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Department of Electrical and Electronics Engineering

Conference Proceedings

of

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on

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Recent Advances in Power electronics and Industrial Drives

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Dear Reader,

RAPID '21 is an annual National Conference organised by Department of Electrical and Electronics Engineering of NSS College of Engineering, Palakkad. RAPID ‘21 aims at bringing academicians, professional engineers, research organisations and research scholars on a common platform to share new ideas, experiences and knowledge in emerging areas of power electronics and industrial drives. The conference will ignite the minds of the participants and delegates for undertaking collaborative research for updating technical know-how to stay in tune with the recent advances. The technical programme consists of peer-review paper presentations, key note lectures, presentation by industry professionals and panel discussion.

We would like to thank all participants who will present their academic works in RAPID '21 and especially to our distinguished guests and keynote speakers for their collaboration and contribution for the success of the conference. We also would like to thank Dr. Leesha Paul, Professor (Retd), NSS College of Engineering, Palakkad for the guidance and support to RAPID '21.

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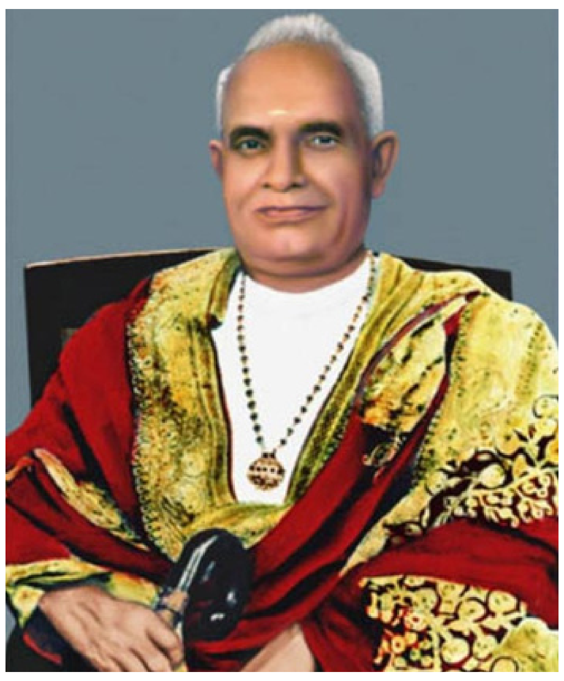

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Non-isolated DC-DC Buck Boost Converter with Renewable Energy Source and Energy Storage

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Abstract: The solar panel power generation system is most attractive to near future generation due to less pollution, environmental friendly, reduction of carbon dioxide emission. To avoid the problem of their intermittency via combining of the panel power with their storage throughMulti-port converters. Among this a three-port converter is used to integrate the solar panel and the energy storage.The main feature of the converter is to handle the diversified energy sources of different voltage and current characteristics with high output voltage. In addition to this it can provide buck and boost output simultaneously. Roof top panel and battery are the two inputs to the converter. The proposed converter charges the battery and thereby eliminate the separate battery management system.

Keywords: Three-port DC-DC converter, battery storage system, solar panel, Continuous conduction mode.

I. INTRODUCTION

Nowadays, the fossil fuels like coal, oil, natural gas are to become vanished due to the enormous depletion. At present the electric vehicle or hybrid electric vehicle is more trending in daily life. These vehicular applications require renewable energy sources as their power generation system thereby reduce the pollution and make environment friendly approach.Power electronics interfaces made a significant role to integrate the solar panel and energy storage system in EV applications. A dc-dc converter with high output gain is feasible to manage power between hybrid sources and the traction system. Ali Ajami et al introduced a dc-dc buck boost converter based on Cuk topology utilizes additional inductors for providing either bucked or boosted output. To operate with a wide range of voltage conversion, the buck-boost converter requires two or more switches than the conventional buck boost dc-dc converter.Non-isolated three port buck boost dc-dc converter needs an extra inductor for an added input which increases the size and electromagnetic interference in the system. A single input multi output dc- dc buck boost converter has the capacity to impart one step-up and numerous step-down outputs. Although a single inductor multiple -output dc-dc converter can provide boost, buck and inverted output simultaneously, it is a unidirectional converter. The multi-input multi-output dc-dc converter topology utilizes the magnetic coupling which enlarge the overall system size. Three port buck-boost bidirectional converter has been inspected for vehicular applications. However, these converters operate in single input dual output and dual input single output modes, they require more switches for operation. To manage a systematic power association between electric vehicle and energy sources, a high- profile power electronic interface is needed. This paper proposed, a scalable three-port dc-dc buck-boost converter for integrating diversified energy sources. The suggested converter can be worked either as dual input single output or single input dual output converter. Consequently, it is accomplished in transferring the power to the load from different sources either individually or simultaneously. Hence, the reliability of the converter system is enhanced.

II. CONVERTER TOPOLOGY

Fig. 1 shows that the block diagram of three-port dc-dc buck-boost converter system with their input and output power flow. The power across the load can be converted into variable power to drive the motor in EV/HEV applications. Fig. 2 depicts the proposed converter structure with solar panel and battery storage system. The converter reveals the feature of providing double the power from the battery source during discharging time. The proposed converter has reduced components count to ensure the compact structure of the converter system to operate in EV. It includes two switches (S1, S2), two inductors (L1 & L2), two capacitors (C1 & C2) and three diodes (D1, D2 & D3). Step-up and step-down operations are performed by varying the duty cycles of switches S1 & S2. The suggested converter operates in four modes in continuous conduction mode.

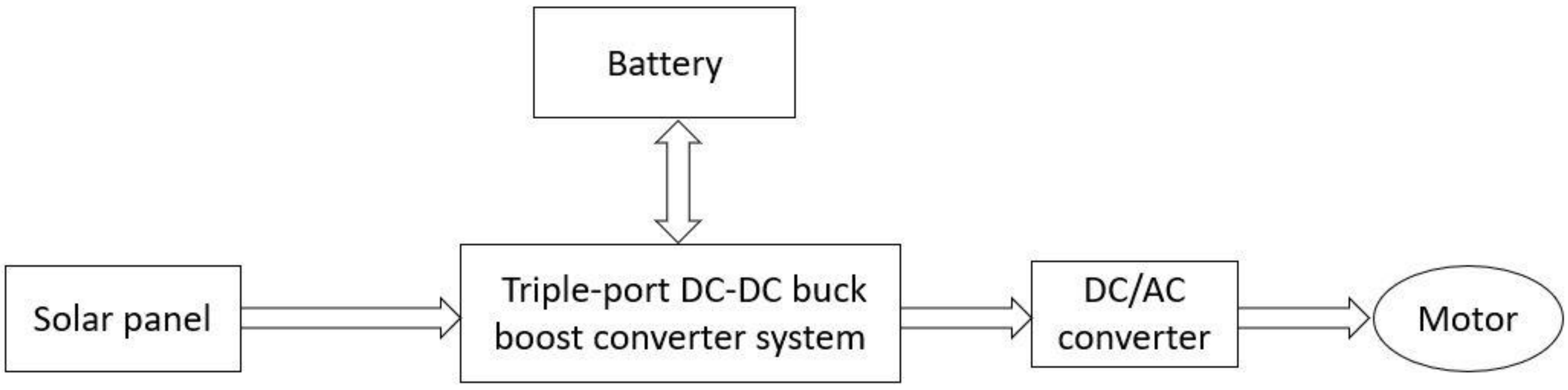

Fig.1Block diagram of Triple-port DC-DC buck boost converter with solar panel and battery

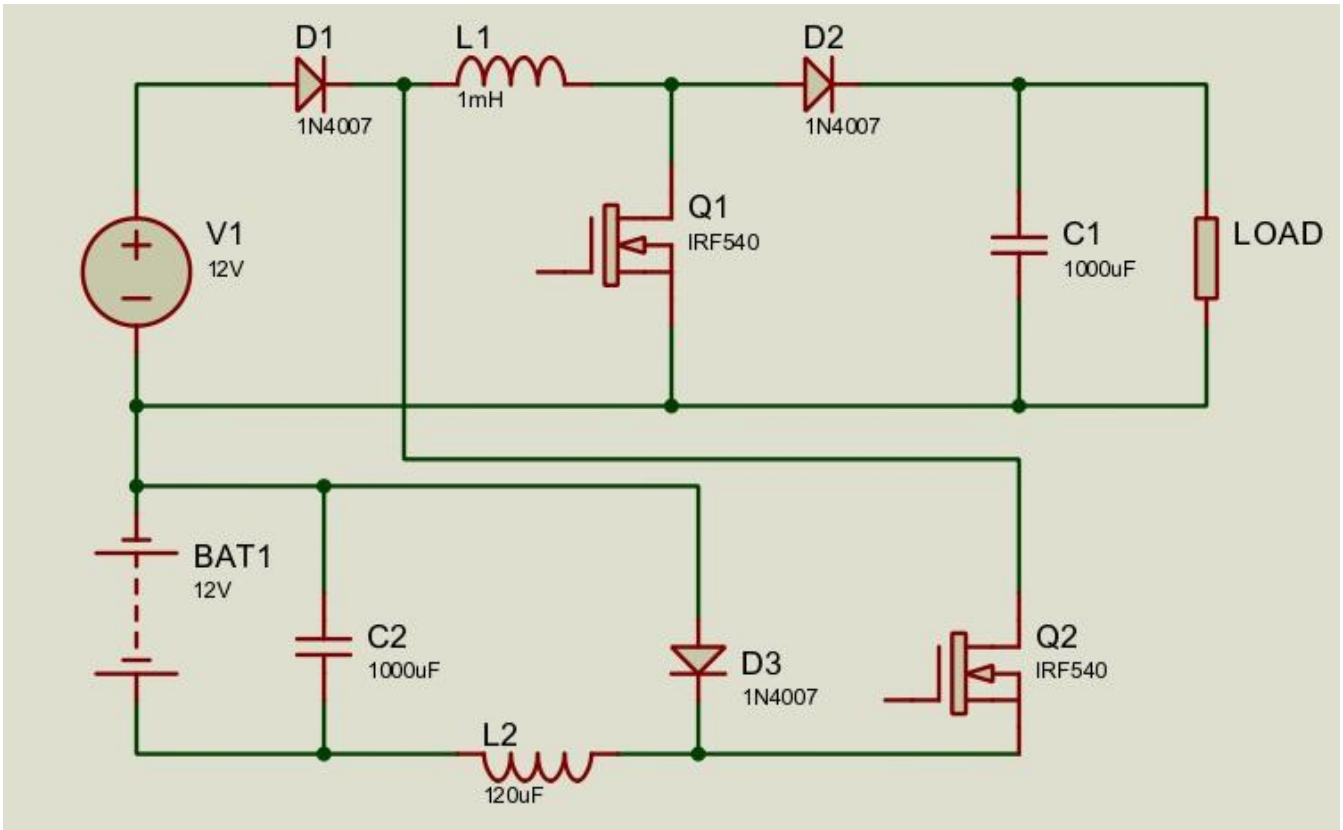

Fig. 2 Proposed structure of three-port buck boost converter system

III.STEADY-STATE PERFORMANCE AND SIMULATION RESULTS

In the suggested topology, the solar panel and the battery storage system are the two input sources to the converter. If solar panel is fails to supply the power to the load, then it is managed by the battery system. Hence, the reliability of the overall system is enhanced. The working of the converter can be classified intofour modes of operation under some conditions.

Mode1: Photovoltaic panel supplies power to load ($P_{pv} > P_0$)

In this mode, the converter can operate two states with varying the duty cycles of switches S1 & S2.

State 1: During the time interval ($t_1 < t$), the switches S1&S2 are turned ON, the diode D1 is permanently in the ON condition and diodes D2 & D3 are OFF. Thus, the inductors L1 and L2 are get energized and supply the power to load which in turn charges the battery simultaneously.

State 2: During the next interval of time ($t_1 < t < t_2$), the switches are turned OFF, the diodes D1, D2 & D3 are turned ON. Hence, inductor L1 get discharged to power the load while charges the battery via the inductor L2.

Consequently, in this mode, the converter behaves like SIDO converter system and provide bucked output across the battery and boosted output across the load simultaneously.

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Mode 2: Solar panel and battery provide the power to load ($P_{pv} < P_o$)

In this mode, the converter operates with switch S1 is permanently in the ON condition. The converter operates like DISO converter.

State1: In the interval ($t_1 < t$), the switches S1, S2 are turned ON, diode D1 is forward biased and D2 and D3 are reverse biased. PV source and inductor L2 is required to charges the inductor L1 and power to load via discharging the battery.

State 2: During this interval ($t_1 < t < t_2$), the switch S1 and diode D3 are OFF; switch S2, diodes D1 and D2 are turned ON. Hence, inductors L1, L2 and battery gets discharged to delivers the power to the load.

Mode 3: Only Solar panel supplies power to the load ($P_b = 0$ &$P_{pv} > P_o$)

In this mode, the switch S2 is permanently in the OFF condition and converter behaves like SISO converter.

State 1: During this interval ($t_1 < t$), the switch S1 and diode D1 are ON and S2, D2 and D3 are turned OFF. The inductor L1 get energized by panel. The output is provided by discharging the capacitor C1.

State 2**:** During this interval ($t_1 < t < t_2$), the switches S1, S2, and diode D3 are OFF except diodes D1 & D2. The inductor L1 discharges to supply the power to the load.

Mode 4: Only battery supplies power to the load ($P_{pv} = 0$ &$P_b > P_o$)

In this mode, the converter operates like SISO with diode D1& D3are permanently in the OFF condition.

State 1**:** During this interval ($t_1 < t$), both switches S1, S2, are turned ON and diodes D1,D2 and D3 are turned OFF. Inductors L1 and L2 charges via battery discharging. The load is provided by discharging the capacitor C1.

State 2**:** During this interval ($t_1 < t < t_2$), the switch S2 and diode D2 are turned ON and the switch S1, diodes D1 and D3 are turned OFF.

