# Dual input-dual output DC-DC converter for powermanagement in solar PV electric vehicle having an additional input source

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***Abstract*—The rising fear over depletion of fossil fuels led people to move towards some alternatives like electric vehicles, hydrogen based vehicles etc., not only in automotive field as well as in power producing sectors. Solar PV, battery and ultra-capacitor are well known viable sources to power the electric vehicles. So we have made this project considering that one input is solar and another one is battery for this solar EV. Here a novel dual input–dual output dc–dc converter is chosen for integrating of the above sources for the electric vehicles.The above mentioned DC-DC converter can be used for transferring the power between the input sources and loads/utility grid/other EVs. The converter which has been proposed can be operated in ten different types of modes using the same structure by controlling the appropriate switches. The significant modes of operation of the converter are discussed in this study using the equivalent circuits with the analytical wave forms. The output equations of all ten modes are derived. The theoretical analysis of the converter is verified experimentally using a 1 kW laboratory prototype and the observed experimental results are shown in the study. The development of a strategy for mode selection according to the status of the vehicle, grid, battery etc. is done. The loss breakdown analysis as well as the efficiency profile of the converter are presented here. At last, the comparison of the performances of the proposed converter with the reported converters are carried out in terms of component counts and number of operating modes etc.**

## I. INTRODUCTION

The popularity of the' electric vehicle(EV)' has seen a tremendous growth in recent years due to search for new ways of energies, which further led to the technological improvements in energy storage, motor drives etc. The number of mechanical parts in electric vehicles are significantly less when compared to the conventional vehicles that use fossil fuels like gasoline. There are several widely known advantages in using EVs such as low maintenance, less noise, environment-friendly etc. For powering the EVs the main components needed is the battery.To power that battery more than one energy sources are preferred in order to ensure the constant supply of power for a longer drive.In many countries Solar PV powered EVs are referred for commercial usage purposes. It uses the battery as a storage unit to support solar PV powered EV by fetching and storing the power. Power management systems are used to interface the PV cells and a rechargeable battery with the load. A lot of research was done to present PV-battery hybrid systems.

But using more than one energy source is preferred as solar power is not even through out all the places, throughout all the countries. Among all the environmental energies, solar energy is one of the most popular renewable energy source in India as it is available in most of the times since India is located in tropical region. It varies with environment. The significant role of integrating the energy sources and delivering the power to the EV according to the requirement is done with the help of power electronic converter. The basic block diagram of the structure of power converter that is used in the EVs to interconnect the input sources with the EV drive, auxiliary circuits of EV and external power supply is shown in Fig. 1.

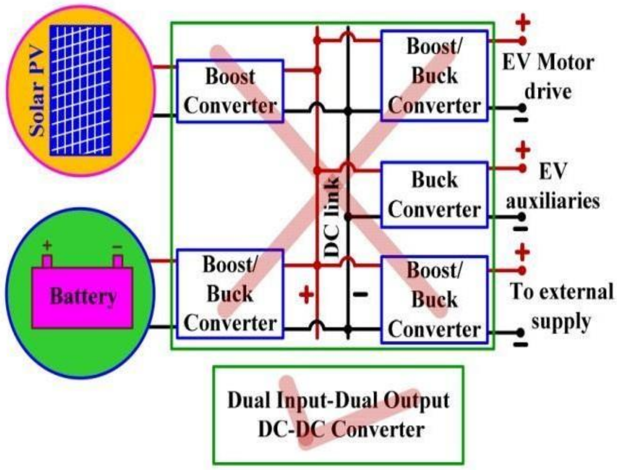



Fig.1 Block diagram of the conventional and proposed approaches for solar PV/battery/ultra capacitor powered EV.

In both the input and output sides,the individual dc-dc converters, through a common DC link which increases its cost, size, protection requirements and complexity in controlling the system. To integrate the input sources, monolithic multi-input single output dc–dc converters are reported in. Even if any one of the sources is absent the converter effectively transfers power to the load.

