

# Multi Input DC-DC Converter for Automotive Applications

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**Abstract:** *Some of the serious problems which we are encountering these days are the Air Pollution, Global Warming and the rapid depletion of the Earth's Petroleum Resources. Hence to accommodate the future challenges, it has been typically proposed to replace conventional vehicles system to new generation Electric Vehicles (EVs), Hybrid Electric Vehicles (HEVs) and Fuel Cell Electric Vehicles (FCEVs). The rapid development of technologies of Power Electronics and Electric Vehicles, suitable energy storage systems allows the production of high efficiency electric vehicles. Hybrid Electric Vehicle (HEV) is one such technology which has this potential and gained enormous attention because of depleting conventional resources and has measured carbon emission there by providing better fuel efficiency with reduced harmful emission and also enhances the performance. Instead of providing single input converter to each load, the use of Multi Input Converter (MIC) in the hybrid system reduces the number of components used, thereby reducing the size of power circuit with higher efficiency which ensures more reliable system and provide regulated power to the vehicles. Due to the intermittent nature of renewable sources, there might be drastic changes in the climatic conditions and are not always same in the given period of time. Due to this intermittent nature the output power changes with change in the climatic condition. "Rechargeable Energy Storage System" (RESS) is used as a backup energy source in case when load demand is high and production is low from the four input renewable energy sources.*

**Keywords:** Renewable energy sources, DC-DC converter and PI controller and RESS.

## 1. Introduction

Increased usage of automobiles across the globe has caused and has continued to cause Global warming and also depletion in fuel has increased the demand for more sustainable means of transportation. To overcome these serious problems Electric Vehicles and Hybrid Electric Vehicles are gaining more importance in the transportation market perspectives. Additionally "Rechargeable energy storage system" (RESS) is used as a backup energy source to overcome natural calamities challenges, which provides good acceleration and regenerative braking. Due to the intermittent nature of climate the output power at the load side varies, which may affect the load. So in order to overcome this problem it is necessary to regulate the power, by regulating both voltage and current, it ensures the load safe. DC-DC converters can be used to interface the elements in the electric power vehicles by boosting or chopping the voltage levels. These technologies are highly robotic, reliable, lightweight, small volume with high efficiency and low current/voltage ripple which helps to overcome constraints associated with the Automotive Designs.

The main objective of this paper is to simply the power system by proposing five input boost converter for the hybrid system which ensures cost reduction. The proposed converter is having four sources which act as an input are wind turbines, PV modules, FC, and electric grid. The fifth source acts as a storage element. Climatic conditions are not always constant in the given interval of time and according to availability of energy sources, the output power may vary. Due to the intermittent nature of renewable sources, a battery backup is normally required when the supply is not available.

Supplying the output load, charging of the battery is done by the wind turbines, PV modules, FC and electric grid and also by "regenerative braking" of the vehicle and discharging is done when load demand is high and production is low from the four input sources. The proposed structure utilizes twelve power switches and eight diodes. Depending on utilization state of the battery, three different power operation modes are defined for the converter.

This converter controls the output power additionally an electric vehicle can convert the vehicle's kinetic energy to electrical energy and store it during the braking. However, a Multi input converter (MIC) can generally have the advantages compare to a combination of several individual converters like cost reduction, compactness, more expandability and greater manageability. MICs are being used in aerospace.

## 2. DC-DC Converter

A DC-DC converter is an electronic circuit that converts a DC source from one level of voltage to another. An unregulated DC voltage is given as input to these converters and therefore it will be fluctuated. In these converters regulated DC output power is obtained although the input voltage is changing. The regulation of output power in a DC-DC converter is based on the on-time of the switch, pulse width and the switching frequency. The control of output voltage depends on the duty cycle  $D$ . The duty ratio is defined as the ratio of the on-time of the switch and the total switching period. Duty cycle is given by the Equation 1

$$D = T_{on} / T_s \quad (1)$$

Where,  
D is the duty cycle  
TON is the on period of the switch  
TS is the total time period (TON + TOFF)

## 2.1 DC-DC Boost Converter

A converter that produces an output voltage higher than that of the input voltage is called Boost converter or step-up converter. The fundamental for a boost converter consists of an inductor, diode, capacitor and switch. The input to a boost converter can be from any kind of sources as well as batteries. The DC input voltage is in series with a large inductor acting as a current source. A switch connected in parallel with the current source and the output is turned off periodically, providing energy from the inductor and source to raise the output voltage. The circuit diagram of DC-DC boost converter is shown in Fig -1.