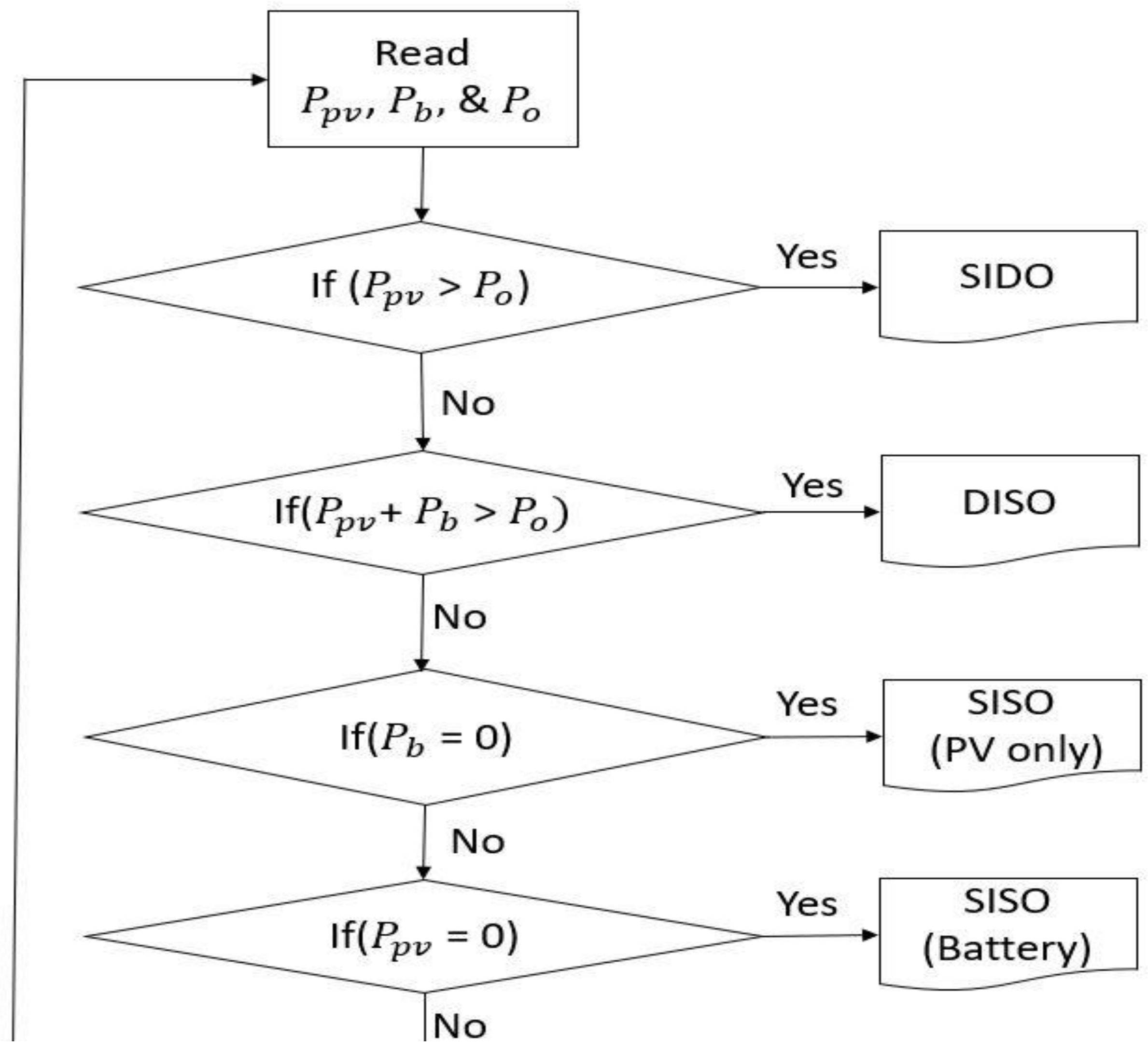

Fig. 3 Operational flow chart of three-port DC-DC buck boost converter

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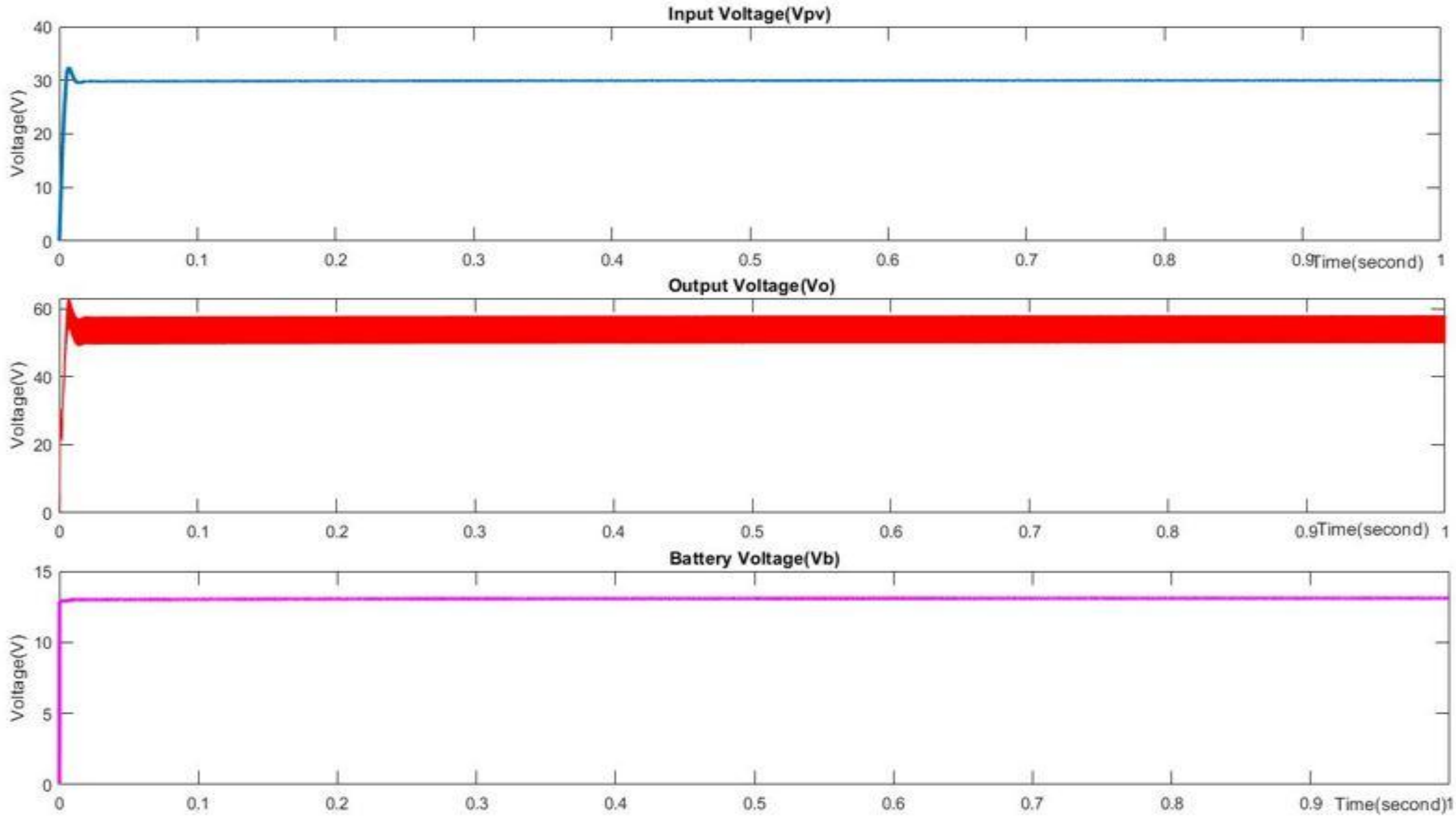

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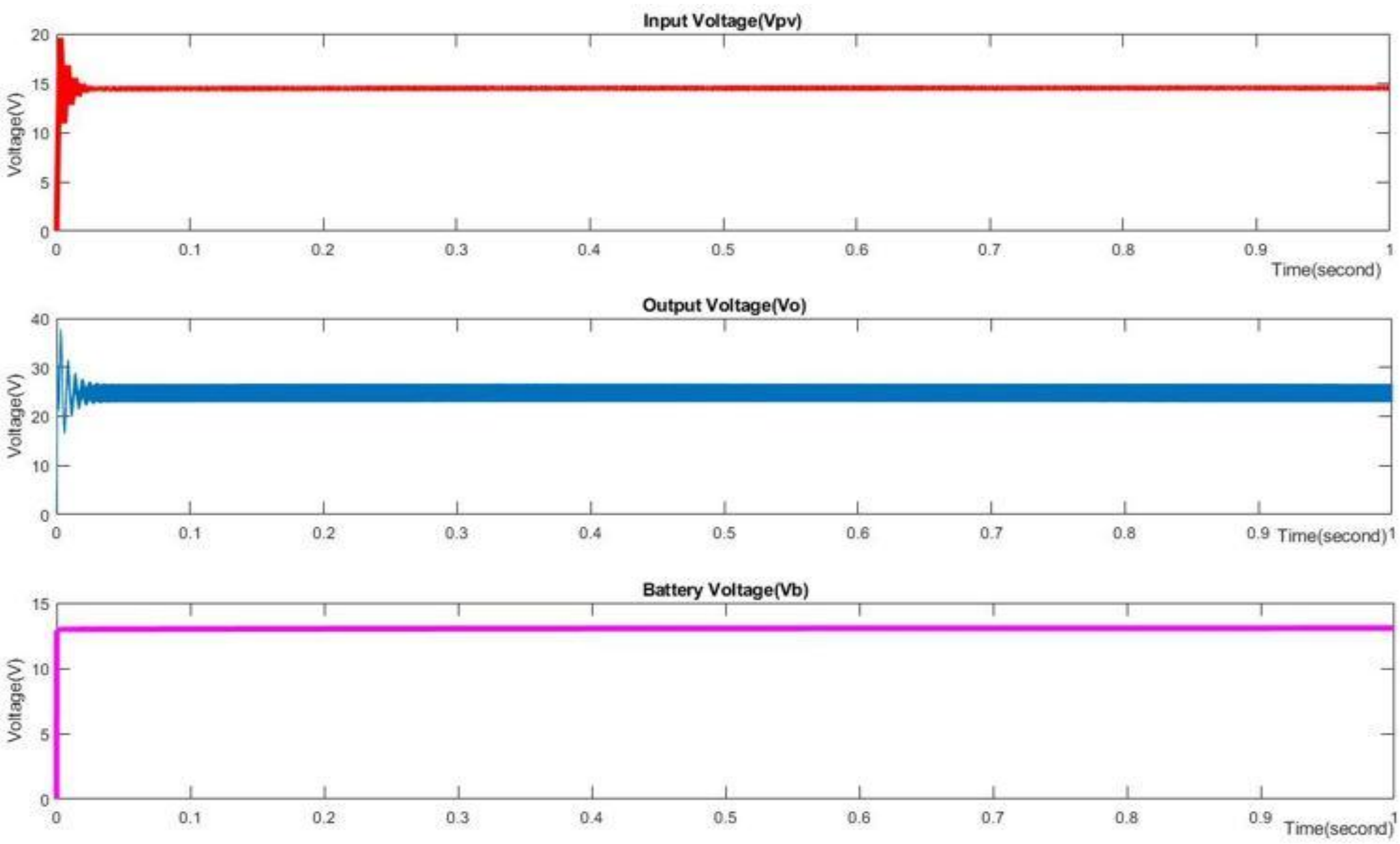

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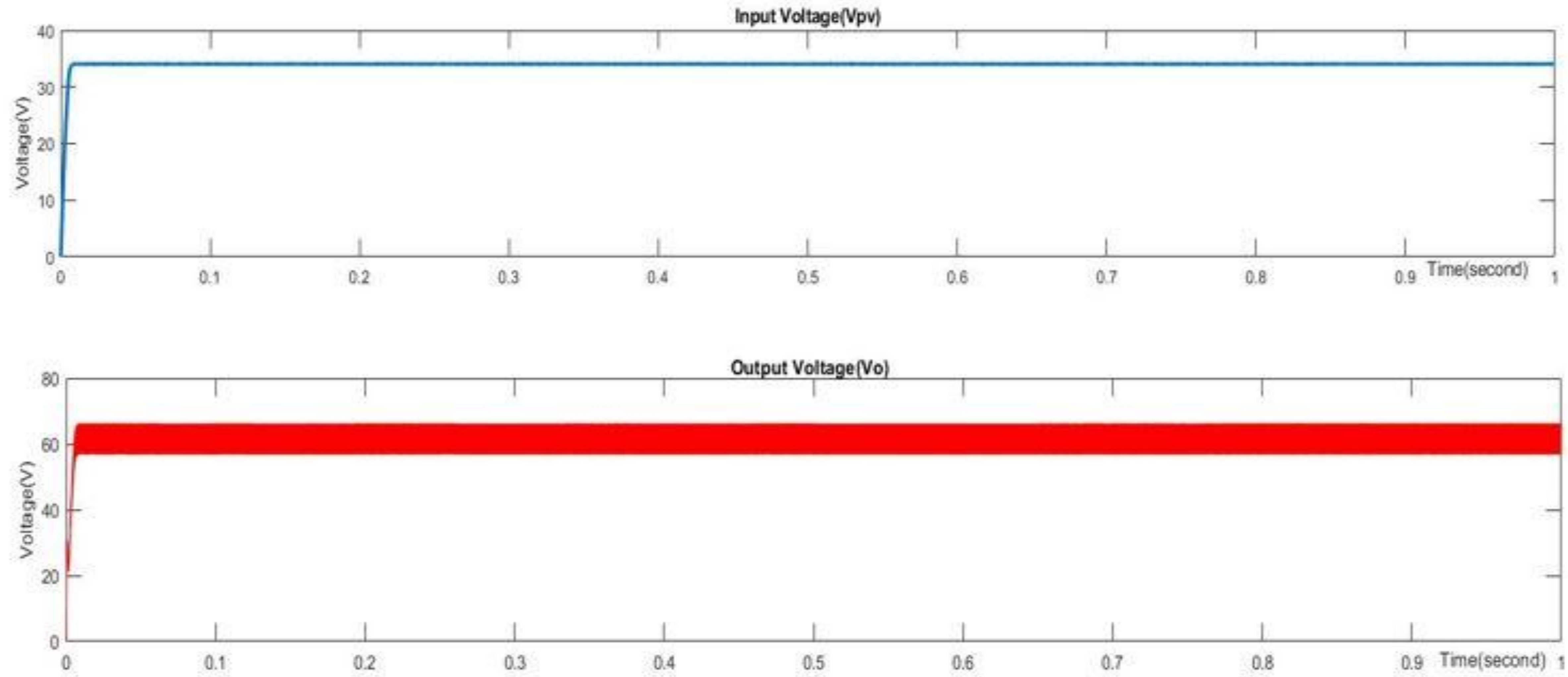

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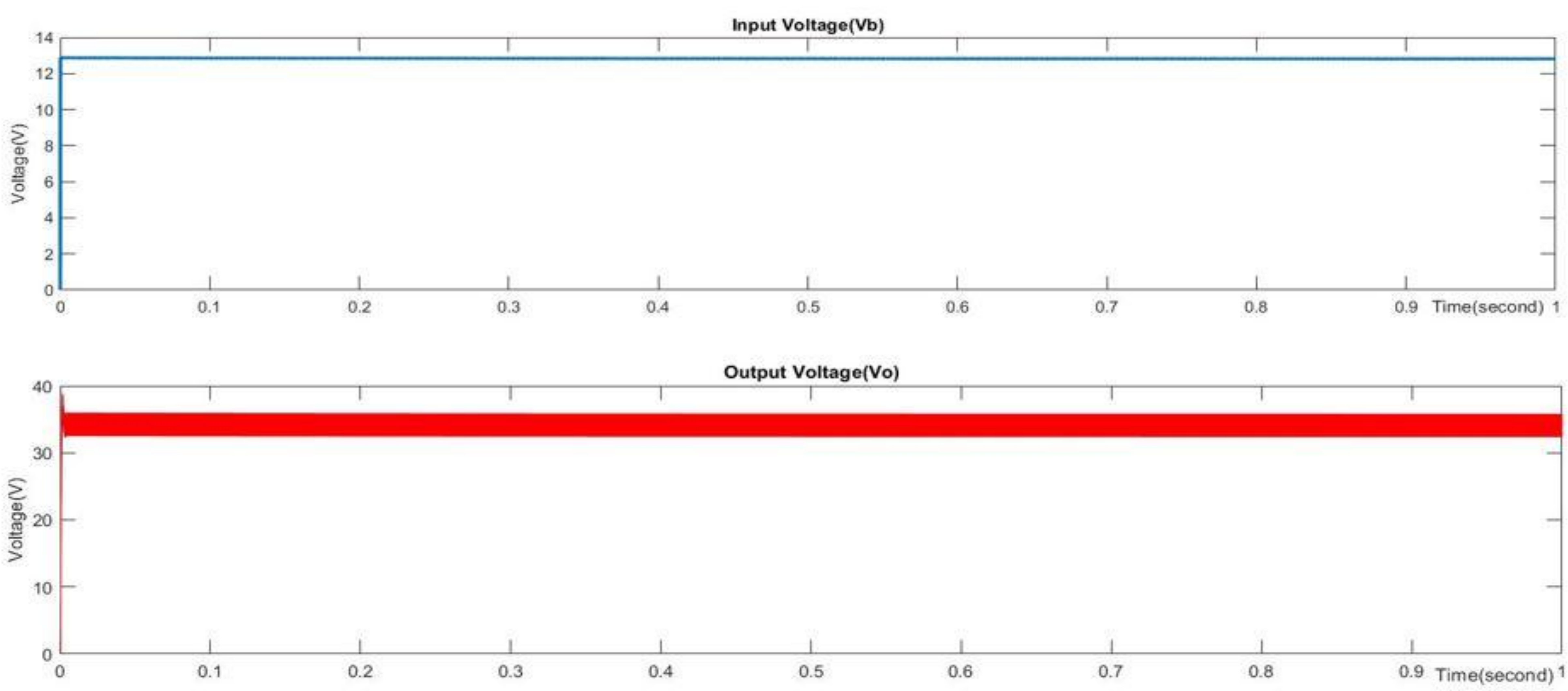

(d)

Fig. 4 Simulation results for (a) SIDO converter in mode 1, (b) DISO converter in mode 2, (c) SISO converter in mode 3, and (d) SISO converter in mode 4.

TABLE I

SPECIFICATION OF THE SIMULATION PARAMETERS

Parameters	Values
Inductors L1 & L2	1.3mH, 110µH
Capacitors C1 & C2	1500µF, 63V
Switching frequency	10kHz
Input sources	24V Panel & 12V, 7Ah battery
Output Voltage	60V

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IV. CONCLUSION

In this paper, a modular three-port dc-dc buck boost converter has been inspected. The suggested converter topology has a compact structure with lesser component count. It has the capacity to supply power to the load even in the absence of any one of the input sources. It can handle the diversified energy sources with equal or unequal magnitudes to analyze the converter operation.

It distinct the operation of step-up and step-down simultaneously without the use of any additional setup. Renewable sources of power generation with energy storage makes the converter performance more reliable and provide better performance compared with the conventional converter system. To utilize the system with EV applications, it can be extended the number of input and output ports of the converter system.

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Solid Sate Transformer: Advanced Topology and Implementation

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Abstract: The Solid-State Transformers (SSTs) are one of the most emerging technologies in power electronics. Comparing with the traditional transformer, SSTs are more advantageous in case of weight, size and volume. Conventional transformers are bulky in size, saturation of core due to non-linear loads, cause environmental pollution, huge losses and poor voltage regulation. To reduce these problems associated with traditional transformers, SSTs can be used. A three stage SST with load sharing capability is discussed in this paper along with the different classification of SSTs. A SIMULINK model of SST for load sharing is developed to demonstrate the desired characteristics and functionalities of SST.

Keywords: Solid-State Transformer, Converters, Conversion stages and HF transformers.

I. INTRODUCTION

Transformers are the essential part of generation and distribution systems. They are highly reliable, economic and efficient. Even though the conventional transformers have their own liabilities or risk factors like voltage drop, protection from unbalance and over load, harmonics, environmental issues etc. The size of conventional transformers is enormous, they are very heavy in size, weight and volume. The main reason for that is they are operated in line frequency (50Hz). In some of the transformers, transformer oil is used as coolant. Transformer oil is highly flammable and is very much harmful to the environment and also for the human beings. Regular inspection is a need for this kind of transformers. To reduce the problem regarding to the conventional transformers, these transformers can be replaced by SSTs. SSTs are the power electronic transformers which uses High-Frequency (HT) transformers. Mass increases with decreasing frequency because of the inverse proportion of frequency and mass. The use of HF transformers reduces the mass of the transformer tremendously and also reduces the problems regarding with the core saturation, environmental pollution etc.

A toroidal core transformer is the first transformer invented by O.T Bathly and then many experiments are conducted till at the development of a transformer which is commercially practical one [1]. The transformers using power electronic devices is discussed by MC Murrey [2], a transformer with thyristor switching. So many power electronic transformer concepts are further developed [3-4]. The development of SST is a great invention and it have more advantages and applications [5,6] comparing with traditional transformers. There are many classifications for SST is available, they differ by number of conversion stages, types of converter used etc [7-9].

HF transformers are the main element in SST for the reduction of size comparing to traditional transformers [10]. The risk factors and compensations of SSTs and its analysis and designs of DAB ideations are also done by the researchers [11-17]. The proper and successive way of evolution of power electronic transformer is a great inspire to this area. In this paper, SST having load sharing capability is discussed along with the SST classifications and developed the simulation model of load sharing idea.