At the time of regenerative breaking the bidirectional power flow is not possible in to retrieve energy . The arrangement of input sources are done effectively to deliver power from the input sources to the loads through appropriate switching scheme. However, some switches experience higher voltage stresses as the input sources are arranged in a cascaded manner. The power available in the input sources can be delivered either simultaneously or individually to the load . As per the reported structure charging the input source 1 from source 2 is not possible. single input multi output buck and boost is reported.

Different converter configurations with 'multi-input multi output (MIMO)' were reported by several researchers. Based on the topologies, the MIMO converter can be classified into two types according to the number of inductors used.

(i) single inductor topologies

(ii) multi inductor topologies.

A single inductor-based MIMO topologies are reported. A MIMO converter with buck–boost operation for integrating battery/PV hybrid system is reported. To charge the battery from solar PV a separate converter is needed when the power is not supplied to the loads. The proposed converter in this has battery terminals in both the input and output sides. The output voltage regulation can be done by controlling the switches connected in the series with the loads. Since the diodes are connected in series with the input sources, power can be transferred from the sources to loads only. A single inductor-based MIMO boost converter is reported. In order to derive a number of outputs more diodes and capacitors are used in the output side and, three capacitors are required for two outputs.The huge demand for power and limited capacity of batteries prevent high performance devices for a long time without a power outlet.

Further, the output voltages are appearing across the cascaded capacitors, i.e. the negative terminal of capacitor C2 is connected to the positive of C. Such a connection may restrict the independent control of the output voltages and higher voltage stress on the diodes. A MIMO converter to integrate battery and fuel cell for EV application is reported in . One of the output is used to drive the motor and another one for the cabin lighting. Here also, the cascaded capacitors are used across the outputs. The failure of one output capacitor affects reliability in the supply of the other output. A 'dual-input dual-output (DIDO)' converter for the integration of solar PV/fuel cell-powered DC microgrid is reported. When the switch S1 is turned off, always the inductor freewheels through the fuel cell.

Though less number of switches are used here, the control of output voltage V2 is difficult. Three input–two output boost dc–dc converter is reported in. The reported converter structure does not permit the bidirectional power flow. A MIMO converter with more than one inductor is reported. A MIMO buck–boost converter is reported in. Though the converter delivers power to the output when any one of the sources is not available, more number of switches are used in the form of a matrix. A high gain MIMO converter is reported. A number of stages are used between the inputs and outputs. Here, the component counts are more. A resonant MIMO bidirectional converter with zero current switching is reported. A resonant circuit and six inductors are used to interconnect the input sources and loads.

A MIMO converter for integrating solar PV and fuel cell is presented. The presented converter utilises 11 switches and four capacitors to integrate two input sources and two loads.

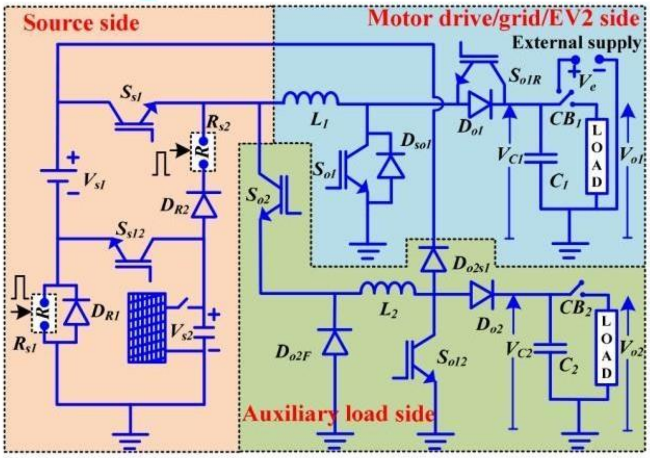



Fig. 2 proposed D2M2 converter configuration.

