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Analysis of Hybrid Electric Vehicle Based on Step-Up Multi-input DC-DC Converter and Renewable Energy Source

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ABSTRACT

A multi-input direct current–direct current converter is suggested and investigated for use in hybrid electric cars. It is more productive than traditional works when compared to conventional works. This converter's input sources include the fuel cell (FC), solar panel, and energy storage system, all of which are currently on the market. The FC is regarded as the primary source of power, with roof-top PV being used to charge the battery, boost efficiency, and minimise fuel use and emissions, respectively. Even if one or two resources are unavailable, the converter has the potential of supplying the necessary power to the load. Furthermore, the power management approach is discussed and shown in the context of a control methodology. Furthermore, the suggested approach is not just applicable to HEVs, but we can also utilise these types of systems for grid-connected systems by utilising a separate converter. The complete system is created and simulated with the help of the MATLAB/SIMULINK programming language.

KEYWORDS: Hybrid electric vehicles(HEV), Multi input converter, power management

1. INTRODUCTION

Hybrid electric vehicles (HEVS) have garnered a great deal of attention in recent years, mostly as a result of increased awareness of the energy issue and environmental conservation. Because of the increased need for transportation, petroleum is being consumed at a greater rate over the world. It plays a crucial part in the design of cars that use the least amount of fuel and are completely fuel-free. So the car industries have been more interested in alternative propulsion technologies, which has resulted in an increase in the utilisation rate of hybrid electric vehicles (HEV). One of the most significant advantages of using a HEV drive is that it increases the efficiency of the motor drive. The bidirectional DC-DC converters with many inputs and outputs used in hybrid electric cars are critical components of the traction systems. A variety of various energy sources, such as batteries, ultracapacitors, solar cells, fuel cells, and other renewable energy sources, have been combined using multi input bidirectional converters, each having a distinct voltage characteristic. HEV (1-6) employs induction motor designs that are characteristic of the induction motor, and an overview of HEV is provided. It is possible to acquire low beginning current and high starting torque from an inverter supplied induction motor by using an appropriate starting frequency and voltage for the motor (7). A high-frequency transformer is being used to link the various sources, with each source being connected by full-bridge cells, with 12 switches being used for three sources (8). [9] proposes a current-fed half-bridge architecture for reducing the ripple current in the battery by employing phase shift modulation to lower the ripple current in the battery. [10] describes the stability assessments of multiple input isolated buck–boost and forward converters with a common output. When using these sorts of converters, it is difficult to regulate the distribution of power among the numerous sources. In [11], the energy flow between a variety of various sources as well as the dc connection is examined in further detail. It is not possible to transmit energy directly between alternating current sources in this topology, and a greater number of devices are employed as a result. It will be suggested in this study to develop a new form of multi input bidirectional DCDC converter that will allow for the integration of a wide range of energy sources. The suggested circuit will be evaluated, analysed, developed, controlled, and simulated in order to determine its feasibility. It has been stated that multi input bidirectional DC-DC converters are being developed for use in hybrid electric vehicles (HEVs) because of their advantages such as low cost and small construction. a DC-DC converter is an electrical circuit that produces variable voltage levels that are different from the voltage that is being provided DCDC converters are used in a wide range of applications nowadays. The input to the DC-DC converter is provided as an unregulated direct current voltage. Despite the fact that the input voltage is fluctuating, the converter maintains the regulated output voltage at all times. It is necessary to employ the MPPT algorithm due to the high cost of PV panels in the outset, as well as in order to enhance the amount of electricity collected from the panels. There is a broad comparison of several MPPT systems in [22], which is based on tracking factor, dynamic reaction time, PV voltage ripple, and the usage of sensors. Enhancing the efficiency of the electric components [23] is another method of increasing the efficiency. It is suggested in this study to use a revolutionary three-input dc–dc converter to combine a PV, a fuel cell, and a battery and link them to the electrical grid. Furthermore, as compared to ordinary converters, the dc gain is increased significantly. PV can be equipped with MPPT in the meanwhile. In order to accomplish power management, the battery can be charged and drained many times. The suggested structure is examined in detail in the next two parts, and several operation modes are addressed in detail.