This paper focuses on the concept of SST having load sharing and the simulation part. The topologies of SSTs based on the count of conversion stages is provided in Section II. Section III deals with the ideology of SST for load sharing and its simulation results in MATLAB SIMULINK. Ends with the conclusion in Section IV.

II. BASIC TOPOLOGIES OF SOLID-STATE TRANSFORMERS

SST is not actually an exact transformer like conventional one. SSTs are the collection of power electronic converters and HF transformer. Many types of power electronic transformer topologies are there, according to the number of conversion-stages the transformer can be categorised into three topologies [7,8].The topologies are as follows:

- Single-Stage Topology
- Two-Stage Topology and
- Three-Stage Topology

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A. Single-Stage Topology

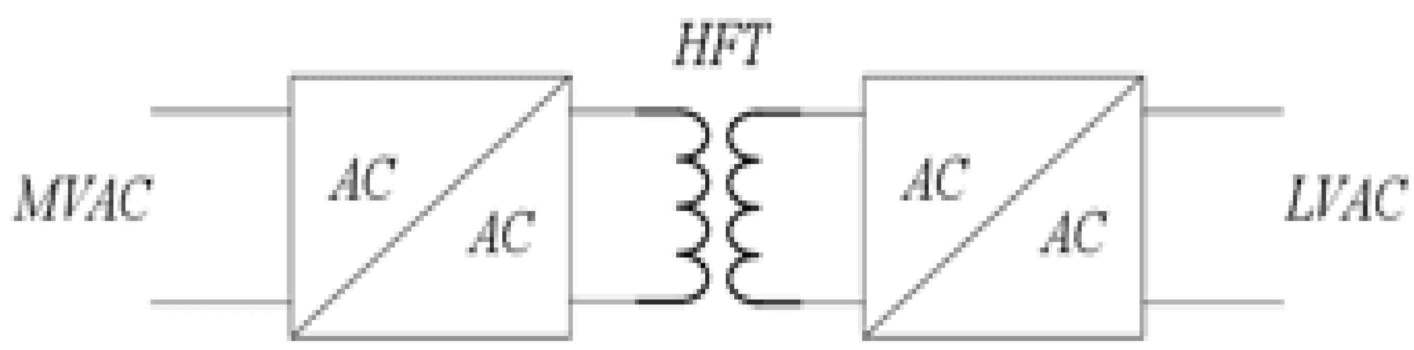

Fig.1 Conversion stage of single-stage SST

The single-stage topology of SST is also known as type A topology. Which is one of the oldest and least adopted configurations. The conversion stages and circuit diagram of single-stage SST is shown in figure 1 and 2 respectively. There is only one conversion stage hence the name single- stage SST, ie., conversion of High-Voltage AC (HVAC) to Low-Voltage DC (LVDC) with an isolation of step-down HF transformer. This is having most simple construction, light weight and cheapest among the different SST topologies. But the lack of DC-link is the major problem due to that the disturbances on one side may affect the other side.

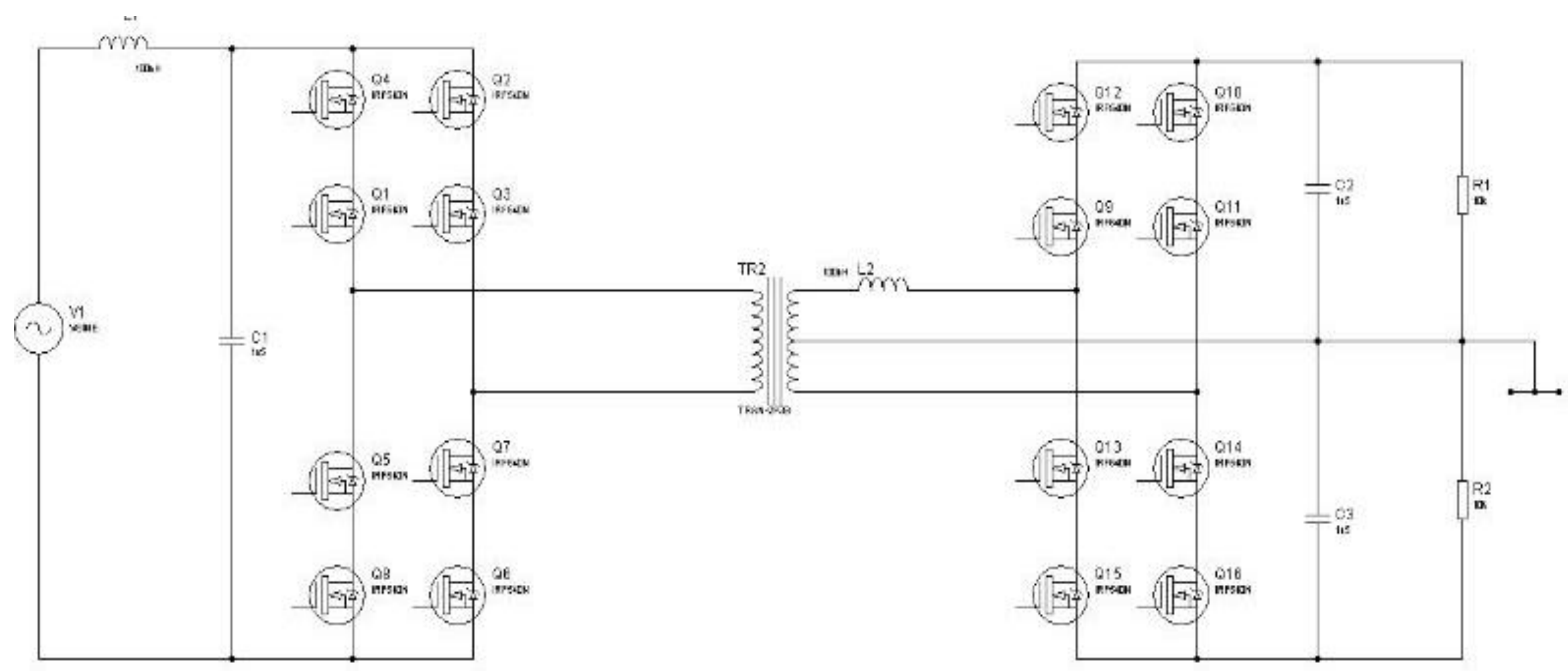

Fig.2 Circuit diagram of single-stage SST

B. Two-Stage Topology

The two-stage topology of SST is having two-stages, AC to DC and DC to AC, hence the name two-stage SST. Two-stage SST can also be classified into two types according to the position of isolation, they are type B and type C.

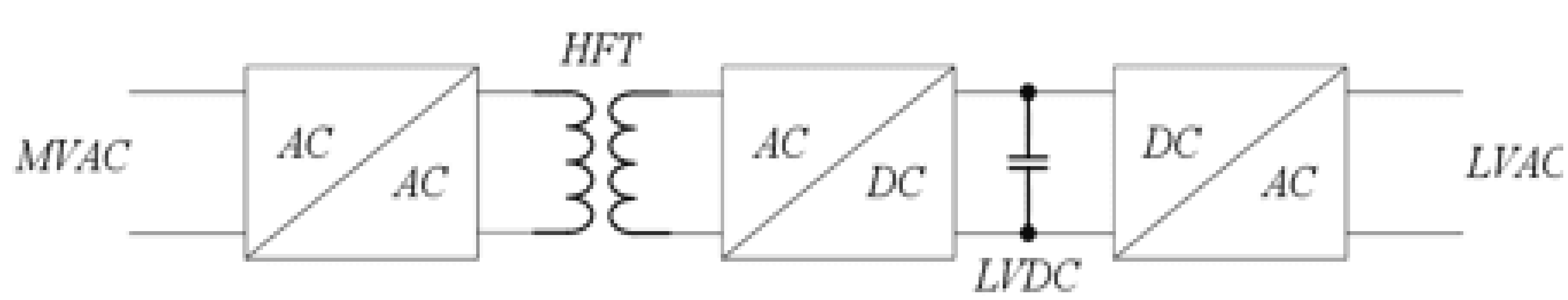

Fig.3 Block diagram of two-stage SST (Type B)

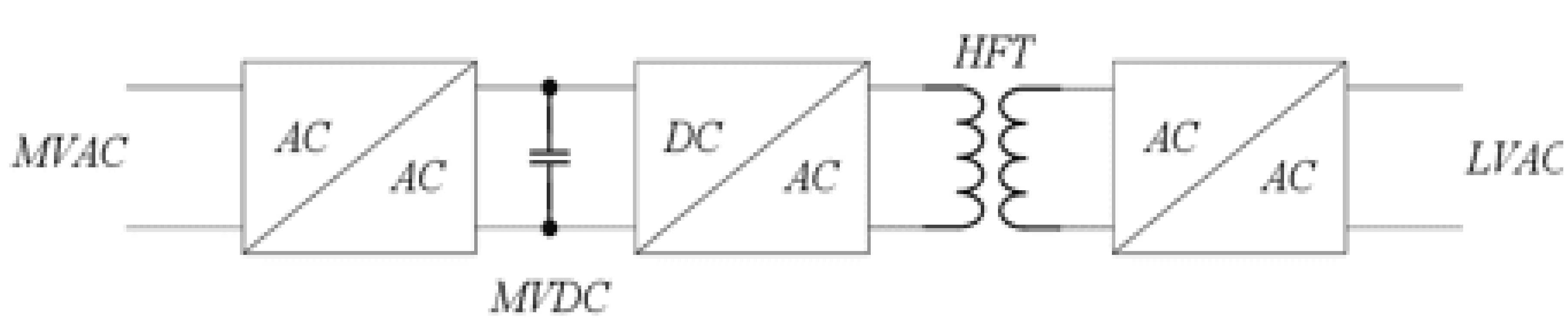

Fig.4 Block diagram of two-stage SST (Type C)

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The block diagrams of type A and type B are shown in the figures 3 and 4 respectively. In type B the isolation is provided in AC to DC conversion stage and in type C it is provided in DC to AC stage. So that the type C configuration do not have any LVDC link. The circuit diagram of two-stage SST is shown in figure 5.

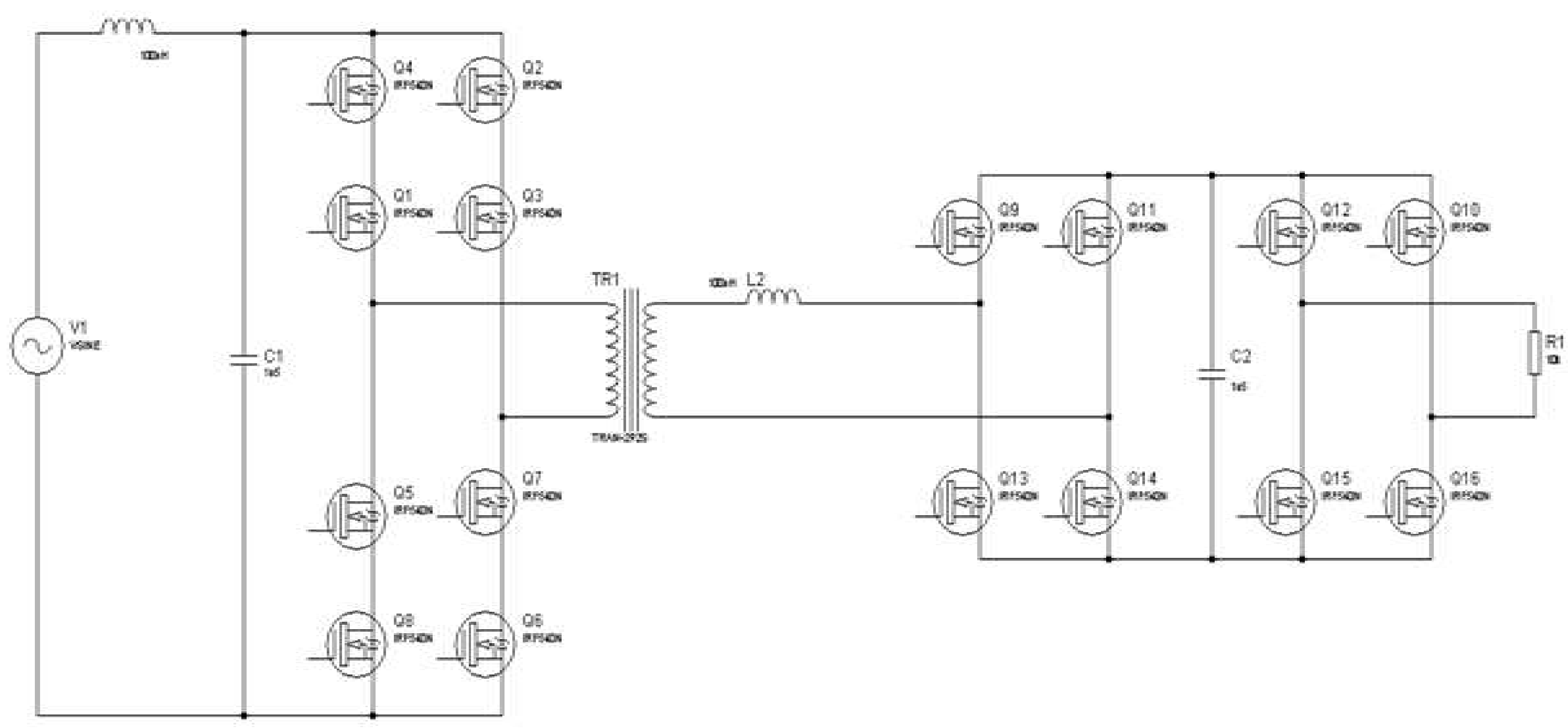

Fig.5 Circuit diagram of two-stage SST

C. Three-Stage Topology

The three-stage topology is having three conversion stages AC to DC, DC to DC and DC to AC, it is the most efficient and widely used topology. The block and circuit diagrams are shown in the figures 6 and 7 respectively.The high frequency isolation is

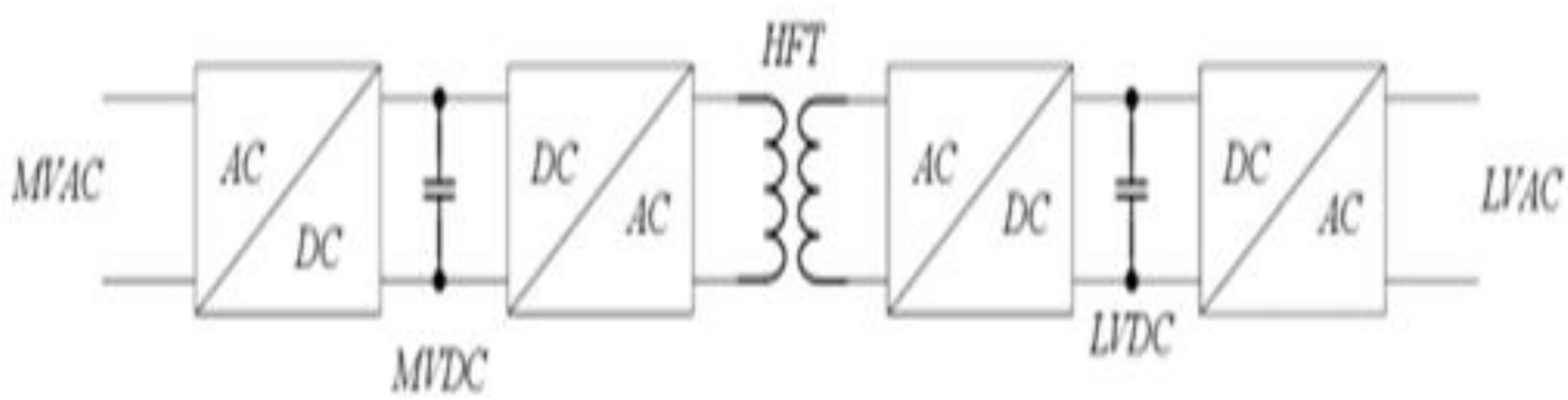

Fig.6 Block diagram of three-stage SST

provided in DC to DC conversion stage. In three-stage topology both HVDC and LVDC links are available, VAR and voltage sag compensations, renewable energy resources and energy storage integration can be achieved also any types of converter topologies can be used in both sides.