Since the switched capacitors without inductor are used in the converter, the application which requires current control may be difficult. MIMO converters with buck–boost or boost or buck are reported in the literature. However, according to the nature of applications, output and input etc. the converter should have multiple operational capacities in buck or boost. A general MIMO dc–dc converter topology is not reported with multiple modes of operations to transfer power among the input sources, regenerative braking, power transfer between load 1 side to load 2 connected in the output side. To overcome the above limitations, a novel 'dual input–dual output multi-mode (D2M2)' DC–DC converter is proposed in this paper. The proposed D2M2 converter replaces the conventional approach as shown in Fig. 1.In this ,for PV-battery system a power management unit is proposed in order to provide dual DC power supplies by using a single inductor DC-DC converter.

## II. DUAL INPUT-DUAL OUTPUT DC-DC CONVERTER

The converter which has been proposed in the circuit diagram is shown in fig.2..There are three parts in the converter, they are source side, motor drive/grid/battery of EV2 side and the auxiliary load side. There are two inputs such as Vs1 and Vs2 in the source side that are interconnected in a bridge form with the use of two IGBTs without anti parallel diodes (Ss1 andSs2),two solid state relays (Rs2 and Rs1) and the two diodes (Dr2 and Dr1) as shown above in fig.2. The power can be delivered either simultaneously or individually from the input sources to the output loads by controlling these IGBTs. Such control will be more helpful to drive the electric vehicle motor at the time of high acceleration. The motor drive/grid/EV2 side has a bidirectional capability to allow the transfer of power from between the input source and the motor drive(regenerative braking) or grid or EV2.

By using the IGBTs with the anti-parallel diode(S01 and S01R) the power flow is controlled. To switch either the motor drive or grid or EV2 a three-way circuit breaker is used. Basically the auxiliary side is a unidirectional side with buck operation and it consists of two IGBT switches with out anti-parallel diode(S02 and S012) and three diodes marked as D02F, D02s1 and D02.The auxiliaries such as indicator lamps, audio systems, focus lamp etc. present in the EV is powered by this. Totally four IGBTs without anti-parallel diode, two IGBTs with anti-parallel diode and five diodes are used in the circuit. The D2M2 converter that has been proposed has the flexibility to operate in the following ten different types of modes:

i. SPV drive (PV) mode
ii. Battery drive (B) mode
iii. SPV+Battery drive (PVB) mode
iv. Regenerative braking (RB) mode
v. SPV to Battery charging (PV2B)
vi. Grid-Battery interactive (G2B) mode
vii. Vehicle to Vehicle interactive (V2V)
viii. Grid-SPV (PV2G) mode
ix. Grid-Load 2 (G2L) mode
x. SPV-Load 2 (PV2L) mode

*PV mode:* When the output power from solar PV is sufficient to drive the EV motor particularly during low acceleration period, this mode is used.

*B mode:* It is recommended only when the solar PV is completely not available or accesible and 'state of charhe(SOC)' of battery should be enough to power the EV motor.

*PVB mode:* During starting,climbing a hill etc. the acceleration is high. Driving the EV only with solar PV is not a reliable one. The proposed D2M2 converter delivers power from both the battery and solar PV simultaneously to the EV.

*RB mode:* In city driving the 20% of the distance the vehicle moves in the braking mode. So there is a chance to retrieve the energy from the EV motor using the regenerative braking system, which improves the mileage of the EV.

*PV2B mode:* While parking in daytime in parkings,the energy obtained from solar pv is wasted. By the use of this mode,the battery can be charged from solar PV. If there is surplus power available with solar PV after charging the battery,the *PV2G mode* can be enabled and the grid is fed with excess power, if the grid is available.

*G2B mode:* By this mode,the D2M2 converter can be used to utilising the EV's battery to support the grid,either by charging (G2B) or discharging (B2G).

*V2V mode:* The D2M2 coverter can interact with the battery of an another EV without the need of an additional charger.It will be very useful in emergency cases like fully drained battery in outstation where no charging stations are found. It can interact with the battery of other EV either in charging or in discharging purpose

*PV2G mode:* The power produced by solar OV will become unused if this mode is not operated.Hence the power obtained from the solar PV can be fed to the grid and it can be used to get some additional revenue.