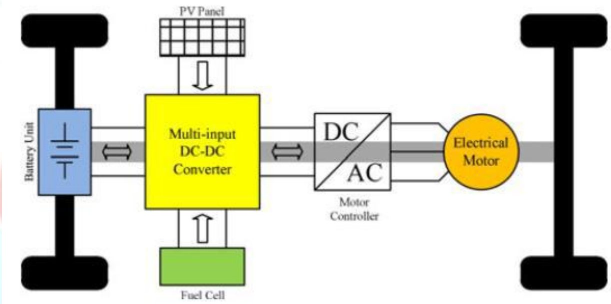


Fig. 3.1. General structure of the multi powered HEV.

2. HYBRID ELECTRIC VEHICLE TECHNOLOGY

In the current world, hybrid electric vehicles (HEVs) are a rapidly developing technology due to the fact that they reduce environmental pollution while simultaneously increasing the fuel efficiency of automobiles. Using a multilevel inverter, you can control the electric drive of a high-capacity HEV and improve its performance, which is a reflection of the fact that it can generate sinusoidal voltages with only the fundamental switching frequency and has virtually no electromagnetic interference, as opposed to a single-level inverter. Specifically, it covers the different topologies of HEVs in detail and proposes a transformer-less multilevel converter for HEVs with high voltage and high current. The cascaded inverter is an IGBT-based device that is activated in a sequential manner. The fact that it makes use of distinct levels of dc sources, such as batteries or fuel cells, makes it a perfect choice for HEV applications. Because of the optimization of engine operation and the recovery of kinetic energy during braking, hybrid electric vehicles (HEVs) are more fuel efficient than conventional cars in comparison to traditional vehicles. Using the plug-in hybrid electric vehicle (PHEV), the car may be driven only on electricity for a driving range of up to 30–60 kilometres. In order to charge their batteries overnight, they are connected to the electric power grid, which may be powered by renewable energy sources like as wind and solar energy, as well as nuclear energy. Fuel cell vehicles (FCVs) generate energy by using hydrogen as a fuel, which means that they emit virtually no emissions. Whenever the FCV is linked to the electric power grid (V2G), it may provide electricity for emergency power backup during a power loss, which is very useful. FCVs are not currently available to the general public because to the difficulties associated with hydrogen generation and storage, as well as the technological constraints of fuel cells at this time. In the future years, hybrid electric vehicles (HEVs) are expected to dominate the advanced propulsion market. A wide range of fuels and engines, including hybrids, can be employed with hybrid technology. As a result, it does not qualify as a transition technology. HEVs and FCVs employ a greater number of electrical components, including electric machines, power electronic converters, batteries, ultra capacitors, sensors, and micro controllers, than other types of vehicles. Other components or subsystems, such as traditional internal combustion engines (ICEs), mechanical and hydraulic systems, may be incorporated in addition to these electrification components or subsystems. Aspects of the challenge presented by these advanced propulsion systems include the design of advanced power train components, including high-speed power electronic converters, electric motors and energy storage, as well as power management techniques such as modelling and simulation of the power train system, hybrid control theory and vehicle control optimization techniques.

Researchers have been concentrating their efforts on various aspects of hybrid electric vehicle (HEV) development in recent years. These include the components of the vehicle's architecture, engine efficiency and reduced fuel emissions; materials for lighter components; power electronics; efficient motors and high power density batteries. In order to satisfy some of the requirements of HEV, a cascaded multilayer inverter is employed in order to meet the high power requirements. It is possible to achieve high voltages with minimum harmonics using multilayer voltage source inverters because of their distinctive construction, which eliminates the need for transformers or series-connected synchronised switching devices. The multilayer inverter's general function is to synthesise a desired voltage from a number of different levels of alternating current (AC). Therefore, multiple inverters are capable of supplying the high power required by a big electric powertrain with relative ease. As the number of levels in the synthesised output waveform rises, the number of steps in the waveform increases, resulting in a staircase wave that approaches the desired waveform. Another benefit of increasing the number of stages in a waveform is that harmonic distortion in the output wave reduces as the number of stages grows, eventually nearing zero. The voltage that may be covered by adding numerous voltage levels grows in direct proportion to the number of levels that are used.