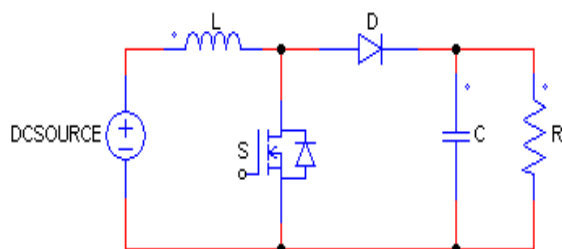


Figure 1: Circuit diagram of DC-DC boost converter

The average output voltage is given by Equation -2.

$$V_O = V_{IN} / (1-D) \quad (2)$$

Where,  
VO is the output voltage  
VIN is the input voltage  
D is the duty cycle

The charging and discharging operation of the DC-DC boost converter depends on switching condition of the switch in the circuit.

Table 1: Switching states of four-input DC-DC converter

Mode 1				Mode 2				Mode 3			
$PPV + PWT = PL$				$PPV + PWT < PL$				$PPV + PWT > PL$			
$S_1$	$S_2$	$S_3$	$S_4$	$S_1$	$S_2$	$S_3$	$S_4$	$S_1$	$S_2$	$S_3$	$S_4$
off / on	off / on	off / on	off / on	off / on	off / on	off / on	off / on	on / off	on / off	on / off	on / off
$S_5$	$S_6$	$S_7$	$S_8$	$S_5$	$S_6$	$S_7$	$S_8$	$S_5$	$S_6$	$S_7$	$S_8$
off / on	off / on	off / on	off / on	off / on	off / on	off / on	off / on	on / off	on / off	on / off	on / off

## 3. Multi-Input DC-DC Converter

Multiple-Input DC-DC converters are the sole key to combine numerous input power sources whose voltage levels are different and to get regulated output voltage for the load from them.

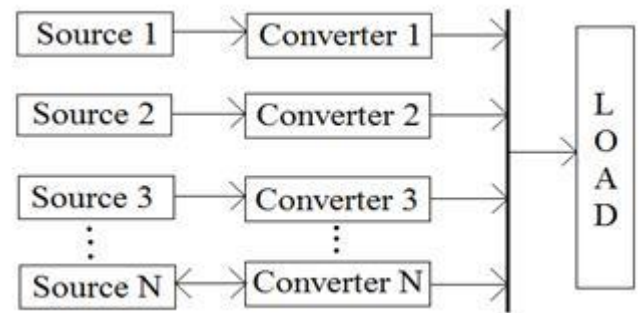


Figure 2: Separate converters for each source

In many applications, there is a requirement for multiple power sources to be connected together, providing the power for a single loads. Fig-2 shows the separate converter for different sources. Source 1 to Source N-1 can be composed of any kind of energy source combinations, such as wind turbines, PV modules, FC, micro turbines and/or electric grid, and Source N could be a storage unit, such as a battery, ultra-capacitor, flywheel or superconducting magnetic energy storage system. All the energy sources are unidirectional where the storage element is bidirectional which can perform both charging and discharging operations [5]-[6].

A single Multi-Input DC-DC Converter replaces several number of parallel connected single converters is shown in Fig -3. Fig -4 shows the structure of the four-input DC-DC boost converter. The converter interfaces voltages from four input power sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  and the storage element battery.