*G2L mode:* During the night time,if we use auxiliary devices like sound systems, decoration light setup in the EV,the batter may be drained fully as there is no power output from solarPV at that time.If a grid is present ,G2L mode can be enabyto power the EV auxiliaries.

*PV2L mode:* At day time the EV can be powered directly from the solar PV.This mode can function simultaneously with *PV2B mode.*

Various relays,switches and diodes are used in different operating modes of the D2M2 converter are shown below in fig.3. The converter uses leass number of switches and diodes in most of the modes,though it seems to have more number of diodes and switches. In PVB mode alone ,four switches are

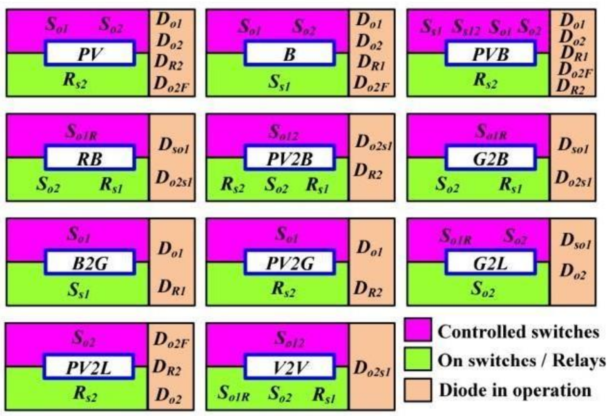



Fig. 3 Switches, relays and diodes used in each mode of D2M2 converter.

Controlled to transfer the power from both solar PV and the battery to the loads. Two switches are controlled in *PV mode* and *B* mode whereas only one switch is controlled in other modes. In the *V2V mode* external EV is used to charge the battery of the EV1 which is connected to the converter.

| Parameters | Specification |
|---|---|
| input sources $V_{S1}$, $V_{S2}$ | 48 V, 36 V |
| output voltages $V_{O1}$, $V_{O2}$ | 110 V, 12 V |
| grid voltage $V_G$ | 155 V |
| EV2 voltage $V_e$ | 48 V |
| capacitors $C_1$, $C_2$ | 470 μF, 100 μF |
| inductors $L_1$, $L_2$ | 10 mH, 5 mH |
| switching frequency | 20 kHz |