Voltage sharing difficulties are not experienced by the active devices because of the design of the multilayer inverter's circuitry and construction. Configurations for Hybrid Electric Vehicles

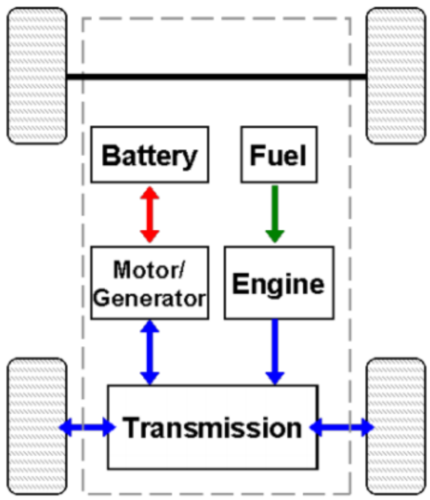


Fig.1.1 HEV Model

3. PROPOSED A NOVEL THREE-INPUT DC–DC CONVERTER

Structure of the proposed three-input direct current–direct current boost converter is presented in Figure 3.2. The converter is composed of two ordinary boost converters, with one of the converters including an additional capacitor in place of the other, and a battery to store the energy produced. The converter's characteristics make it appropriate for use in hybrid systems. During the power management and control section of this study, the behaviour of the converter is examined in terms of controlling the sources, and the results are presented. In this case, the output of vPV and vFC are two separate power sources whose output is determined by their respective characteristics. The input filters of a PV panel and a fuel cell have inductances L1 and L2, respectively. PV and FC modules are converted to current sources by connecting L1 and L2 in series with the input sources. r1 and r2 represent the equivalent resistances of vPV 'S and vF C 'S, respectively. RLoad is the resistance of loads connected to the dc bus that is comparable to the resistance of the bus. The power switches are labelled S1, S2, S3, and S4. The diodes D1, D2, D3, and D4 are utilised to establish the various modes that will be discussed later. Capacitor C1 is utilised to boost output gain, while output capacitor Co is used to filter the voltage at the output end of the circuit. The system is working in continuous-conduct mode in order to generate smooth current with the least amount of current ripple as feasible..

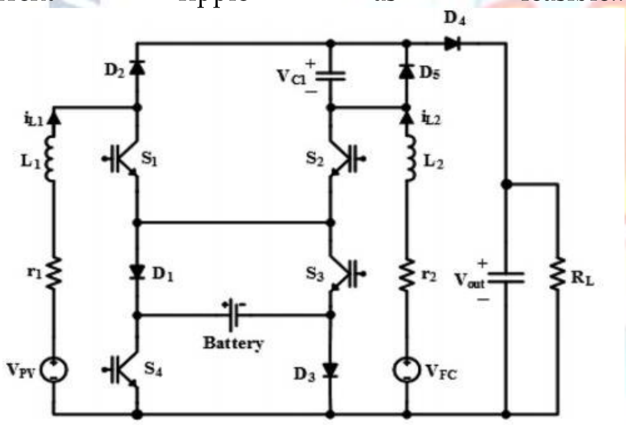


Fig. 3.2. Three-input dc–dc boost converter

Operation Modes

In this section, principles of the proposed converter are discussed. Operation of the converter is divided into three states:

1) The load is supplied by PV and FC and battery is not used.

2) The load is supplied by PV, FC, and battery, in this state, battery is in discharging mode

First Operation State (the Load is supplied by PV and FC While Battery is not used)

In this state, as it is illustrated in Figure 3, there are three operation modes. During this state, the system is operating without battery charging or discharging. Therefore, there are two paths for current to flow (through S3 and D3 or D1 and S4). In this paper, S3 and D3 is considered as common path. However, D1 and S4 could be chosen as an alternative path. During this state, switch S3 is permanently ON and switch S4 is OFF.