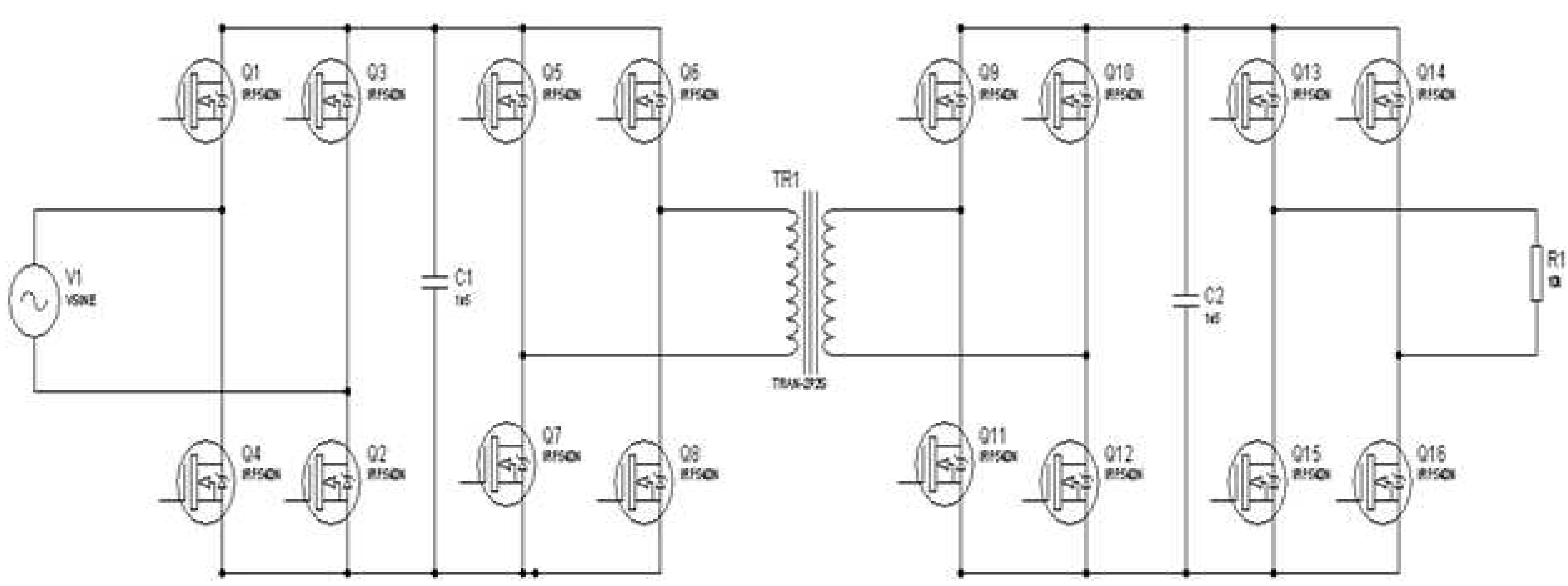

Fig.7 Circuit diagram of three-stage SST

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III. SOLID STATE TRANSFORMER FOR LOAD SHARING

The section deals with the concept of SST for load sharing. The secondary winding of HF transformer [18] in the three-stage SST is made as dual winding. The circuit diagram of three-stage SST with dual winding secondary is shown in figure 8. This load sharing concept of SST add additional benefits to the system, such as different load voltages according to the number of turns in secondary, increase efficiency, better controlling and power quality, reduction of losses etc.

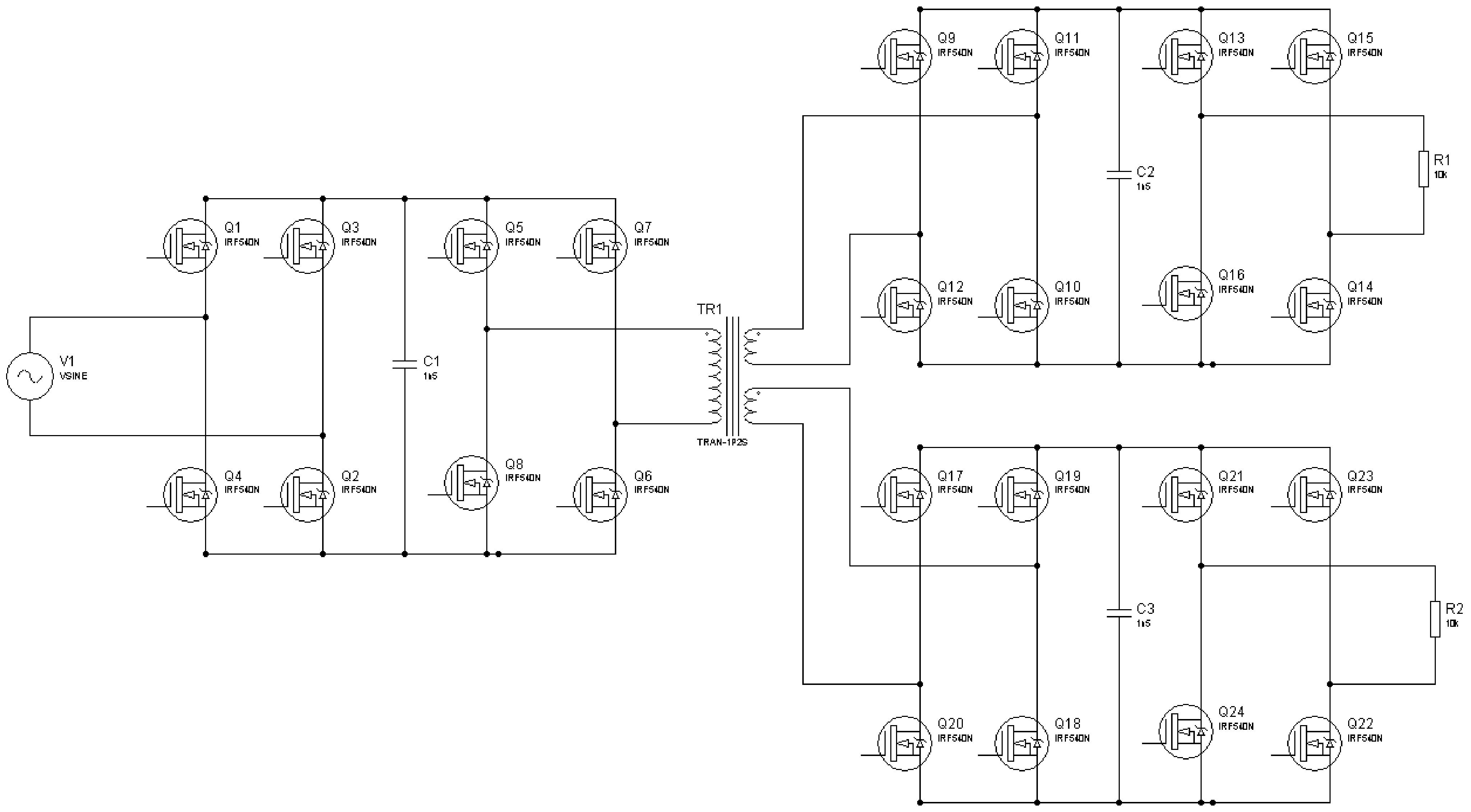

Fig.8 Circuit diagram of three-stage SST with load sharing

This is also a three-stage topology, so it is having three stages of conversions AC to DC, DC to DC and DC to AC. The stages can also be classified into input stage, isolation stage and output stage. The simulation parameters are shown in the table:

TABLE I
SIMULATION PARAMETERS

SL. NO	PARAMETERS	SPECIFICATIONS
1	Power	250 W
2	$V_{IN(RMS)}$	230 V
3	$V_{O(RMS)}$	110 V
4	$I_{IN(RMS)}$	1.486 A
5	$I_{O(RMS)}$	2.27 A
6	Frequency (f_s)	50 kHz
7	$V_{P(RMS)}$	230 V
8	$V_{S(RMS)}$	110 V
9	Capacitor (C_1)	1000 μF
10	Capacitor (C_2)	100 μF
11	Inductor (L)	30 mH
12	Load (R)	48 Ω

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Initially the input stage conversion is done by a rectifier, can be a controlled or uncontrolled rectifier. Different kinds of converter topologies also can be incorporated with this. Any kind of control can be used for the semiconductor switching devices like MOSFETs or IGBTs. The 230 V and 50 Hz input supply is converted to DC voltage using a rectifier stage. A DC link of 1000 µFis provided to reduce the ripples and harmonics to obtain pure DC voltage as rectified out.
High voltage DC is then converted into low voltage DC with the help of a HF transformer and converter circuitry. Isolation stage consists of an inverter, a HF transformer and a rectifier. Inverter in the primary side of the HF transformer converts the low frequency voltage into high frequency AC voltage it is then fed in to the primary of HF transformer. The secondary side of HF transformer is having a dual winging. The HF transformer can be step-down, step-up or the combination of bothie., the output can have different secondary voltages. The output of transformer is rectified and filtered to get a DC voltage.
DC is then inverted by the help of an inverter in the output stage. The DC is converted again into 50 Hz AC voltage for distribution. Because of the dual winding we can have load sharing, different loads can be run at the same time. The MATLAB SIMULINK model is shown in the figure 9, sine PWM is used for doing the simulation.

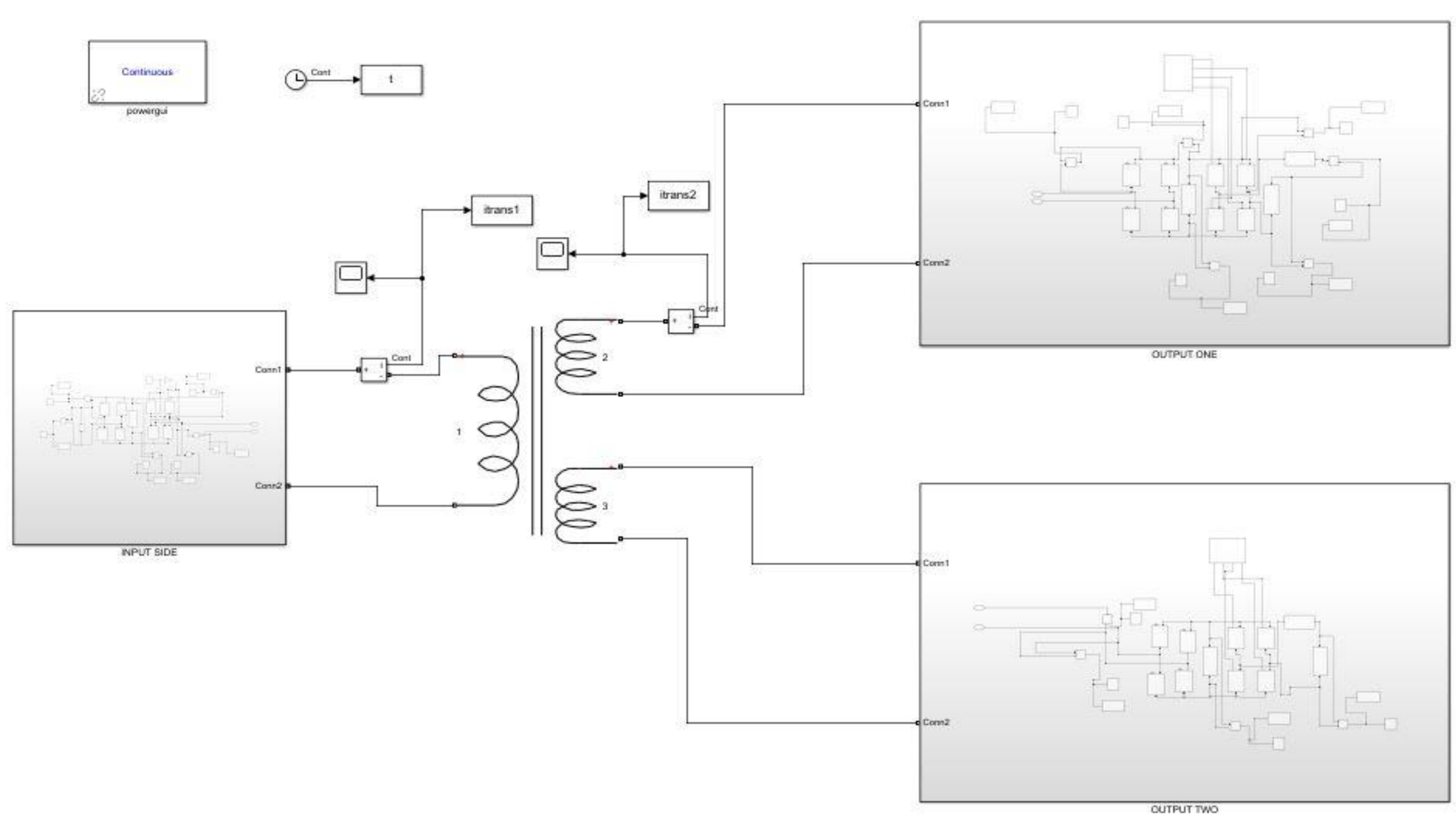

Fig.9 Simulation diagram of three-stage SST with load sharing

The simulation wave forms, input and output are shown in figures 10 and 11 respectively.

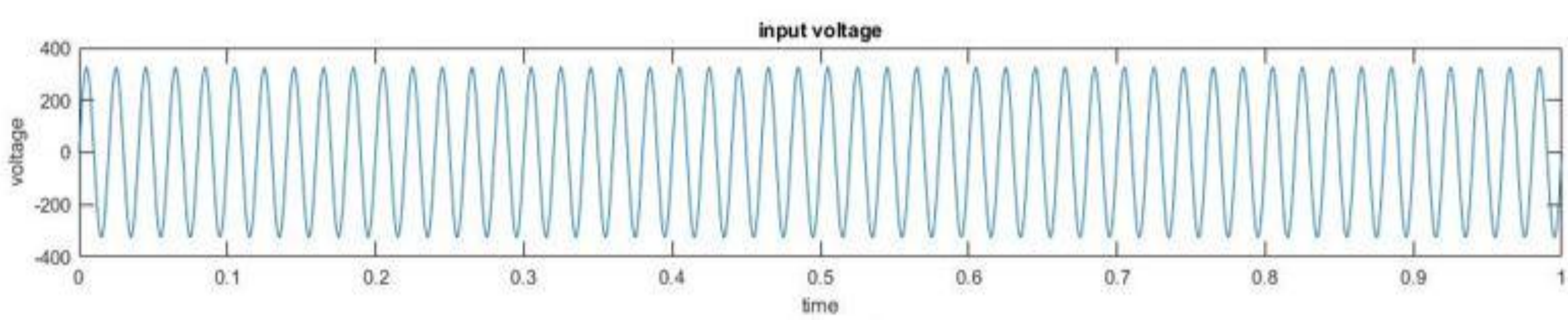

Fig.10 Input voltage

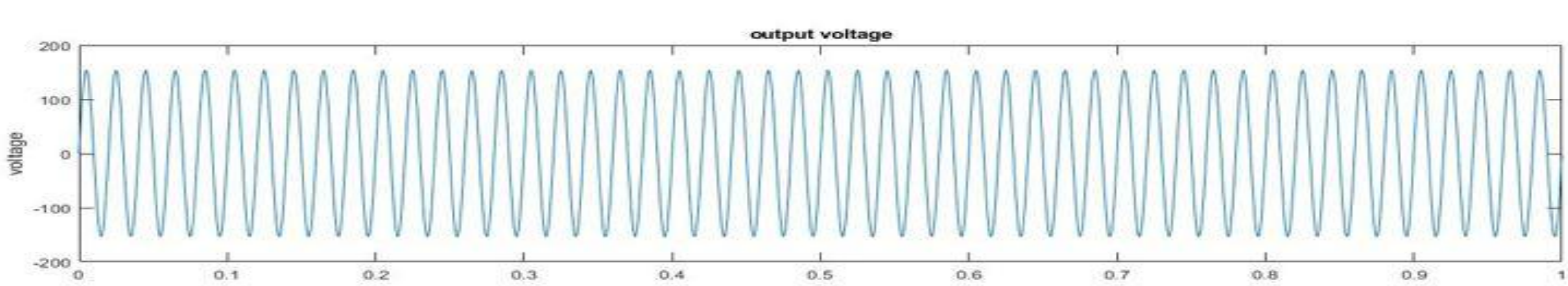

Fig.11 Output voltage

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IV. CONCLUSION

The solid-state transformer classifications, SST for load sharing concept and the simulation using MATLAB SIMULINK model is discussed in this paper. Paper also include the parameters and resulting waveforms of SST for load sharing. The traditional transformers have a vital role in distribution system, even though they are having so many liabilities in their own way. The heavy size of traditional transformers is major issue. That can be overcome by using HF transformers incorporating with power electronic converters, that forms the SST concept.

The concept of SST for load sharing adds much more benefits to the normal three-stage SST. We can have different voltages on the secondary side of the HF transformer, different loads can be driven parallelly. The presence of both HVDC and LVDC links makes them more reliable for different converter topologies on either side of the transformer. It can be concluded that the SST for load sharing have increased efficiency than normal SST configurations.

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Closed Loop Performance of Voltage-Multiplier Interleaved Bidirectional DC-DC Converter

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Abstract: A voltage quadrupler interleaved converter is a bi-directional DC-DC converter which has high voltage conversion ratio. The converter has low voltage stress across the components thus it has high efficiency. Current ripple will be reduced by the interleaved connection at the low voltage side. Current sharing is obtained by two inductors, thus current control scheme is not necessary. In this paper a voltage quadrupler interleaved converter is discussed. Converter is designed to a power of 250W. Finally it will be simulated in Matlab/Simulink. In order to get steady state operation a PI controller is provided as feedback.

Keywords: Bi-directional converter, voltage quadrupler, electric vehicles, non-isolated converter

I. INTRODUCTION

The demand for transportation is increasing day by day. Due to the depletion of fossil fuels, availability of fuel for conventional vehicle has reduced. Hence, the need for electric vehicle came in action. In electric vehicles, it is necessary to integrate an energy storage system along with power conditioning unit. Thus a power electronic converter is an important part of electric vehicle.

Some of the conventional buck-boost converters are mentioned in [1]. In those converters, single switch is used to step up or step down the voltage. Thus there will be high voltage and current stress on the components compared to the conventional buck or conventional boost converters. To overcome these drawbacks buck-boost converter with two independently controlled switch has introduced. [2] Deals with a two switch buck-boost converter to achieve low component stress. It has low energy storage requirement and therefore size will be reduced and efficiency will be increased.

In electric vehicles, power flows from the battery to motor during motoring state. While braking, the power may flow in opposite direction due to regeneration. Thus, there came the need of converters which can have power flow in both directions. So, bi-directional converters were introduced. [3] compared two bi-directional DC- DC converters. First topology has two switches and second topology has four switches. In step up mode, the rms value of current through inductor, power switches and converters are high in first compared to second. But the number of components in latter is high. [4] compared several non-isolated bi-directional DC-DC converter configuration for their use in hybrid vehicles. From that half bridge converter is more preferred compared to other converters as it have only one inductor. [5] and [6] Discussed about multilevel converter which is a most commonly used type of bi-directional converters which has low voltage stress. Then came the introduction of switched capacitor based power converters[7]. These converters have high voltage gain and efficiency. But having high component count is its disadvantage. Bi-directional converters with switched capacitors and z-source mentioned in [8]-[9] are good examples of BDC with high conversion ratio. But still these converters suffer from high voltage stress. The interleaved voltage doubler with automatic current sharing characteristics has been discussed in [10]-[11]. These converters have low voltage stress across the switch and has high voltage conversion ratio. But the stress across the diode is still high.

