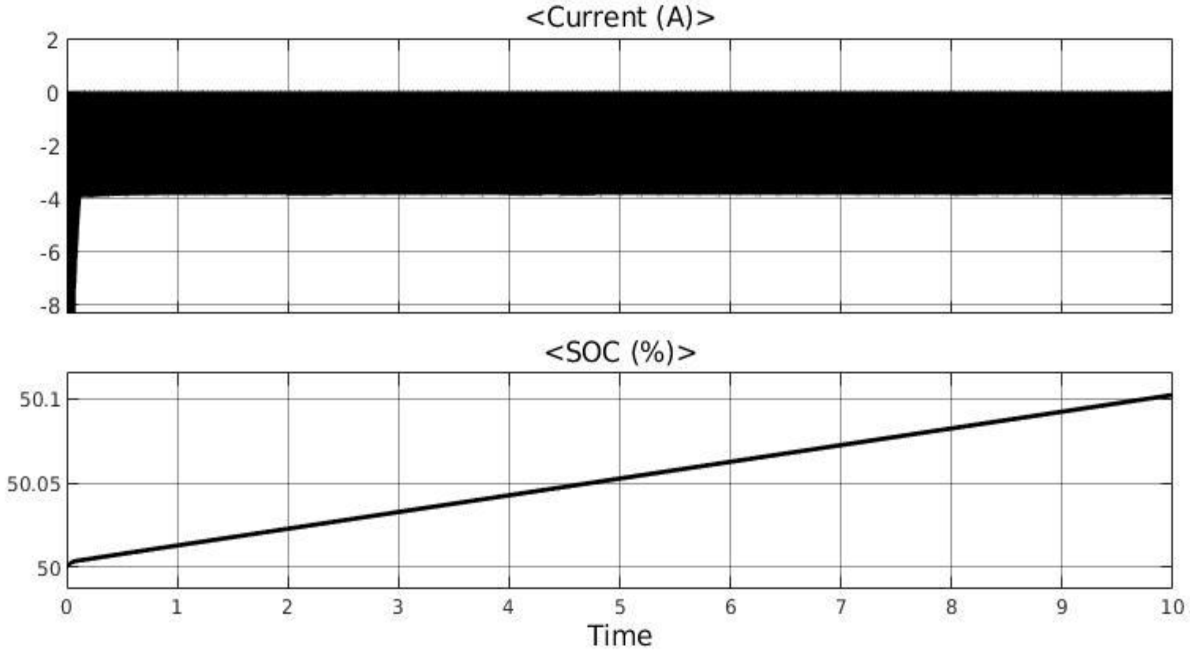

Fig.9 (a). Second states operation, SOC of battery.

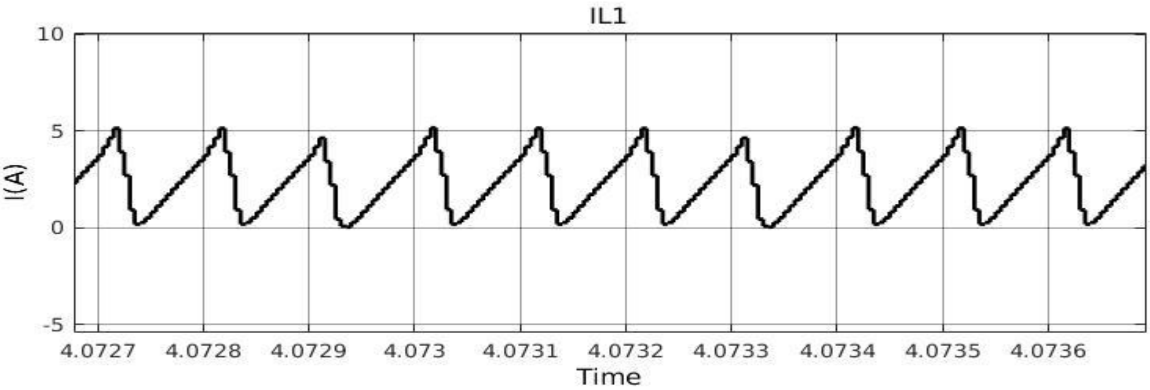

Fig.9 (b). Second states operation, Current through IL1.