Mode 1: (0< t <d1T): In this interval, switches S1, S2, S3, and diode D3 are turned ON. Inductors L1 and L2 are charged via power sources vPV and vF C , respectively [see Figure 3(a)].

Mode 2: (d1T < t < d2T): In this interval, switch S1 is turned OFF and D2 is turned ON and S2, S3 , and D3 are Still ON. Inductor L2 is still charged and inductor L1 is being discharged via VPC − VF C [see Figure 3(b)].

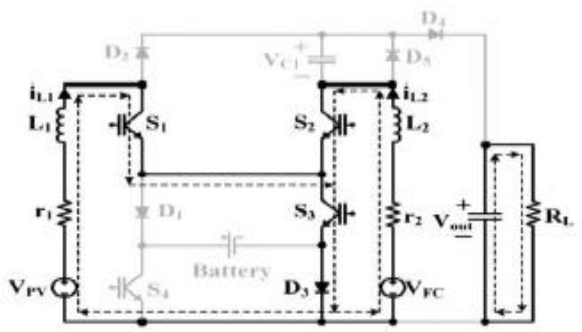
Mode 3: (d2T < t < T): In this interval, S1 is turned ON and S2 is turned OFF and S3 and D3 are still ON. Inductor L1 is charged with vPV and inductor L2 is discharged via VPV + VC1 − Vo [see Figure 3(c)].

$$L_1 : d_1 \left[V_{\mathrm{PV}} - r_1 i_{L_1}\right] + (d_2 - d_1)\left[V_{\mathrm{PV}} - r_1 i_{L_1} - V_{C_1}\right] + (1 - d_2)\left[V_{\mathrm{PV}} - r_1 i_{L_1}\right] = 0$$

$$V_{C_1} = \frac{V_{\mathrm{PV}} - r_1 i_{L_1}}{d_2 - d_1}$$

$$L_2 : d_2 \left[V_{FC} - r_2 i_{L_2}\right] + (1 - d_2)\left[V_{FC} + V_{C_1} - r_2 i_{L_2} - V_o\right] = 0$$

$$V_o = \frac{(d_2 - d_1)\left(V_{FC} - r_2 i_{L_2}\right) + (1 - d_2)\left(V_{FC} - r_1 i_{L_1}\right)}{(1 - d_2)(d_2 - d_1)}.$$



(a)

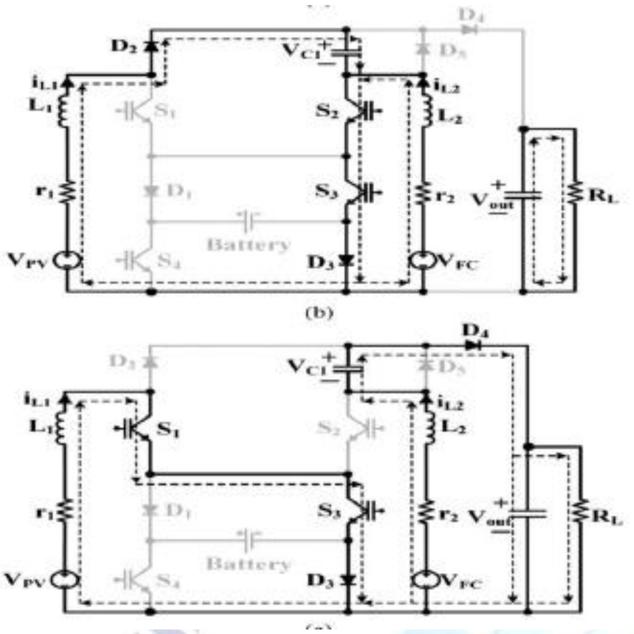


Figure 3. Current-flow path of operating modes in first operating state. (a) Mode 1. (b) Mode 2. (c) Mode 3.