A voltage quadrupler interleaved bi-directional DC-DC converter is introduced in [12]. This has high voltage conversion ratio and reduced stress across switch. This converter acts as boost converter in motoring mode and buck converter in regenerating mode. In this paper voltage quadrupler interleaved bi-directional converter was designed for a power of 250 W and simulated using Simulink/matlab. Further the simulation of the converter with a feedback controller was also simulated in Simulink/matlab.

In next section operating principle of the converter is discussed. Then the converter is designed for a power of 250W. Further it is analysed in Matlab software.

II. OPERATING PRINCIPLE

Voltage quadrupler interleaved bi-directional DC-DC converter consist of six power switches(S_1, S_2, S_3, S_4, S_5 and S_6), two inductors (L_1 and L_2) and five capacitors(C_L, C_{m1}, C_{m2}, C_{H1} and C_{H2}). The circuit diagram is shown in Figure 1.

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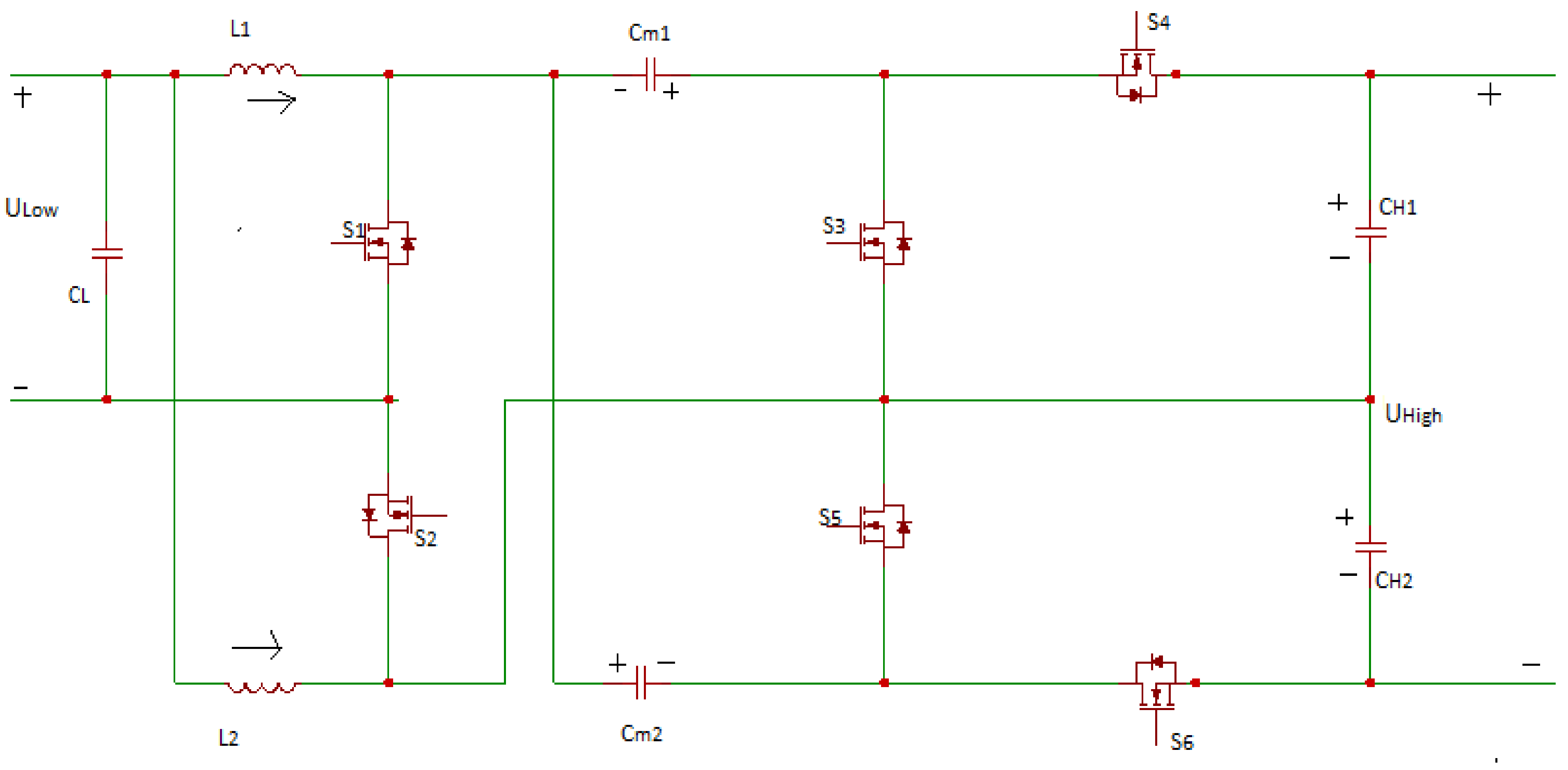

Fig 1: Circuit diagram

A. **Forward mode**

In this mode of operation, energy flows from low voltage side to high voltage side. The switches S_1 and S_2 will be switched with a duty ratio DF and there is a phase difference of 180° between the pulse of S_1 and S_2. Switch S_3 and S_6 has the same pulse and S_4 and S_5 has the same pulse. Gate signal of switch S_3 and S_6 are complimentary to that of S1 and gate signal of switch S_4 and S_5 are complimentary to that of S_2. This mode of operation takes place in four intervals.

Interval 1 ($t_0 - t_1$)- Switch S_2 is ON before this interval. Switch S_1 will be turned on at t_0. Inductor L_1 and L_2 will be charged by LVS. Load is supplied by HVS.

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{U_{Low}}{L} \tag{1}$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt} = C_{H2}\frac{dv_{CH2}(t)}{dt} = -\frac{U_{High}}{R_{LF}} \tag{2}$$

$$\frac{dv_{Cm1}(t)}{dt} = \frac{dv_{Cm2}(t)}{dt} = 0 \quad \{3\}$$

Interval 2 (t_1-t_2)- Switch S_1 will be in ON position. Switch S_2 will be switched off. Switches S_3 and S_6 will be turned ON. Load and C_{H2} are supplied by inductor L_2. Capacitor C_{m1} is charged by inductor L_2.

$$\frac{di_{L1}(t)}{dt} = \frac{U_{Low}}{L} \tag{4}$$

$$\frac{di_{L2}(t)}{dt} = \frac{U_{Low} - U_{m1}}{L} \tag{5}$$

$$\frac{dv_{Cm1}(t)}{dt} = \frac{i_{Cm1} - i_{L2}}{C_{m1}} \tag{6}$$

$$\frac{dv_{Cm2}(t)}{dt} = \frac{i_{Cm1} + i_{L2}}{C_{m2}} \tag{7}$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt} = -\frac{U_{High}}{R_{LF}} \tag{8}$$

$$C_{H2}\frac{dv_{CH2}(t)}{dt} = i_{Cm2} - \frac{U_{High}}{R_{LF}} \tag{9}$$

Interval 3(t_2 – t_3)- This interval is same as interval . Switch S_2 will be turned ON. Switches S_3 and S_6 will be turned OFF. Inductor L_1 and L_2 will be charged by LVS. Load is supplied by HVS.

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{U_{Low}}{L} \tag{10}$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt} = C_{H2}\frac{dv_{CH2}(t)}{dt} = -\frac{U_{High}}{R_{LF}} \tag{11}$$

$$\frac{dv_{Cm1}(t)}{dt}=\frac{dv_{Cm2}(t)}{dt}=0 \tag{12}$$

Interval 4(t_3-t_4)- Switch S_1 is turned OFF. Switch S_2 will be in ON position. Switches S_4 and S_5 will be turned ON. Load and capacitor C_{H1} are supplied by the energy stored in the inductor L_1. Capacitor Cm2 will be charged by inductor L_1.

$$\frac{di_{L1}(t)}{dt}=\frac{U_{Low}-U_{m2}}{L} \tag{13}$$

$$\frac{di_{L2}(t)}{dt}=\frac{U_{Low}}{L} \tag{14}$$

$$\frac{dv_{Cm1}(t)}{dt}=\frac{i_{Cm2}+i_{L1}}{C_{m1}} \tag{16}$$

$$\frac{dv_{Cm1}(t)}{dt}=\frac{i_{Cm2}-i_{L1}}{C_{m2}} \tag{17}$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt}=i_{Cm1}-\frac{U_{High}}{R_{LF}} \tag{18}$$

$$C_{H2}\frac{dv_{CH2}(t)}{dt}=-\frac{U_{High}}{R_{LF}} \tag{19}$$

B. **Backward mode**

In this mode energy flows from High voltage side to low voltage side. Here the converter acts as a buck converter. Switch S4 and S6 will be switched with a duty ratio of D_B and there pulses will be in a phase shift of 180°. Switch S3 is switched along with S6 and switch S5 is switched along with S4. Gate pulse of switch S_2 is complimentary to switches S_3 and S_6 and Gate pulse of switch S_1 is complimentary to switches S_4 and S_5. This mode also takes place in four intervals.

Interval 1 (t_0 – t_1)- Switches S_1, S_3 and S_6 will be turned ON. A part of load is supplied by inductor L_1.Energy stored in capacitor C_{m1} transfers to inductor L_2 and load. Capacitor C_{H2} transfers energy to capacitor C_{m2}, inductor L_2 and load.

$$\frac{di_{L1}(t)}{dt}=\frac{U_{Low}}{L} \tag{20}$$

$$\frac{di_{L2}(t)}{dt}=\frac{U_{Low}-U_{m1}}{L} \tag{21}$$

$$\frac{dv_{Cm1}(t)}{dt}=\frac{i_{Cm1}-i_{L2}}{C_{m1}} \tag{22}$$

$$\frac{dv_{Cm2}(t)}{dt}=\frac{i_{Cm1}+i_{L2}}{C_{m2}} \tag{23}$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt}=-\frac{U_{High}}{R_{LF}} \tag{24}$$

$$C_{H2}\frac{dv_{CH2}(t)}{dt}=i_{Cm2}-\frac{U_{High}}{R_{LF}} \tag{25}$$

Interval 2(t_1 – t_2)- Switches S_3 and S_6 are turned off. Switch S1 remains in ON position from the last interval. Switch S_2 will be turned ON. Energy stored in inductor L_1 and L_2 will be transferred to load.

$$\frac{di_{L1}(t)}{dt}=\frac{di_{L2}(t)}{dt}=\frac{U_{Low}}{L} \tag{26}$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt}=C_{H2}\frac{dv_{CH2}(t)}{dt}=-\frac{U_{High}}{R_{LF}} \tag{27}$$

$$\frac{dv_{Cm1}(t)}{dt}=\frac{dv_{Cm2}(t)}{dt}=0 \tag{28}$$

Interval 3(t_2 – t_3)- In this interval switch S_1 will be turned off, switch S_2 remains turned on and switches S_4 and S_5 will be switched ON.A part of load is supplied by inductor L_2. Energy stored in capacitor C_{m2} transfers to inductor L_1 and load. Capacitor C_{H1} transfers energy to capacitor C_{m1}, inductor L_1 and load.

$$\frac{di_{L1}(t)}{dt}=\frac{U_{Low}-U_{m2}}{L} \tag{29}$$

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$$\frac{di_{L2}(t)}{dt} = \frac{U_{Low}}{L} \quad (30)$$

$$\frac{dv_{Cm1}(t)}{dt} = \frac{i_{Cm2}+i_{L1}}{C_{m1}} \quad (31)$$

$$\frac{dv_{Cm1}(t)}{dt} = \frac{i_{Cm2}-i_{L1}}{C_{m2}} \quad (32)$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt} = i_{Cm1} - \frac{U_{High}}{R_{LF}} \quad (33)$$

$$C_{H2}\frac{dv_{CH2}(t)}{dt} = -\frac{U_{High}}{R_{LF}} \quad (34)$$

Interval 4 ($t_3 - t_4$)- This interval is similar to interval 2.Switch S_1 will be turned ON. Switches S_4 and S_5 will be turned OFF. Energy stored in inductor L_1 and L_2 will be transferred to load.

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{U_{Low}}{L} \quad (35)$$

$$C_{H1}\frac{dv_{CH1}(t)}{dt} = C_{H2}\frac{dv_{CH2}(t)}{dt} = -\frac{U_{High}}{R_{LF}} \quad (36)$$

$$\frac{dv_{Cm1}(t)}{dt} = \frac{dv_{Cm2}(t)}{dt} = 0 \quad (37)$$

III.DESIGN AND ANALYSIS

A. Design Considerations

In forward mode, by applying volt-second balance principle,

$$d_F U_{Low} + (1-d_F).(U_{Low} - U_{m1} + U_{H1}) = 0 \quad (38)$$

$$d_F U_{Low} + (1-d_F).(U_{Low} - U_{m2} + U_{H2}) = 0 \quad (39)$$

Applying Kirchhof' voltage law

$$U_{High} = U_{H1} + U_{H2} \quad (40)$$

$$U_{H1} = U_{m1} + U_{m2} \quad (41)$$

$$U_{H1} = U_{m1} + U_{m2} \quad (42)$$

Voltage across the capacitor is given by,

$$U_{m1} = U_{m2} = \frac{U_{Low}}{1-d_F} \quad (43)$$

$$U_{H1} = U_{H2} = 2U_{m1} = \frac{2U_{Low}}{1-d_F} \quad (44)$$

$$U_{High} = 2U_{H1} = \frac{4U_{Low}}{1-d_F} \quad (45)$$

From these equations, voltage ratio in forward mode can be found out as:

$$M_F = \frac{U_{High}}{U_{Low}} = \frac{4}{1-d_F} \quad (46)$$

Similarly, voltage ratio in backward mode can be found as,

$$M_B = \frac{U_{High}}{U_{Low}} = \frac{4}{d_B} \quad (47)$$

Value of inductor can be calculated by knowing the value of current ripple, by the equation,

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$$L = \frac{d_F \times (1-d_F) \times U_{High}}{4\Delta i_{L1} \times f_s} \tag{48}$$

B. Simulation and Analysis

By considering the equations from the previous section, the value of inductor and capacitor can be calculated. This is shown in Table 1.

TABLE I
SIMULATION PARAMETERS

Components	Ratings
Power	250 W
V_{in}	6 V
V_{out}	48 V
Frequency	10 kHz
Duty ratio	50%
Load Resistance	10 Ω
Capacitor C_{H1}, C_{H2}	40 mF
Inductor L_1, L_2	0.72 mH
Capacitor C_L, C_{m1}, C_{m2}	20 mF

Voltage and current waveform of the open loop simulation of the converter in forward mode is shown in figure 2 and that of the converter in backward mode is shown in figure 3. Simulation diagram of the closed loop system is shown in figure 4. Voltage and current waveform of the closed loop simulation of the converter in forward mode is shown in figure 5.