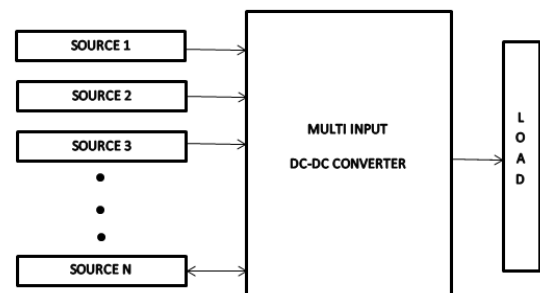


Figure 3: An MIC for all sources

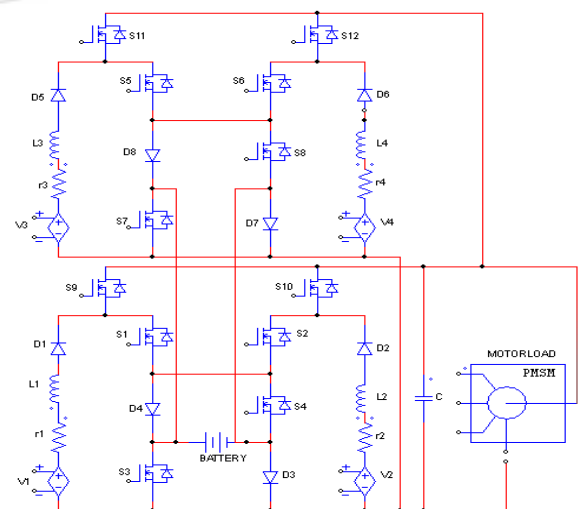


Figure 4: Circuit topology of four-input DC-DC converter

Therefore,  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  are shown as four dependent power sources and the determination of their output characteristics are based on the type of input power sources. Four inductors  $L_1$ ,  $L_2$ ,  $L_3$  and  $L_4$  make the input power ports as two current type sources, which result in obtaining even dc currents from the input power sources. The major controlling elements that control the power flow of the MIC system are the twelve power switches  $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$ ,  $S_5$ ,  $S_6$ ,  $S_7$ ,  $S_8$ ,  $S_9$ ,  $S_{10}$ ,  $S_{11}$ , and  $S_{12}$  in the converter. The switches  $S_9$ ,  $S_{10}$ ,  $S_{11}$  and  $S_{12}$  helps in reverse flow of current to the battery in 3<sup>rd</sup> mode of operation. And the diodes  $D_1$ ,  $D_2$ ,  $D_5$ ,  $D_6$  prevent the reverse flow of current to the four dependent input sources. The switches  $S_1$  and  $S_2$ ,  $S_5$  and  $S_6$  conduct in complimentary helps in charging and discharging of the battery. The converter structure shows three modes of operation.

## 4. Modes of Operation

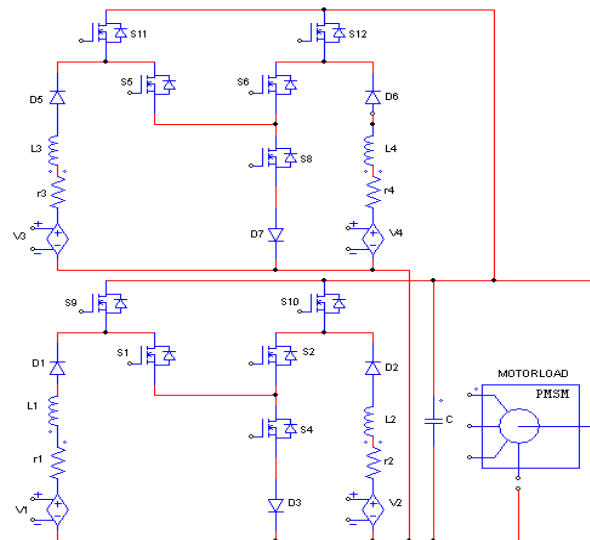
The proposed four-input DC-DC converter is operated in three different modes based on the performance of the storage element.

- Mode 1  
Supplying the load with sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  without battery
- Mode 2  
Supplying the load with sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  and the battery discharging performance.
- Mode 3  
Supplying the load with sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  and battery charging performance.

The various switching condition for the operating modes of four-input DC-DC converter is shown in Table -1.

### 4.1 Mode 1

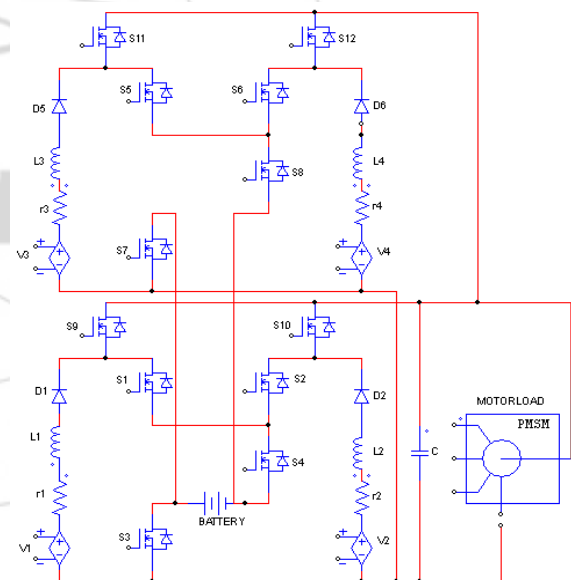
The first operation mode is shown in Fig -5. In this operation mode, four input power sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  are in charge for supplying power to the load, and battery charging or discharging is not done. This operation mode is considered as the basic operation mode of the converter. As clearly seen from the converter structure, there are two options to conduct input power sources currents  $i_{L1}$ ,  $i_{L2}$ ,  $i_{L3}$  and  $i_{L4}$  without passing through the battery; path 1:  $S_4$ - $D_3$  and  $S_8$ - $D_7$ , path 2:  $S_3$ - $D_4$  and  $S_7$ - $D_8$ . In this operation mode, the first path is chosen; therefore, switch  $S_3$  and  $S_7$  are turned OFF while switch  $S_4$  and  $S_8$  are turned ON entirely in the switching period. Switches  $S_1$ ,  $S_2$ ,  $S_5$  and  $S_6$  are turned ON and inductors  $L_1$ ,  $L_2$ ,  $L_3$  and  $L_4$  are charged with voltages across  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  respectively. In this mode, when switches  $S_1$ ,  $S_2$ ,  $S_5$  and  $S_6$  are turned OFF, voltage from the input sources is directly fed to the load and the battery remains unused[7]-[9]