Also, by applying the current–second balance low over the capacitors C1 and Co, voltage of capacitor C1, we have

$$C_1 : (d_2 - d_1)\, i_{L_1} - (1 - d_2)\, i_{L_2} = 0$$

$$C_o : (1 - d_2)\, i_{L_2} = \frac{V_o}{R_{\text{Load}}}.$$

In this case, battery is not used and so we have

$$i_{\text{batt}} = 0$$

$$P_{\text{batt}} = 0.$$

Second Operation State (the Load is Supplied by PV, FC, and Battery)

In this state, as it is illustrated in Figure 4, there are four operation modes. During this state, the load is supplied by all input sources (PV, FC, and battery). In first mode, there is only one current path. However, in other three modes, there are two current paths (through S3 and D3 or D1 and S4). In this state, current flows through D1 and S4 . Switch S4 is permanently ON during this state.

Mode 1: (0 < t < d1T): In this interval, S1, S2, S3 , and S4 are turned ON. Inductors L1 and L2 are charged by VPV + vBattery and VF C + vBattery , respectively [see Figure 4(a)].

Mode 2: (d1T < t < d2T): In this interval, S1, S2, S4 , And D1 are turned ON. Inductors L1 and L2 are charged by VPV and VF C , respectively [see Figure 4(b)].

Mode 3: (d2 T < t < d3T): In this interval, S2, S4,D1 ,and D2 are turned ON. Inductor L1 is discharged to capacitor C1 and L2 is charged by vF C [see Figure 4(c)].

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

$$L_1 : d_1 \left[V_{\text{PV}} + V_{\text{batt}} - r_1 i_{L_1}\right] + (d_2 - d_1)\left[V_{\text{PV}} - r_1 i_{L_1}\right]$$
$$+ (d_3 - d_2)\left[V_{\text{PV}} - r_1 i_{L_1} - V_{C_1}\right] + (1 - d_3)\left[V_{\text{PV}} - r_1 i_{L_1}\right] = 0$$

$$V_{C_1} = \frac{V_{\text{PV}} + d_1 V_{\text{batt}} - r_1 i_{L_1}}{d_3 - d_2}$$

$$\times L_2 : d_1 \left[V_{FC} + V_{\text{batt}} - r_2 i_{L_2}\right] + (d_3 - d_1)\left[V_{FC} - r_2 i_{L_2}\right]$$
$$+ (1 - d_3)\left[V_{FC} + V_{C_1} - r_2 i_{L_2} - V_o\right] = 0.$$

$$V_o = \frac{(d_3 - d_2)\left(V_{FC} + d_1 V_{\text{batt}} - r_2 i_{L_2}\right) + (1 - d_3)\left(V_{\text{PV}} + d_1 V_{\text{batt}} - r_1 i_{L_1}\right)}{(1 - d_3)(d_3 - d_2)}.$$

'Also, by applying the current–second balance low over the capacitors C1 and Co, voltage of capacitor C1, we have

$$C_1 : (d_3 - d_2)\, i_{L_1} - (1 - d_3)\, i_{L_2} = 0$$

$$C_o : (1 - d_3)\, i_{L_2} = \frac{V_o}{R_{\text{Load}}}.$$

In this state, the current and power of battery can be calculated as (4.13) and (4.14), respectively

$$i_{\text{batt}} = d_1 \left(i_{L_2} + i_{L_1}\right)$$

$$P_{\text{batt}} = V_{\text{batt}}\left[d_1 \left(i_{L_2} + i_{L_1}\right)\right].$$