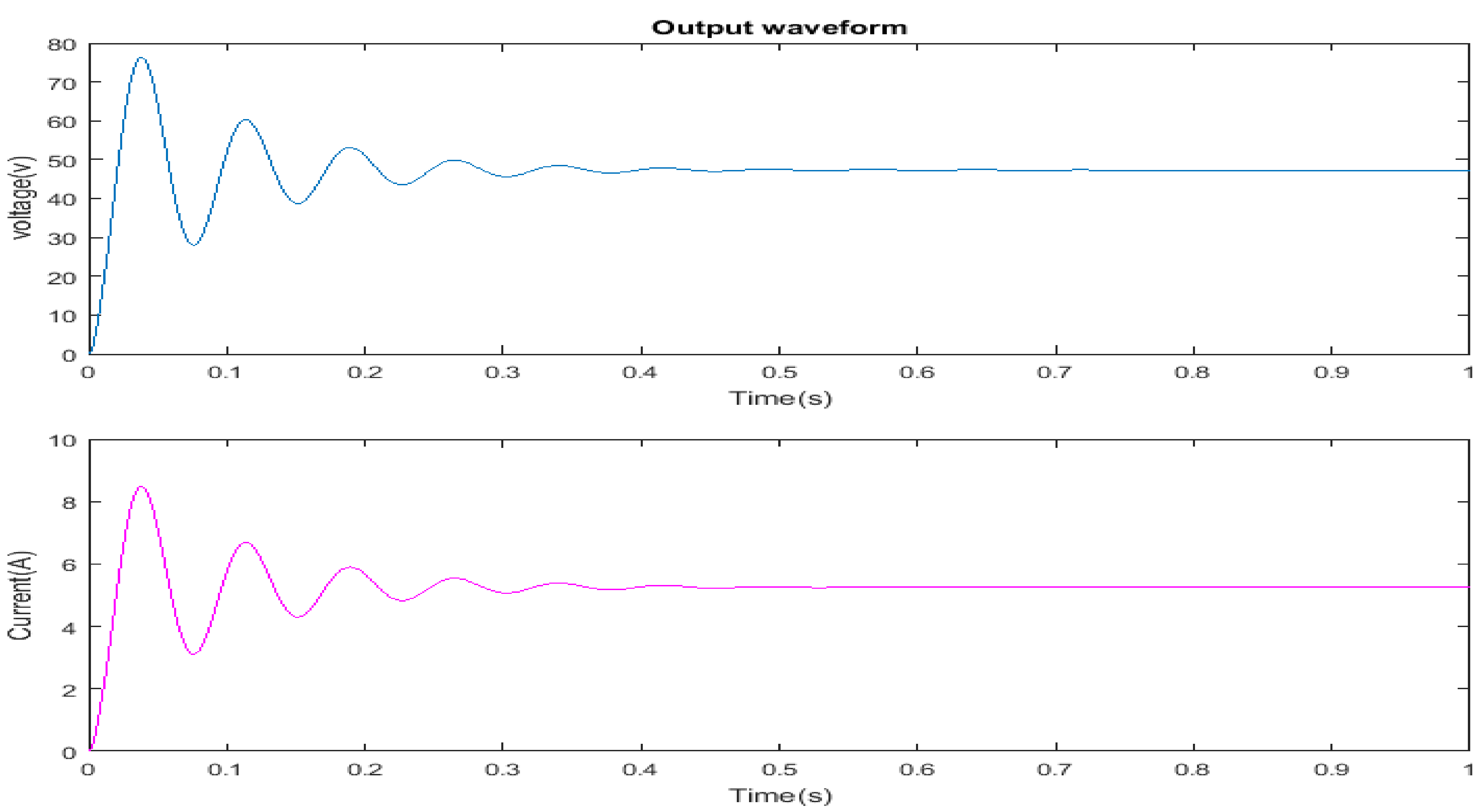

Figure 2: Voltage and current waveform of open loop converter in forward mode

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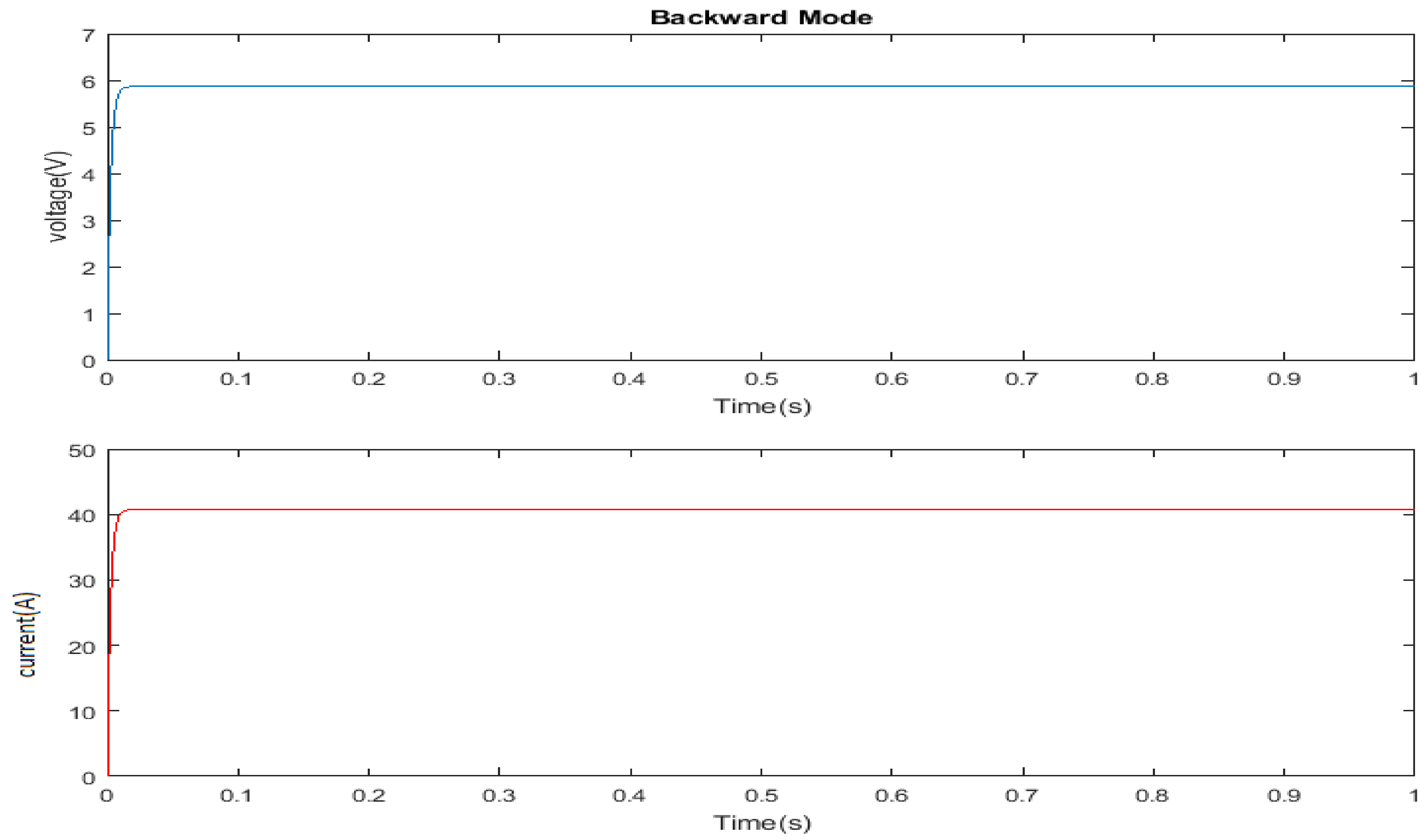

Figure 3: Voltage and current waveform of open loop converter in backward mode

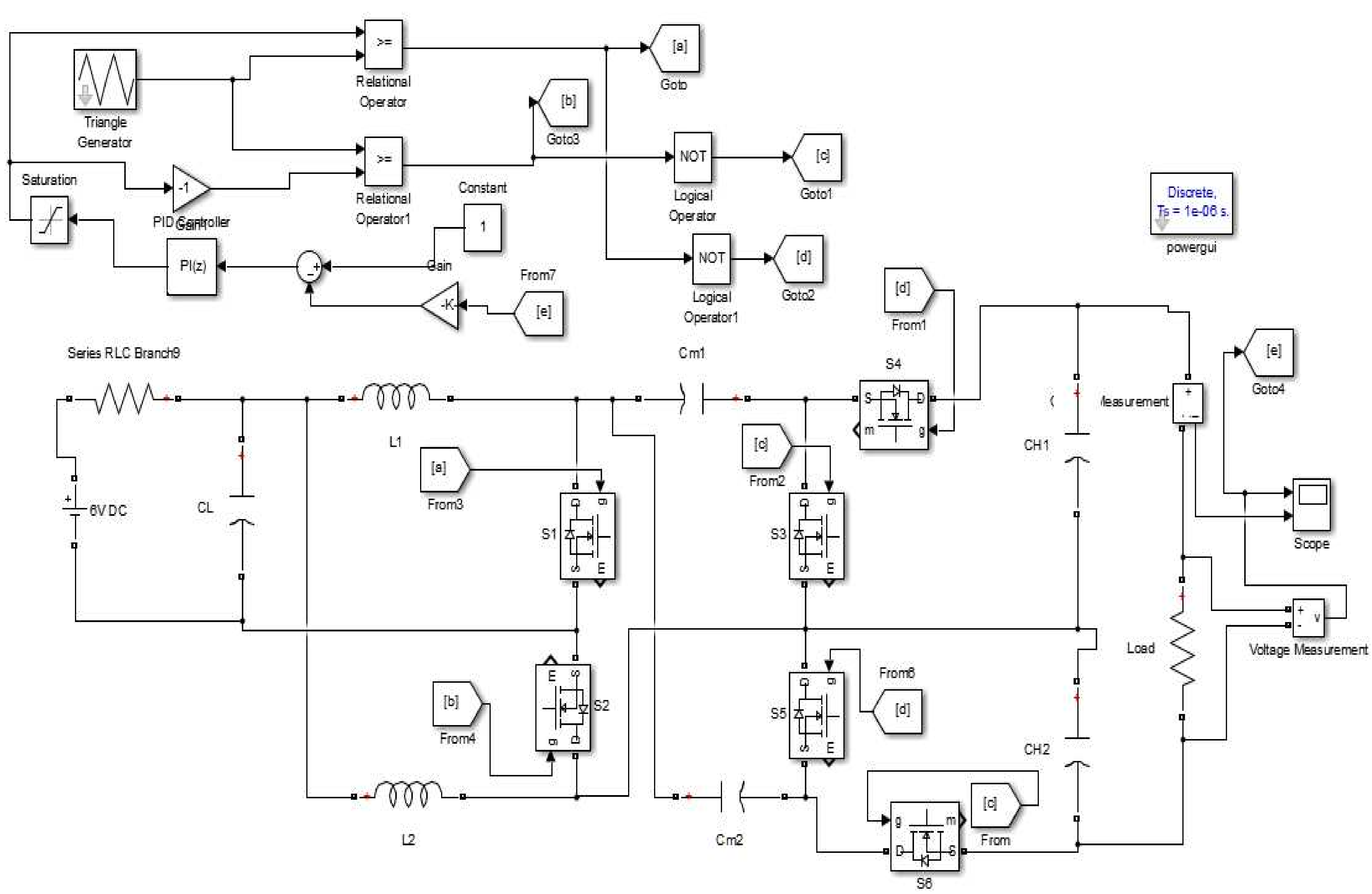

Figure 4: Simulation Diagram

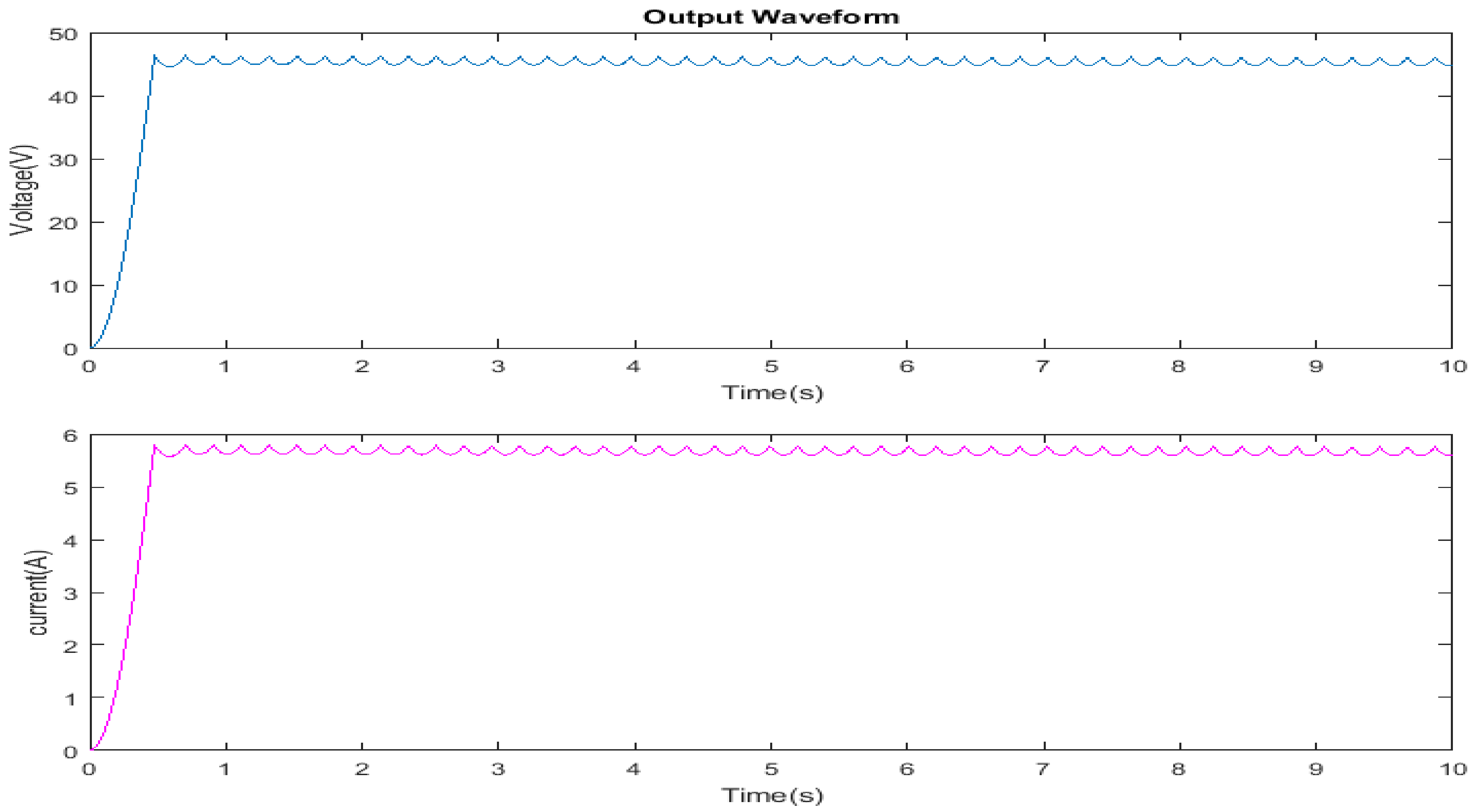

Figure 5: Voltage and current waveform of closed loop converter in forward mode

Feedback to the converter is given by a PI controller. This controller is used to correct the error between set point and actual value. Proportional controller is used in the system to achieve immediate response whereas integral controller is used to eliminate long term error and offset system. By adding this controller, peak value and settling time of the output got reduced. The system reached to a stable state with a short span of time.

IV CONCLUSION

A voltage quadrupler interleaved bi-directional convert has been discussed. The converter has equal current sharing capacity and has reduced stress across the switch. The converter has high conversion ratio and less conduction losses. This converter can be used for power conditioning in electric vehicles. In this paper, the converter is designed for a power of 250W. It was simulated in Matlab/Simulink and verified the output. As the converter has high rise time and settling time, a PI controller is used to provide feedback. The converter has been analysed in closed loop configuration by providing the feedback.

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Dual Input Micro-inverter With One Cycle Control

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Abstract: Slow dynamic response to input power source perturbation rejection is the major drawback of conventional PWM methods. In order to address this concern, a dual input micro-inverter with a control strategy called one cycle control (OCC) is presented. One cycle control achieves fast dynamic response and good input power perturbation rejection. The topology consists of electrically coupled forward inverter and two boost converters in series. The input powers are controlled by the duty cycle of primary side switches. Inorder to control thedirection of current in each half cycle, secondary side switches are operated at low frequency. Based on the analysis of dual input micro-inverter, the OCC control law and required circuitry for control is presentedand it is verified by simulation using MATLAB simulation tool.

Keywords: Multi input inverter, OCC, Soft switching, Micro-inverter

I. INTRODUCTION

Application of renewable energy sources are increasing day by day. Since solar energy is one of the important renewable energy sources, the advancement in this area of application is more. In order to extract solar energy and to amplify that low voltage and to produce required AC voltage we use Photovoltaic (PV) structures. PV structures are classified as centralized inverter, string inverter and micro-inverter. The micro inverter has many advantages over other two such as it enables MPPT from string level to panel level, increases energy harvesting and system efficiency, prevents the interruption power when one panel is damaged or shaded ,used as plug and play application[1,2]. In various topologies of micro-inverter, the topologies with flyback inverter are commonly used. A flyback inverter with centre tapped secondary winding and power decoupling capacitor is introduced [3-5]. Double power conversion and need of additional power decoupling method, hard switching are disadvantages of these micro-inverters. Many topologies are introduced in order to improve the efficiency by eliminating this double power conversion [6]. Several methods such as using of snubber circuit, bidirectional switches at secondary side, additional auxiliary circuit are used for enabling soft switching of flyback inverters and to improve efficiency [7-9]. Even though micro inverter has many advantages, itis not commonly used because of itshigh cost. The structures with multiple inputs proposed as solution to this problem of higher cost. In [10] dual input inverter is proposed. But the topology is a non-isolated one. Another way is to use two separate micro inverters whichincrease the number of components and cost.

We need simple and reliable methods to control these micro inverters. Conventional PWM methods suffer the drawback of slow dynamic response and weak in rejecting input perturbations. In these methods duty ratio is linearly modulated in order to reduce the error. So a large number of switching cycles are required to reach steady state. In order to address this concern a control strategy called one cycle control used. One cycle control (OCC) is anonlinear control and also a PWM method for switched mode system. In OCC the average value of switching variable follows the dynamic reference in each switching cycle by varying the duty cycle of switches[12,13]. It corrects the switching error in each switching cycle andrejects input power perturbations without any feedback loop. Also the OCC have the advantages of constant switching frequency and fast dynamic response [14]. In this paper, one cycle control (OCC) is applied to a dual input micro-inverter topology. The eachinput can be controlled separately using this control.

The dual input micro-inverter topology consists of a forward inverter and two boost converters in series.The rest of the paper is organised as follows. In section II a dual input micro-inverter ispresented. In section III the derivation of OCC control law and modulator circuitry for the dual input micro-inverter is provided. To verify the analysis, simulation results are provided in section IV. The conclusion is provided in section V.

II. DUAL INPUT MICRO-INVERTER TOPOLOGY

The dual input micro-inverter topology consists of two boost converters and a forward inverter. The micro-inverter is electrically isolated using a high frequency transformer.The schematic diagram of dual micro inverter is shown in Fig 1. The energy is not stored in transformer core. There are three primary switches Q_1, Q_2, $Q_3$and two secondary switches Q_4, $Q_5$for microinverter. When the switches are turned on capacitors get discharged and inductors get charged. When the switches $Q_1$and $Q_2$are turned on, the capacitors of two boost converters are connected in series and energy is transferred to output through third switch $Q_3$and transformer's leakage inductorL_{lk}. A auxiliary circuit consist of inductor L_s, capacitor $C_s$and diode $D_s$to clamp the voltage across switch $Q_3$and provide soft switching condition. The secondary switches $Q_4$and $Q_5$are used to control the direction of current in

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each half cycle. For the positive half cycle the switch $Q_4$is turned on and switch $Q_5$is turned off. And for the negative half cycle switch $Q_5$is turned on and $Q_4$is turned off [15].