Table 1: Simulation and experimental setup parameters

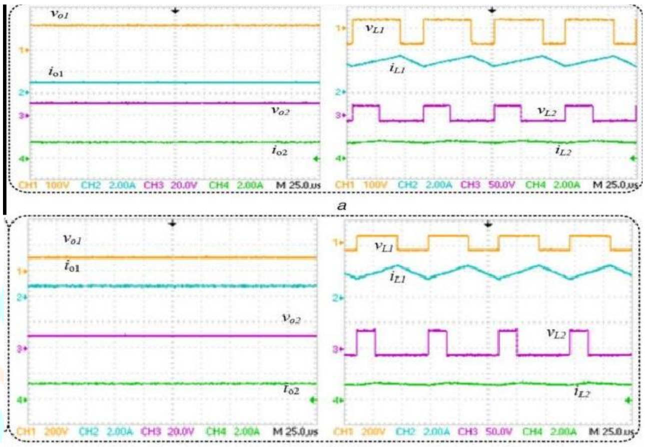
## III. LITERATURE SURVEY

The main component of this project,DC-DC converter can be identified as an electronic circuit which converts DC supply obtained from a source from one voltage level to another. The power levels can be ranging from very low as in small battery to high level (High-voltage power transmission). If the input is an AC source then the rectifier can be used to get DC supply and then connected to the input. In this input supply sources like combinations of solar and fuel cell, wind power and battery, solar PV and battery etc. can be used. These are explained by Engr Fahad from electroniclinic.com. The usage of dual sources is to supply the load uniformly without any interruption as if one source could not supply the other source will manage the power supply.Mr. Shaun Alan Stickel from Boise State University explained that the control scheme of the converter is the concept and circuits that control the converters switches in order to achieve a stable output voltage. In the IET paper ISSN 1755-4535 clearly says that the above proposed converter can be operated in ten types of modes by using the same structure by controlling the respective switches. Here the mode selection occurs based status of the vehicle, grid, battery etc. These ten types of modes are explained. In this project we can use BLDC motor for solar electric vehicle. From EdWiki we can understand that the BLDC ( Brushless DC motor) is as a permanent magnet DC motor, with the exception that the commutation is done by an electronic means. The consumption of power is less than any induction motor, which were used in old EVs but efficiency is high than those motors.

## IV. EXPERIMENTAL RESULTS

The prototype of the proposed converter is fabricated and assembled for testing in laboratory environment.The components required are designed for the power rating of 1kW and the detailed converter parameters are given above.The semiconductor switches Ss1, Ss12, So2, and So12 are realised by the IGW100N60H3 (IGBT without anti-parallel diode). The switches So1 and So1R are realised by the IKP40N65F5 (IGBT with anti-parallel diode). To suppress the voltage transients during switching operations of the IGBTs,here we use a snubber circuit with $R = 470\ \Omega$, 2 W and $C = 0.1\ \mu F$ .For all the diodes present in the converter the MUR 860 ultra-fast diode which has a low forward voltage drop is used. For the conceptual verification of different operating modes of the proposed D2M2 converter, the actual input sources, i.e. source 1:battery and source 2: solar PV + ultra-capacitor, as shown in Fig. 2 are represented by isolated dc power supplies in the experiment. At the frequency of 20kHz the switching pulses of various IGBTs of the converter are generated .For rapid prototyping of controller to generate the switch pulses for D2M2 converter the d-space 1104® real-time controller is used in this project. By using a dedicated slave PWM channel from the controller board is used to generate pulses and given to the corresponding gate driver circuits. The TLP 250 is used as the driver to provide necessary isolation between the controller board and the power stage. The performance of the D2M2 converter in all ten modes of operations and the output waveforms are observed using a 'digital storage oscilloscope (DSO)'. For this purpose a detailed experimental study is conducted. voltages Vs1 and Vs2 are set at 48 and 36V, respectively. The experiments are conductedand the performance of the converter in various modes where both or any one of the input sources involved are verified. While testing the various modes of operations, it is verified that the circulating currents are not created due to the presence of two input sources with dissimilar voltages in the converter.

The PV mode of the converter Is verified by considering



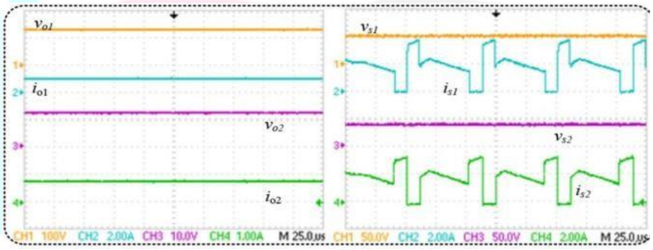
a

b

the load resistors across the output 1 and output 2. The observed waveforms such as the voltage and current of L1 and L2 are shown in Fig. 4a

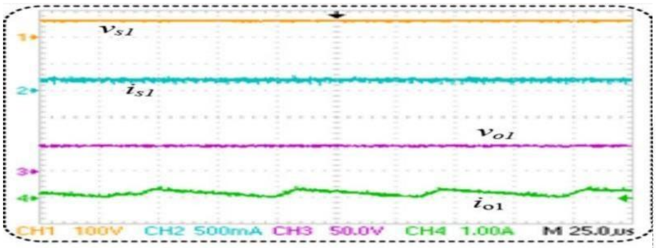
The figure shows the inductors charge from the input source independently for different duty ratios. Fig. 4b shows the output waveforms of the converter during B mode.