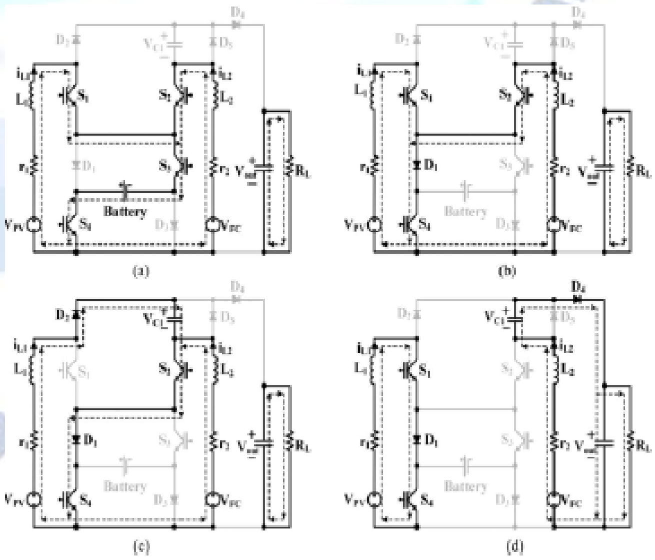


Figure 4. Current-flow paths in different operation modes of second state. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4.

Third Operation State (the Load is Supplied by PV and FC While Battery is in Charging Mode)

In this state, as it is illustrated in Figure 5, there are four modes. During this state, PV and FC charges the battery and supply the energy of load. In the first- and second-operation modes, there are two possible current paths through S3 and D3 or D1 and S4). The path D1 and S4 is chosen to flow the current in this state. During this state, switch S3 is permanently OFF and diode D1 conducts.

Mode 1: (0 < t < d1T): In this interval, S1, S2, S4 , and D1 are turned ON. Inductors L1 and L2 are charged by vPV and vF C , respectively [see Figure 5(a)].

Mode 2: (d1T < t < d2T): In this interval, S2, S4 , and D1 are turned ON. Inductor L1 is discharged to capacitor C1 and inductor L2 is charged by vF C [see Figure 5(b)].

Mode 3: (d2 T < t < d3T): In this interval, S1, S2,D1 ,and D3 are turned ON. Inductors L1 and L2 are charged by vPV − vBattery and vF C − vBattery , respectively [see Figure 5(c)].

Mode 4: (d3 T < t < d4T): In this interval, S1, S4,D1 , and D4 are turned ON. Inductor L1 is charged by vPV − vBattery and inductor L2 is discharged by vF C − vC1 − vo [see Figure 5(d)].

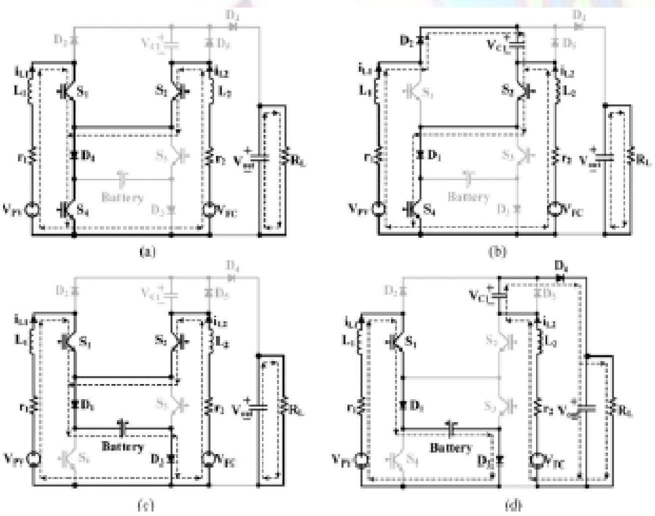


Figure 5. Current-flow path of operating modes in third operating state. (a) Mode 1. (b) Mode 2. (c) Mode 3. (d) Mode 4.