**Figure 5: Mode 1 of four-input DC-DC converter**

### 4.2 Mode 2

Second operation mode is shown in Fig -6. In this operation mode, four input power sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  along with the battery are accountable for supplying the load power. Therefore, discharging operation of the battery is performed in this operation mode.



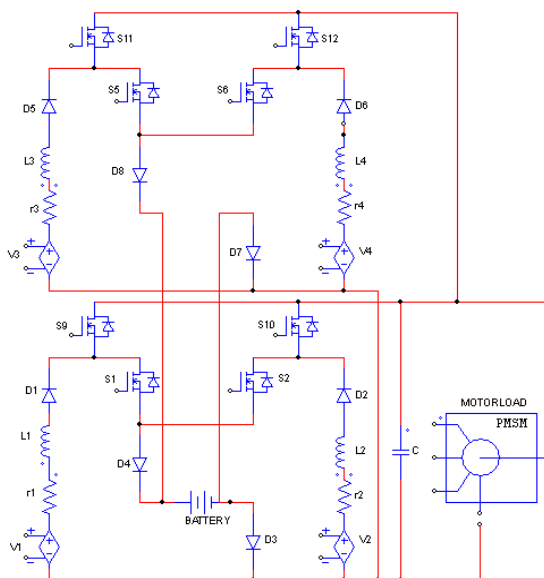
**Figure 6: Mode 2 of four-input DC-DC converter**

Referring to the converter topology, when switches  $S_3$ ,  $S_4$ ,  $S_7$  and  $S_8$  are turned ON simultaneously in the entire process, and the switches  $S_1$ ,  $S_5$  and  $S_2$ ,  $S_6$  are turned ON in alternative manner to allow the battery discharging operation. When the switches  $S_1$ ,  $S_5$  and  $S_2$ ,  $S_6$  are in turn OFF condition, the battery discharges and directly feed the load with all the four input sources. And when the switches  $S_1$ ,  $S_5$  or  $S_2$ ,  $S_6$  are turned ON, provides closed path so discharging operation of the battery will last and charging operation starts. As a result, the maximum discharge power of the battery depends on inductor currents  $i_{L1}$ ,  $i_{L2}$ ,  $i_{L3}$  and  $i_{L4}$ . Therefore, in order to acquire a maximum charge power of the battery, the input power sources should be designed in

proper current and voltage values. On the other hand, regulate the discharging power of the battery below the maximum discharging power [10]-[11].

### 4.3 Mode 3

Fig -7 shows the third operation mode. In this operation mode, four input power sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  are responsible for supplying the load while the battery charging action is accomplished. Therefore, the charging state of the battery should be provided in this operation mode. Referring to the converter topology, the switches  $S_1$ ,  $S_5$  and  $S_2$ ,  $S_6$  are initially in turn ON condition. When regenerative braking action occurs, motor acts as generator and current flows in reverse direction from load to battery through the switches  $S_9$ ,  $S_{10}$ ,  $S_{11}$ ,  $S_{12}$  and charging action of the battery takes place. And the diodes  $D_1$ ,  $D_2$ ,  $D_5$ ,  $D_6$  prevent the reverse flow of current to the four input sources. When the switches  $S_1$ ,  $S_5$  or  $S_2$ ,  $S_6$  are turned OFF charging operation of the battery will last.