The waveform clearly evidences that the required output voltages are obtained across the output terminals. The capability of the converter to deliver power simultaneously from both the input sources in PVB mode is verified experimentally and the output waveforms are shown in Fig.4c

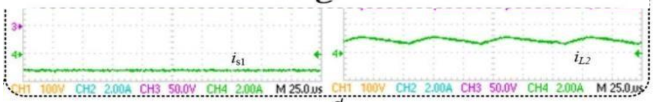


c

During this operation, the source currents are discontinuous and may cause current stress on the sources. This current can be made continuous by connecting a small LC filter across



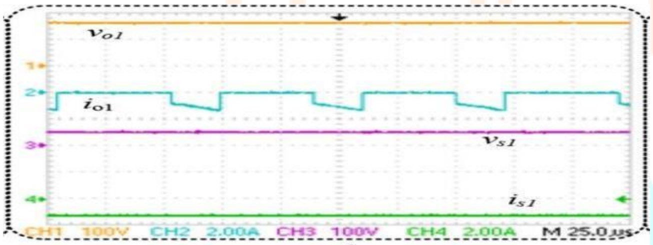

e




d

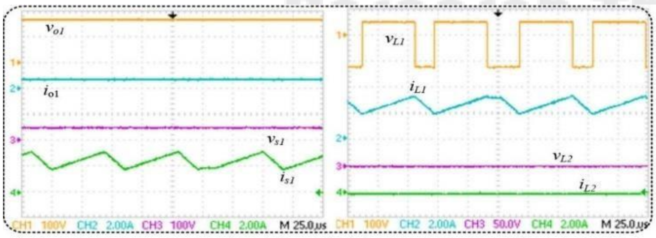
the input source. Hence, the impact of current stress on sources such as the battery, ultra-capacitor etc. can be eliminated.The RB mode of the converter is verified by connecting 110 V isolated DC supply across the load side and a resistor in the source1 side. The observed waveform using the DSO is shown in Fig. 4d. The performance of the converter In V2V mode is verified. The converter is operated in boost mode when power transfer from EV2 battery to EV1 battery. The voltages of Vs1of 55 V and Vo1 of 48 V are considered in the testing. The output waveforms are shown in Fig. 4e.

The proposed converter has the capability to operate in bidirectional mode during the interaction between the EV battery and the grid. The G2B mode of operation is verified by transferring power from the load 1 side to source 1 side. The grid side voltage of 155 V is considered in the experiment. Since, 110 V 50 Hz single-phase AC system requires the dc-link voltage of 155 V. The observed waveforms are shown in Fig. 4f



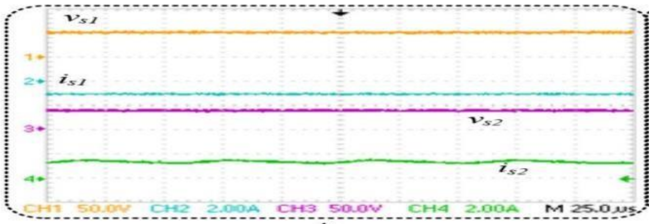

f

Fig. 4g shows the output waveforms during B2G mode of operation.



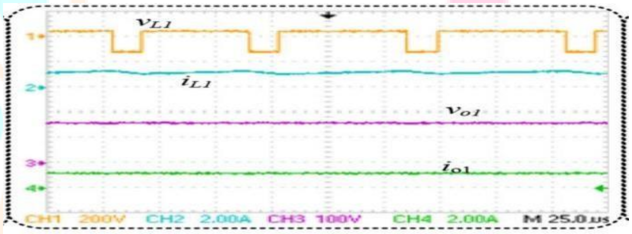

g

The PV2B mode is one of the special types of operation which can be performed in the D2M2 converter. By keeping the duty of So12 as 25%, the battery charging voltage of 48 V is obtained from the source Vs2 as shown in Fig. 4h.