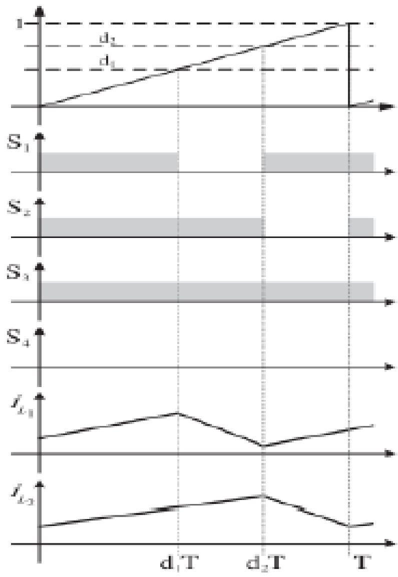


Fig. Switching pattern for First state

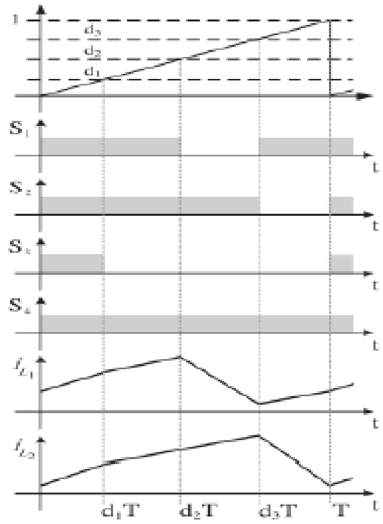


Fig. Switching pattern for Second state

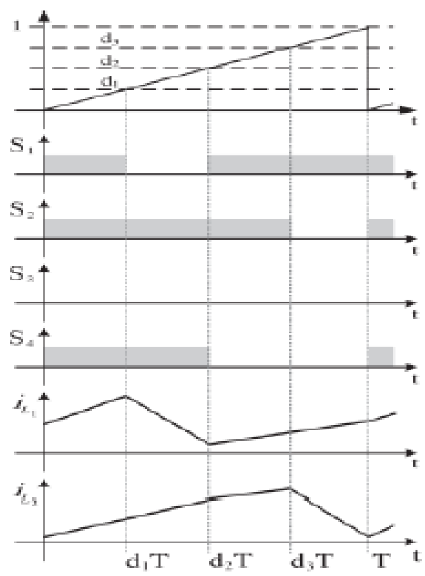


Fig. Switching pattern for Third state

4. SIMULATION RESULTS

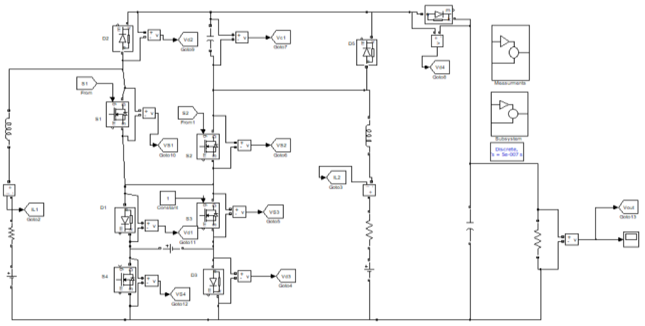


Figure shows the Matlab/Simulink model of proposed three input DC-DC converter

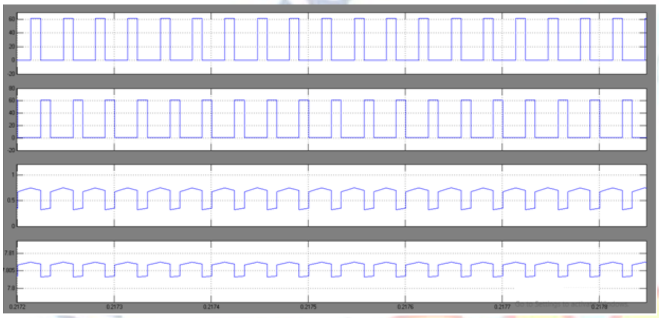


Figure shows the switch voltages S1,S2,S3 and S4

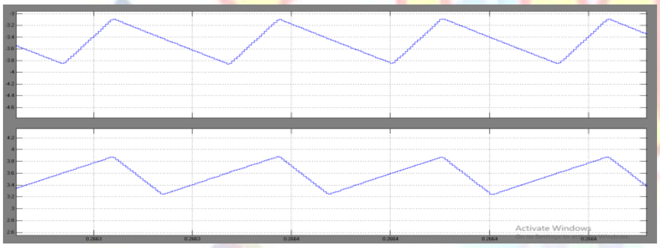
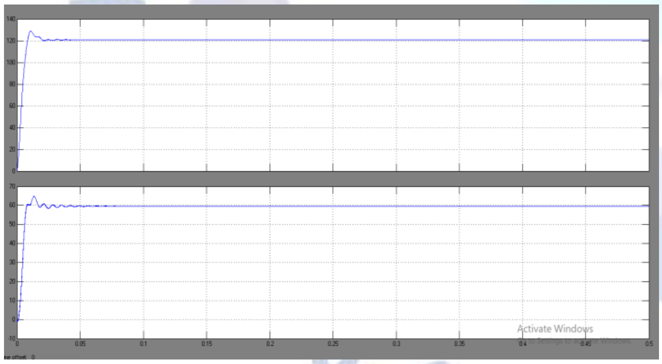