**Figure 7: Mode 3 of four-input DC-DC converter**

As a result, the maximum charge power of the battery depends on inductor currents  $i_{L1}$ ,  $i_{L2}$ ,  $i_{L3}$  and  $i_{L4}$  [12]-[15].

## 5. Simulation Results

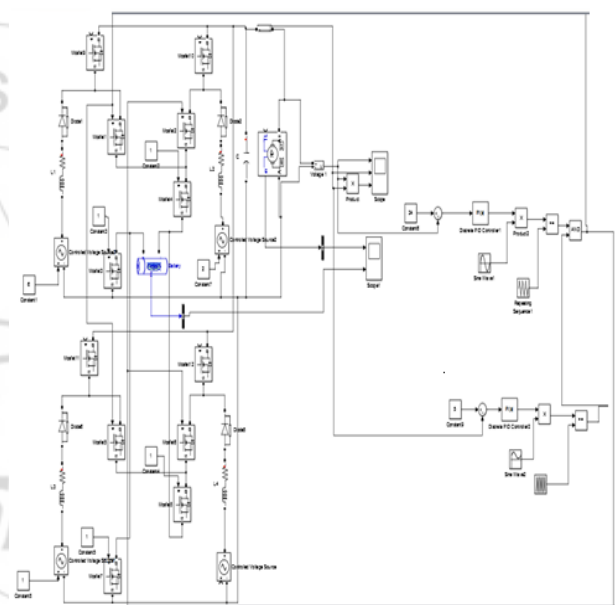
MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy to use environment. MATLAB is an excellent tool for teaching and research. In this, the MATLAB simulink model for Multi-Input DC-DC Converter is modeled and simulated with PI controller. The results are studied based on the performance of DC-DC converter and battery in obtaining a continuous regulated output power. The parameters of MIC with four input sources are listed below in Table -2.

**Table 2: Simulation parameters**

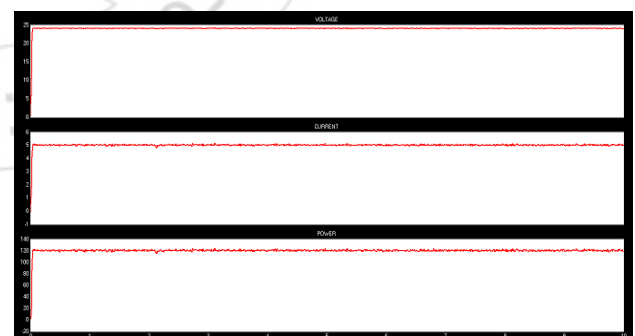
Parameters	Ratings
Input voltage ( $V_1, V_2, V_3, V_4$ )	0-15 V
Output voltage ( $V_o$ )	24 V
Inductor ( $L_1, L_2, L_3, L_4$ )	1.76e-3H
Capacitor (C)	93.75e-3F
Frequency (f)	2000 Hz
Motat load (L)	Permanent Magnet
Battery	6 V

### 5.1 Mode 1

In this operation mode, four input power sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  are responsible for supplying the load, and battery charging or discharging is not done. Fig -8 shows the first mode of operation with input voltages  $V_1$  as 2V,  $V_2$  as 8V,  $V_3$  as 0V and  $V_4$  as 3V.



**Figure 8: Simulation diagram for Mode 1**



**Figure 9: Mode 1 waveform with  $V_1$  as 2V,  $V_2$  as 8V,  $V_3$  as 0V and  $V_4$  as 3V**

### 5.2 Mode 2

Four input power sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  along with the battery are responsible for supplying the load in this operation mode. Fig -9 shows the second mode of operation with input voltages  $V_1$  as 6V,  $V_2$  as 2V,  $V_3$  as 1V and  $V_4$  as 0V.