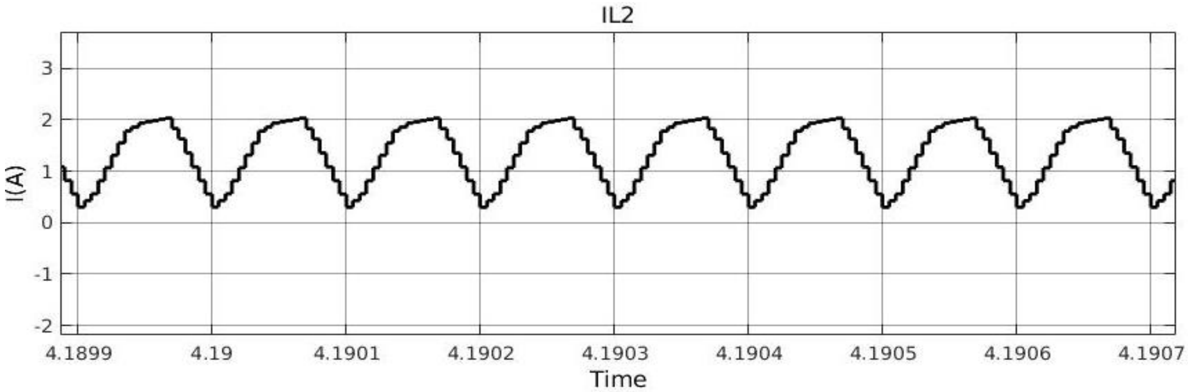

Fig.9 (c). Second states operation, Current through IL2.

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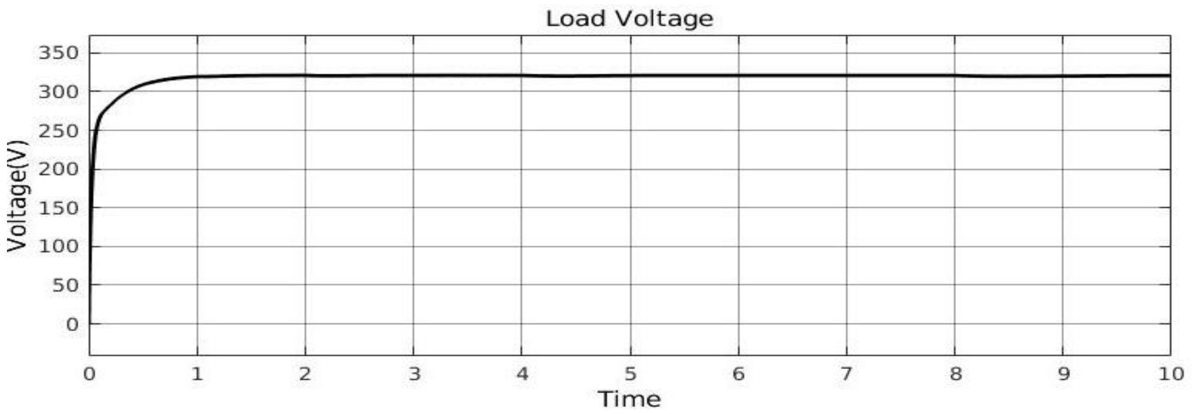

Fig.9 (d). Second states operation, Output Voltage V.

7. CONCLUSION

In this study, a novel approach to step-up three input DC to DC Converterisproposed and analysed thoroughly. The DC-to-DCconverter has theability of providing the required power by load inabsence of one or more resources. The ensuringperformanceof the converter and used control method offer a highreliability to utilizing the converter in domestic and industrial applications. The converter is modelled for three differentoperational states and utilized to design a proper controller. Neural Network technology has been used for switchingFinally, MATLABprototype of the presented converted is rolled out.Results are taken and depicted. Results prove the performance andanalysis of the converter.

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