Figure shows the Inductor Currents of L1 and L2



' Figure shows the output voltage of the proposed converter and voltage across capacitor

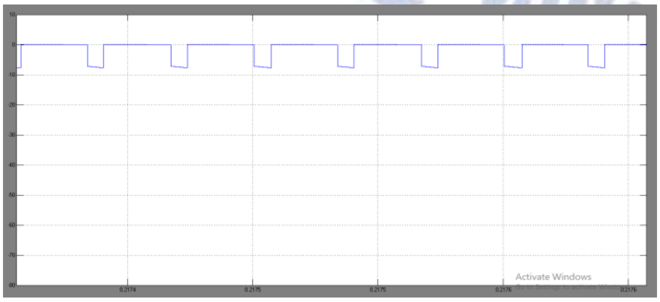


Figure shows the battery discharging mode

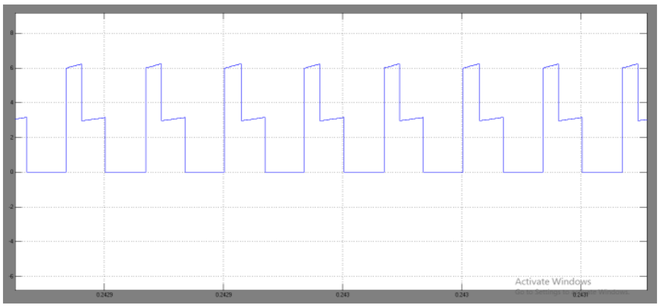


Figure shows the battery charging mode

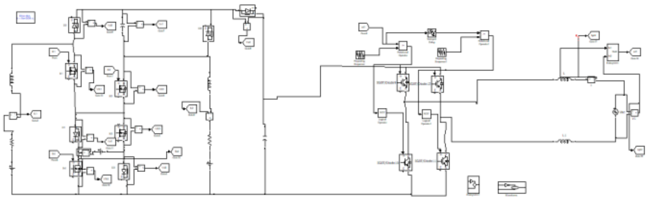


Figure shows the Matlab/Simulink model of proposed three input DC-DC converter applied to grid-tied inverter system

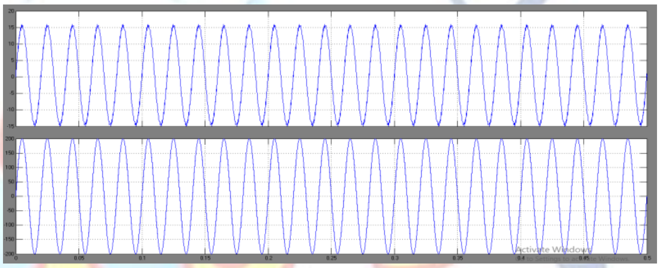


Figure shows the grid current and grid voltage of the grid-tied system

5. CONCLUSION

In this paper, a unique three-input dc/dc converter is suggested and extensively examined, and its performance is evaluated. Even if one or two resources are unavailable, the converter has the potential of supplying the necessary power to the load. The converter's promising performance, together with the control system adopted, ensures a high level of dependability when used in industrial and home applications. The converter is modelled for three distinct operational states and then simulated to determine its performance. The topic was further developed using a grid-connected inverter that used PLL logic to synchronise PV with the grid. The results demonstrate that grid current has a lower tolerance for total harmonic distortion (THD). The entire study is simulated using Matlab/Simulink, and the outcomes are observed.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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