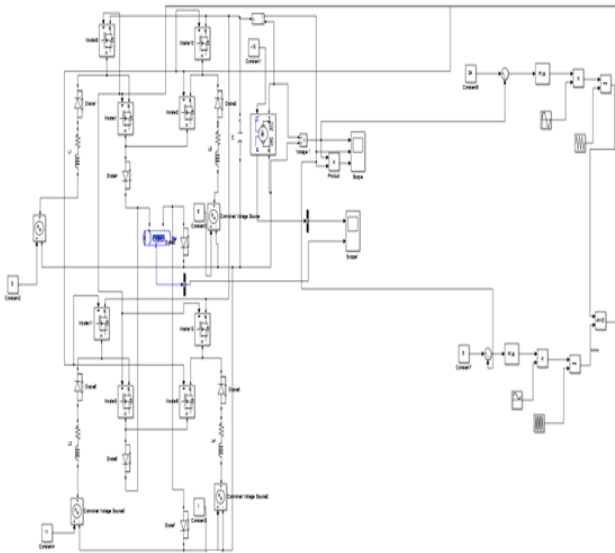


Figure 10: Simulation diagram for Mode 2

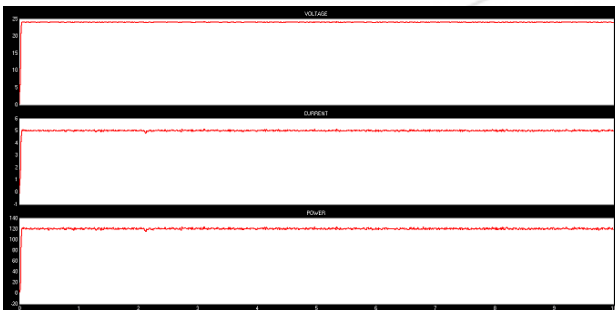


Figure 11: Mode 2 waveform with  $V_1$  as 6V,  $V_2$  as 2V,  $V_3$  as 1V and  $V_4$  as 0V

### 5.3 Mode 3

In this operation mode, four input power sources  $V_1$ ,  $V_2$ ,  $V_3$  and  $V_4$  are responsible for supplying the load while the battery charging is performed. Fig -10 shows the third mode of operation with input voltages  $V_1$  as 2V,  $V_2$  as 8V,  $V_3$  as 11V and  $V_4$  as 1V.

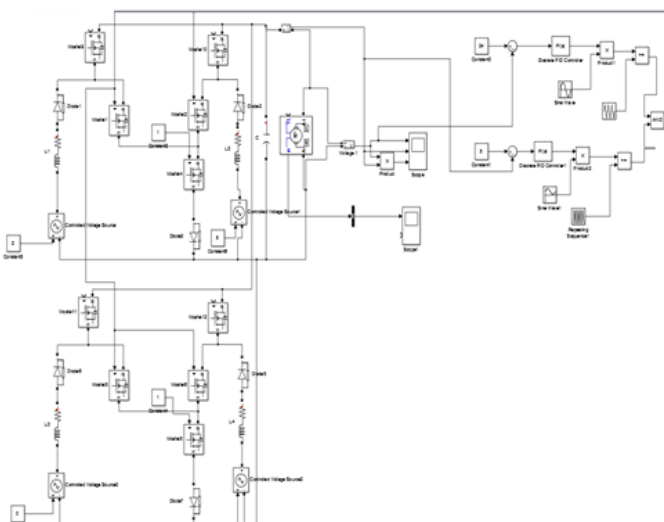


Figure 12: Simulation diagram for Mode 3

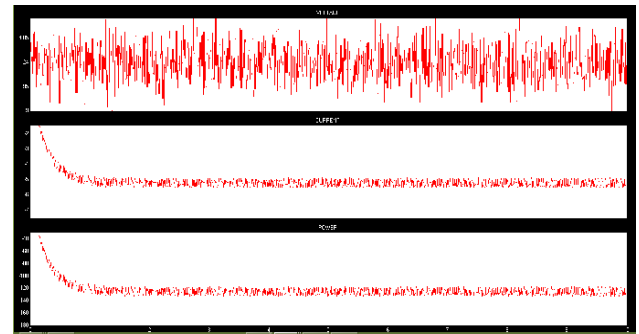


Figure 13: Mode 3 waveform with  $V_1$  as 2V,  $V_2$  as 8V,  $V_3$  as 11V and  $V_4$  as 1V

## 6. Conclusion

The proposed Multi-Input DC-DC converter in HEV produces regulated output power to the load from the different input sources. MIC supplies power to the load either individually or simultaneously from the input sources. The power delivered by the multi input converter (MIC) to the load is fluctuating in nature, which may affect the load. So PI controller is used to regulate both voltage and current which is obtained from all four renewable energy sources in order to provide regulated output power to the load. As the power delivered is discontinuous due to change in weather conditions, a storage element battery is provided. Battery starts discharging, when the power delivered by the all four input sources is not much, to provide a continuous supply to the load. Instead of using individual converter for each source in hybrid system, MIC is used which reduces the system size, cost and increases the vehicles efficiency. The efficiency of the system can be further increased by increasing the number of inputs. Here this system can be implemented for 'N' number of input sources.

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