The two input sources are controlled separately by the duty cycle of switches $Q_1$and Q_2. If the input powers of two sources are same then the three primary switches will operates at duty cycle D. But in many renewable applications each input will have different power as in case of shading of PV panels. So the switches $Q_1$and Q_2want to operate in different duty cycle $D_1$and D_2 respectively. This duty cycle is determined according to the available input power [16].

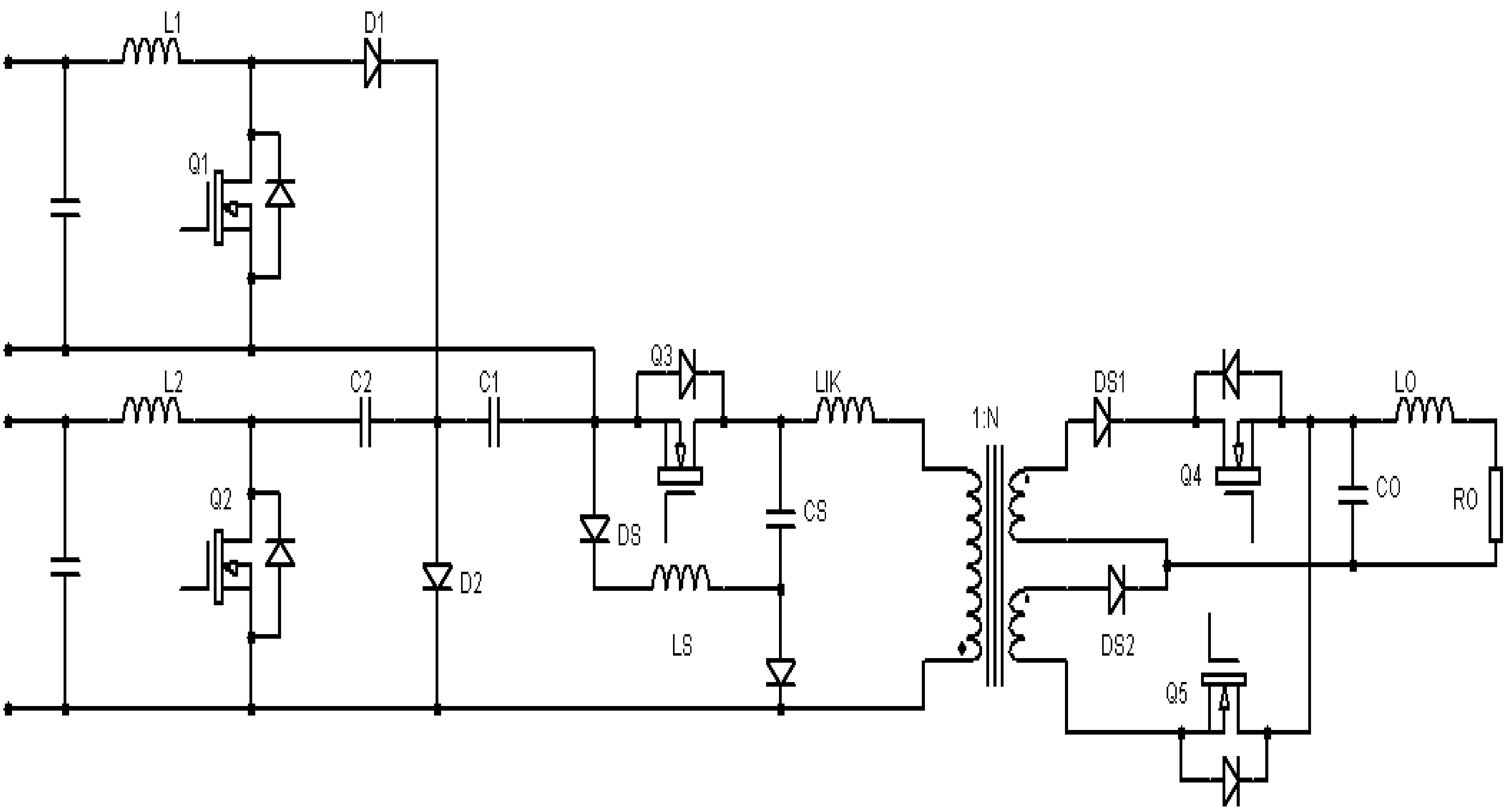

Fig.1 Dual input micro-inverter

III. ONE CYCLE CONTROL

The One cycle control is a non-linear control which has the advantages of fast dynamic response and good input power perturbations.The OCC consist of a resettable integrator, SR flip flop and a clock.A constant frequency clock is used to make the switching pulse high at the beginning of each switching cycle .When the integrator output becomes equals to reference voltage the SR flip flop gets reset and switching pulse becomes low.The control objective of a standalone micro-inverter is to generate a output AC voltage with magnitude and frequency same as that of reference voltage. In One cycle control (OCC) the average value of switching variable follows the dynamic reference voltage in each switching cycle. The controller corrects switching error in each switching cycle and rejects input perturbations.
Assume that the two input sources of dual input micro-inverter are operating at the same power. The switches $Q_1$and $Q_2$are turned on for duration D T_S which is determined by controller, where D is the duty cycle and $T_S$switching period of switching pulse. The energy transferred from input to output in each switching period is sum of energies from two boost converters.ie,

$$E = \frac{Li_{pk\,1}^{\;2}}{2} + \frac{Li_{pk\,2}^{\;2}}{2} \tag{1}$$

Therefore average power over switching cycle is,

$$P_{av} = \frac{Li_{pk\,1}^{\;2}}{2T_S} + \frac{Li_{pk\,2}^{\;2}}{2T_S} = \frac{V_1^{\,2}D^2T_S}{2L} + \frac{V_2^{\,2}D^2T_S}{2L}\, P_{av} = \frac{T_SD^2}{2L}\left[V_1^{\,2} + V_2^{\,2}\right] \tag{2}$$

Average switching current per cycle injected into grid,

$$I_{acav}\,(t) = \frac{P_{av}}{v_{ac}\,(t)} = \frac{v_{ac}\,(t)}{R} \tag{3}$$

$$v_{ac}{}^{2}(t) = P_{av}R \tag{4}$$

$$v_{ac}\,(t) = \sqrt{\frac{R}{2f_S L}}V_1 D + \sqrt{\frac{R}{2f_S L}}V_2 D = \sqrt{\frac{R}{2f_S L}}D[V_1 + V_2] \tag{5}$$

$$v_{ac}\,(t) = v_m D \tag{6}$$

Where v_m is modulating voltage, $v_m = \sqrt{\frac{R}{2f_S L}}[V_1 + V_2]$. And the OCC control law can be written as, $v_{ac}\,(t) = \frac{1}{T_S}\int_0^{DT_S} v_m\ dt$.

The block diagram of OCC controller is shown in Fig 2. OCC controller for dual input micro-inverter consists of a resettable integrator, comparator, SR flipflop, power distribution block (PDB), a line voltage sensor and absolute value block. The voltage v_m is given as input to resettable integrator. Here integrator time constant is set same as switching time period T_S.

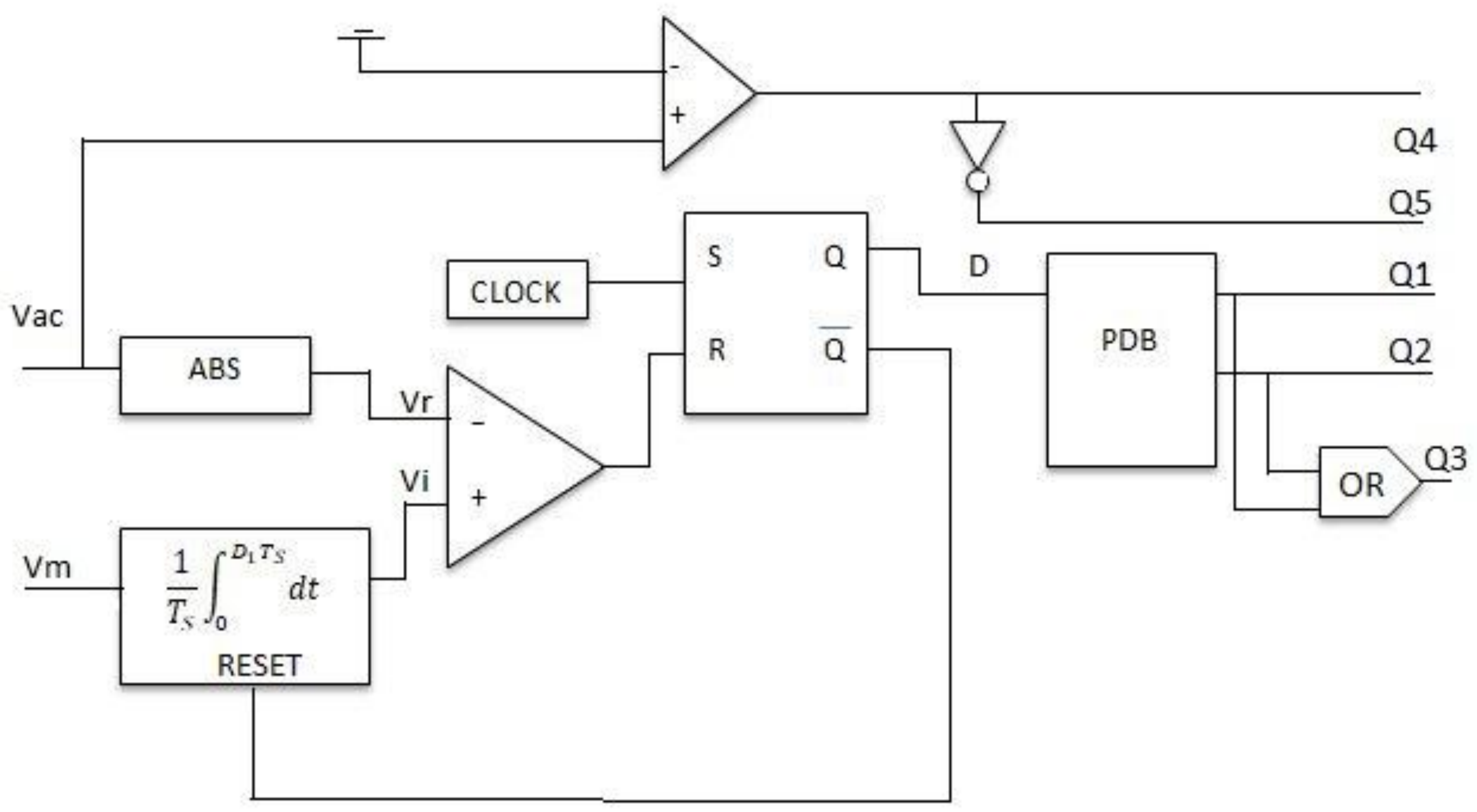

Fig.2. One cycle control of dual input micro-inverter

When both inputs have same power then the duty cycle will be same as that of output from SR flip flop. But when input powers are different then duty ratios for each switches Q_1 and Q_2 are calculated in power distribution block. For better and accurate output in photo voltaic applications the modulating voltage v_m is provided for OCC controller by maximum power point tracker.

IV. SIMULATION RESULTS

Inorder to verify the derived OCC control law dual input micro inverter simulations are carried out by MATLAB software. Simulation parameters are shown in Table 1. The simulation of OCC controlled dual input micro inverter is carried out for total power P_o=100W, input voltages V_{in1}= V_{in2} =30V and power of each input source is 50W. A load resistance of 529 Ω is used. The Fig 3 shows the generation of duty cycle D by one cycle control. Here switching pulse becomes high at the beginning of switching cycle and when integrator output V_i equals to reference voltage V_r the switching pulse becomes low. Fig 3 illustrates the key waveforms of OCC controller on switching period scale and Fig 4 illustrates the same in line frequency scale.

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TABLE I
SIMULATION PARAMETERS

Parameters	Values
Switching frequency, f_s	100 kHz
Input inductors, L	33 µH
Inductor , L_s	20 µH
Capacitors , C	150 nF
Snubber capacitor, C_s	20 nF
Leakage inductance, L_{lk}	18 µH
Output filter capacitor, C_O	5 µF
Output filter inductor, L_O	2 mH

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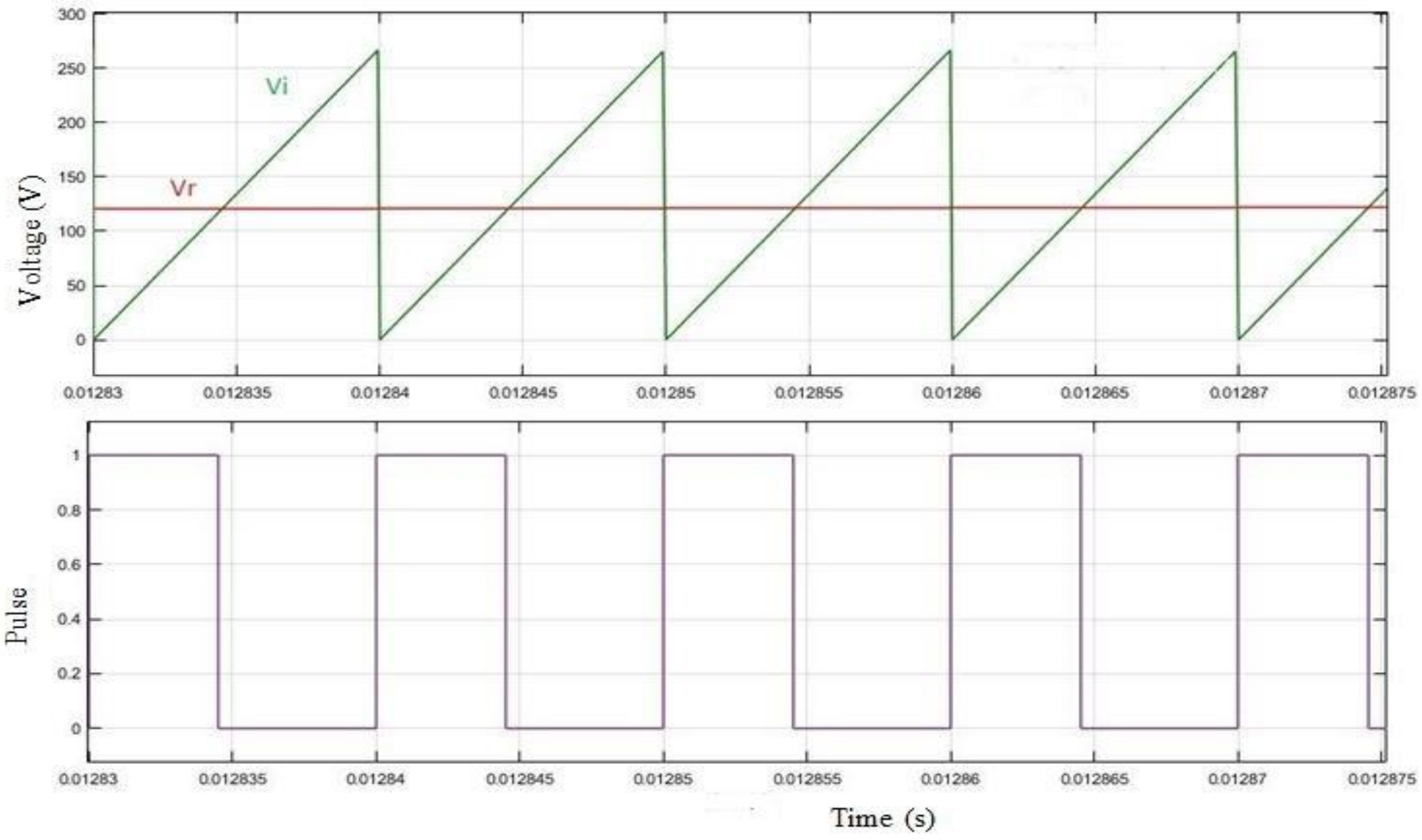

Fig. 3 Key waveforms of OCC controller on switching period scale

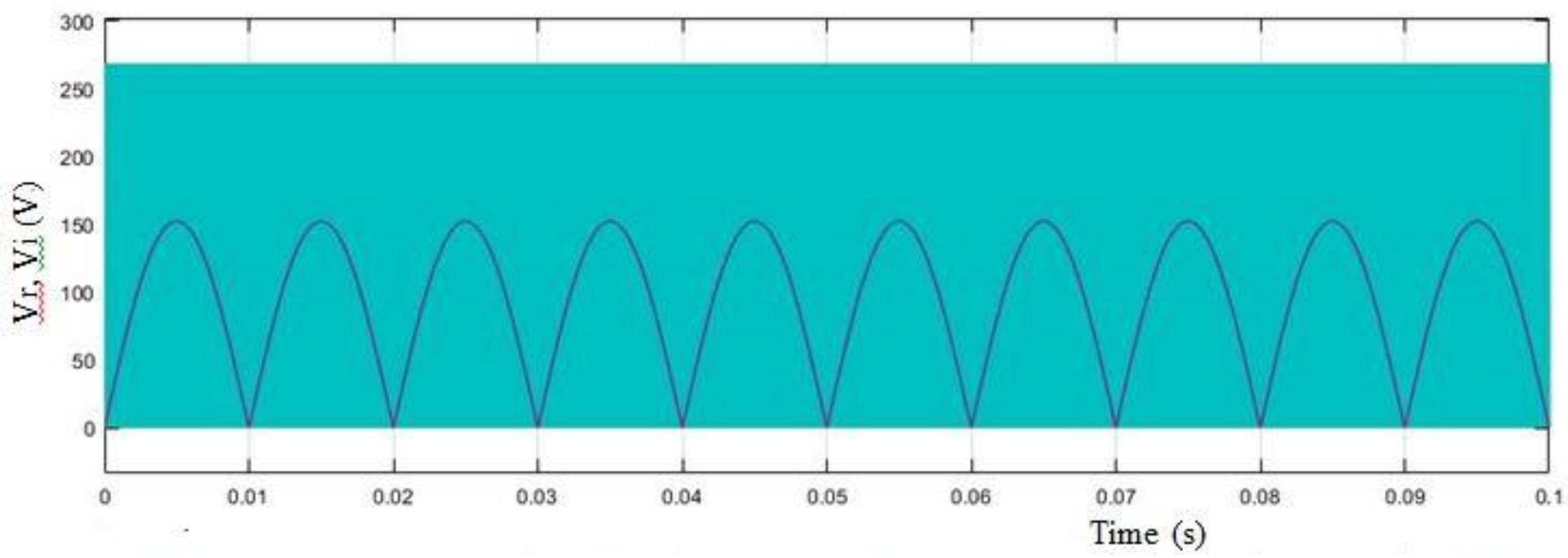

Fig. 4 Key waveform of OCC controller on line period scale

Fig 5 illustrates the output waveform of dual input micro-inverter with OCC. Output voltage is 50 Hz 230 V rms.By examining the simulation results, it is clear that dual input micro-inverter gives desired average sinusoidal output current and voltage.