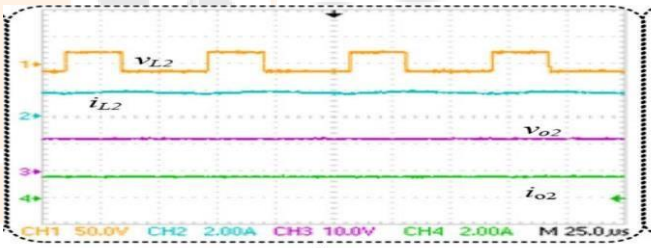

h

The performance of the converter during the PV2G mode is verified by considering the voltage of 155 V DC across the output1.The 155 V DC is considered to pump the power generated by solar PV into the 110 V, 50 Hz single-phase AC grid. The observed waveforms using DSO for the PV2G mode is shown in Fig. 4i.




i

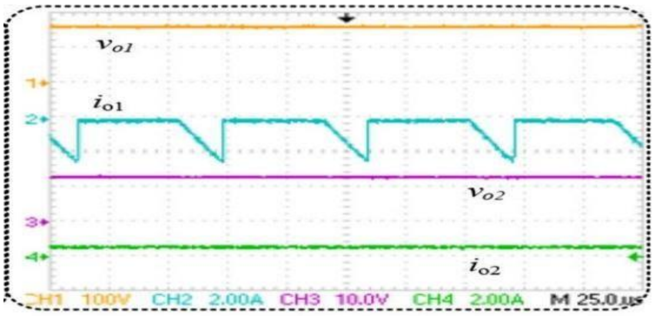
The figure shows that the converter pumps power from solar PV into the dc-link of the utility grid. The voltage across the




j

inductor L1 proves that L1 charges with 36 V and discharges with 155 V.similarly, the output waveforms during the PV2L mode are shown in Fig. 4j.

The converter produces the output voltage of 12 V across the load 2. The operation of the converter for the G2L mode is carried out by considering the voltage of 155 V DC. By controlling the duty ratios of both the switches So2 and So1R,the step-down voltage gain of 155 V/12 V is achieved in the D2M2 converter with a slight modification (inserting a capacitor C3 next to L1) in the structure. This modification alters the structure of the converter to perform two-stage buck operation with large step-down voltage ratio. The output equation during this operation is given in Table 1. The variation in the step-down output voltage with respect to the duty ratio ds02 (ds01R = 20%) is shown in Fig. 6(secondary y-axis). The hardware waveforms are shown in Fig. 4k.




k

Witness that the converter produces 12 V output across load 2 from thee grid voltage of 155 V. The experimental waveforms prove that the proposed D2M2 converter can be operated in all ten modes successfully.

| Conditions | | | | | | Load | | Mode |
|---|---|---|---|---|---|---|---|---|
| EV | Grid | SPV | Battery | | EV2 | $L_1$ | $L2$ | |
| A | × | √ | # | * | * | √ | √ | PV |
| A | × | × | >60% | discharge | * | √ | √ | B |
| HA | × | √ | >60% | charge | * | √ | √ | PVB |
| HA | × | √ | <40% | idle | * | √ | × | PV |
| HA | × | × | >60% | discharge | * | √ | × | B |
| RB | × | # | <100% | charge | * | * | × | RB |
| P | # | √ | <100% | charge | # | × | × | PV2B |
| P | # | √ | 100% | idle | # | × | √ | PVL2 |
| P | √ | √ | 100% | idle | # | * | × | PV2G |
| P | √ | × | <60% | charge | × | * | × | G2B |
| P | √ | × | >60% | discharge | × | * | × | B2G |
| P | × | × | <60% | charge | √ | * | × | V2V |
| P | × | × | >60% | discharge | √ | * | × | V2V |
| P | √ | × | 100% | idle | # | * | √ | G2L |

$L_1$ – EV motor load, $L_2$ – auxiliary power load.

# – Do not care situation, √ – Yes, × – No, * – not applicable.

Table 2: Strategy for mode selection of D2M2 converter

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