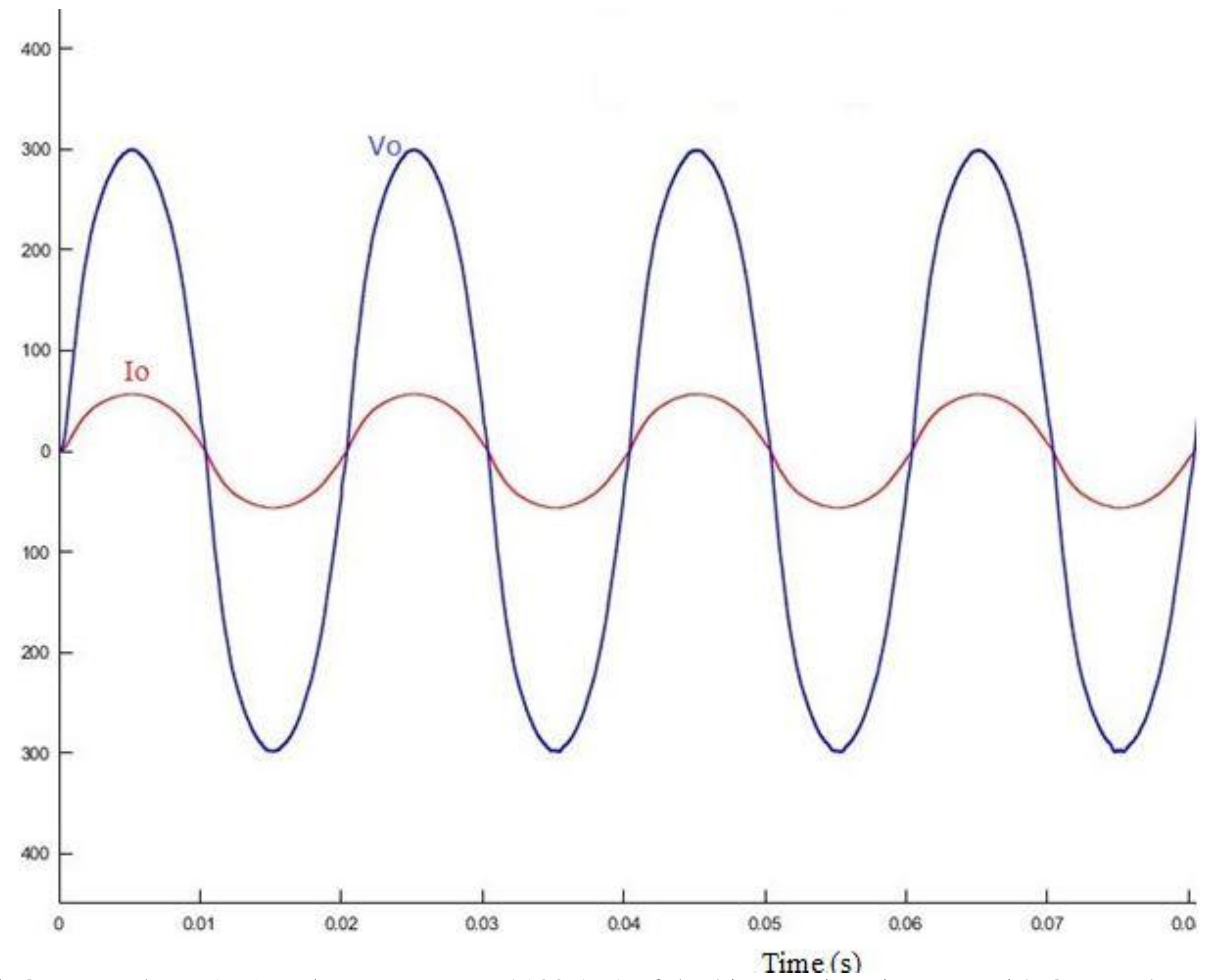

Fig.5 Output voltage (Vo) and output current *100 (Io) of dual input micro-inverter with One cycle control

V. CONCLUSION

The one cycle control (OCC) of a dual input micro-inverter is presented. The micro inverter consistsof two boost converters and a forward inverter which are electrically isolated .When switches are closed, the two boost converters are connected in series and power is transferred to output through forward inverter.Each input can be controlled separately using one cycle control.The good input power perturbation rejectionis the advantage of this micro-inverter with one cycle control. The one cycle control law for this micro-inverter is derived and the same is verified through simulation using MATLAB software.

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Open Loop Performance of Cuk and Bridge Type Converter

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Abstract: A Comparative study of CUK converter based EV charger and a Bridge dual input DC to DC converter for the EV application is presenting in this paper. Both converter having their own merits and demerits. Analysis done on the basisof simulation. Simulation of converter done by using MATLAB SIMULINK Software. Cuk converter is highly efficient charger which reduces thecondution losses than normal converters. Dual input converter is simple reliable converter having lesser number of components.

Keywords: Energy sources, Converter, Cuk , Dual input

I. INTRODUCTION

Our India's main target to become a fully sustained green planet .In order to switch into a green world EV hold the key to better solutions of our crucial problems .The main clash is that fossil fuel based electric vehicle contribute 60% of particulate matter causing atmospheric pollution and also 20% of CO_2 .Another fact is that rapid increase in petrol and diesel price majorly affecting the common people. So vehicle owners have to carry the whole burden of price .so cost factor is recurring one. On other hand in case of EV we want to just buy a battery, it will be last for long years. So it is the best time to customers to switch into electric vehicle. Petrol and diesel based vehicles are neither be recycled, recovered or reused. Unlike the batteries that can be made as and when you required .So by using these smoke free vehicle we can build an environment with zero carbon emission. We already see that during COVID 19 pandemic lockdown days how the ecology improved due to lesser emission of fossil fuels. So main aim to increase the popularity of electric vehicle among common people in order to cut the fossil fuel based vehicular mobility. By switching to clean green energy runs EV can develop a sustainable country with lesser pollutions, zero emissions, and reduced global warming. Power generation based renewable energy sources are gaining more popularity in this current scenario. Individual use of the sources are not beneficial in power generation due to their intermittent nature .So integration of these energy sources will helpful meeting widely varying electricity demand. Hence the concept Hybrid energy system comes into practice. Hybrid energy systems have grater applications in distributed energy systems applications, electric vehicle ,uninterrupted power supplies .For proper integration of energy sources a power electronic interfacing circuit most important one. There are different type of converters are already developedfor this integration purpose.

Multi input DC to DC converter [1] for renewable energy systems can be used to obtain well regulated output voltages from several renewable sources .But in this converter the presence of inductor and transformer for coupling 2 different output is different .And also diode bridge in output side cause the system to become costly. Then a transformerless converter for integration of energys sources in [2] have fewer cicuit components, higher power density and centralized control. But inductor charging and discharging stage is very difficult in practical cases. In paper [3] and [4] involves paralleling of input sources. But these sources are operated in a time sharing manner, only one source can operate at a time to deliver power to the load. And also contain large number of switches , which will cause higher losses in circuit .Thus in [5] converter consist of half number of components compared to the previous one. But the inductor in each input stage make the system more complex. In [6] integration of different sources are done through with the help of H bridge cells.

Multiple input multiple output are obtained with the help of transformer coupled configurations using flyback converter [7] and forward converter [8].In [9] and [10] PV and energy storage systems are connected through DC link to separate converter.The dc link should be bidirectional in nature to transfer the power from energy storage system to dc link and vice versa.The drawback of this system are including more number of switches and which reduce the reliability of system and make more compact. .In [11] magnetically coupled converters and in [12] electrically coupled converters are proposed.The concept of Multi Input DC-DC Converter is developed to overcome the defects in the conventional ways of integration of 2 or more energy sources Less part counts,compactness, cost effectiveness is the major merits of the MICs. Different sources can be integrated using MICs to supply the load individually or simultaneously [13].3 input dc to dc converter using PV, fuel cell and battery using the integration of energy sources used in higher energy application. It increase the voltage gain and efficiency of conventional converter .Dual input single output converter using hybrid arrangement .But during switch on period a circulating current always flows through the circuit .

In this a detailed open loop simulation analysis of cuk converter based EV charger and Bridge type dual input converter for EV application is done. Conduction losses in previous converter is incurred in CUK converter based EV charger and also total harmonic distortion is reduced to limit specified by the threshold. Dual input converter incoperates two inputs , we can decide it according toour requirement. It can be used in EV applications , Uninterrupted power supplies and in hynrid energy integration.

II. CONVERTER TOPOLOGIES

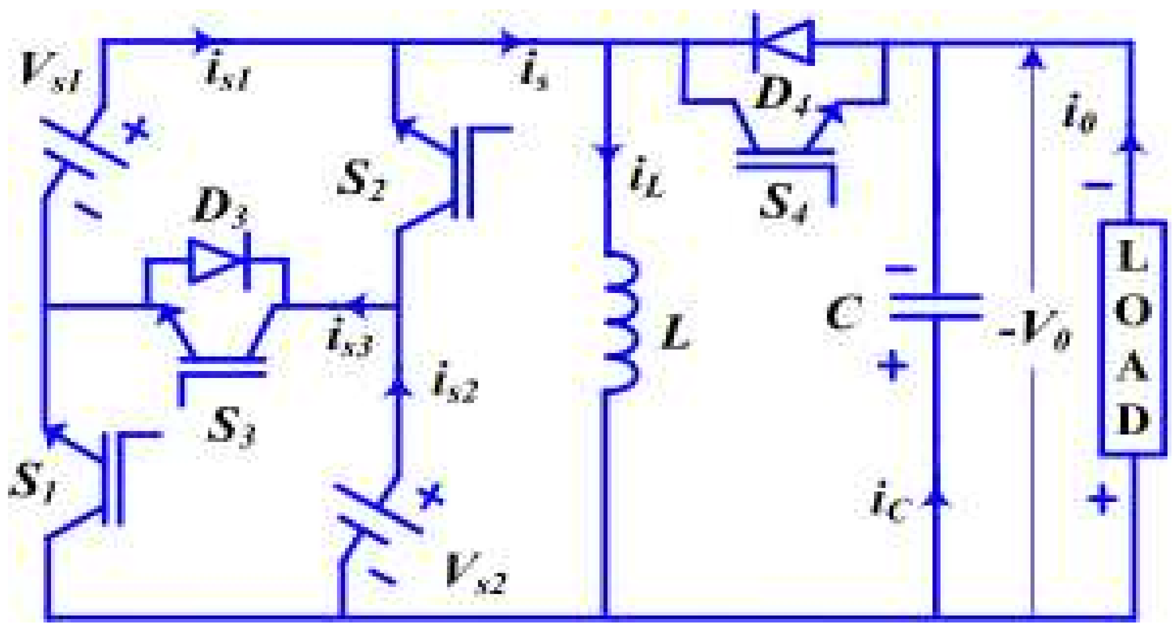

Fig. 1. Bridge type dual input Converter

Fig. 1. represents the Bridge type dual input converter [13]. Consist of lesser number of components.Operating principal same as thatof conventional buck boost converter. Converter charges for a specific period and transfer the stored energy to the load for rest of the period.Input sources can deliver power to the load either individualy or simulataneously by the proper operation of powerswitches.Bidirectional power flow from the load to the source is possible by using this converter.

A. *Modes of Operation*

There are 4 modes of operation which explains the working of unidirectional mode of converter. In each mode the output voltage across the load depend on the charging and discharging of inductor .Main advantage of this that consist of only one inductor . In thecase of other previously developed converter it consist of transformer, coupled inductor and lots of inductors . So construction waysunidirectional converter is simple compared to others.

Mode 1

During this mode switch S1 is only in conducting mode. Voltage source V_1 only providing energy to the inductor to charge .So that inductor getting charged. Voltage across the load is equal to the voltage across the capacitor.

Mode 2

In this mode both the voltage sources V_1 and V_2 providing energy to the inductor to charge .Switch S_3 only conducting in thisstage
.Voltage across the inductor is equal to the sum of the voltage across the voltage sources V_1 and V_2. Total voltage obtained attheload is more compared to other stages. So that voltage deficiency will not affect the load at this stage.

Mode 3

Switch S_2 is conducting in this mode. Voltage source V_2 only providing energy to the inductor to charge .Voltage across the inductoris same as the voltage applied in V_2.

Mode 4

During this mode, all the energy stored in the inductor on previous stages get discharged in to the load .Here all the switches are off. So not any source providing energy to the load. Diode D1 is only conducting. A negative voltage appears across the inductor due to its discharging.

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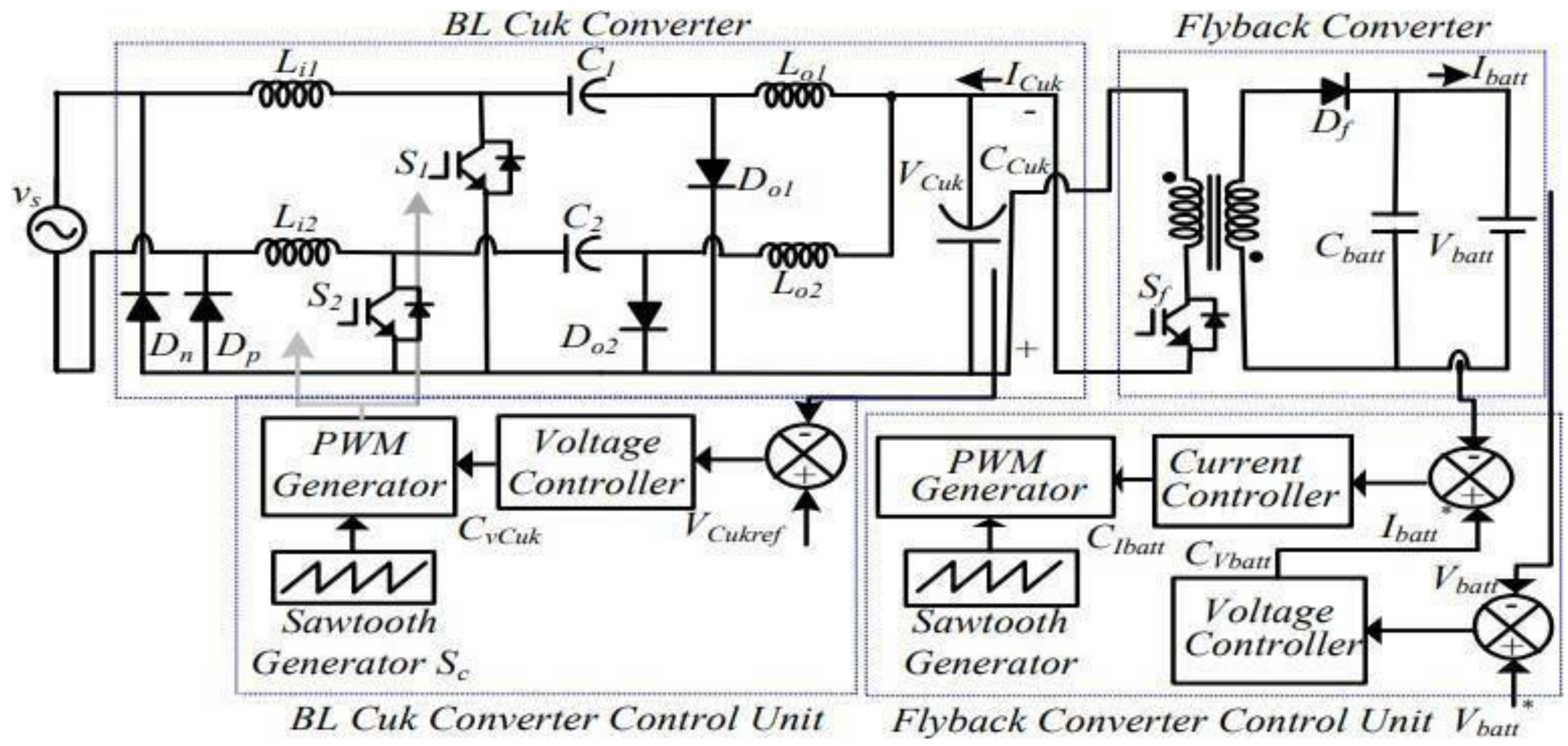

Fig. 2. Cuk converter based EV charger

The intermediate capacitors are acting independently in Cuk converter [14].There is no return current through the body diode of inactive switches inthe other half cycle due to applied control. The control of the PFC converter is simple owing to use of same gate drive and control circuitry for each half cycles. The output inductors of Cuk converter, are designed small enough to ensure converter operation in DCM.The conduction loss in proposed converter, is reduced due to BL structure, which in turn, improves the charger efficiency.

B. Modes of Operation

Operation of BL CUK CONVERTER

Mode 1

The first mode of positive half cycle operation begins at t1, when gate pulse to switch S1 is applied. The current through the input inductor Li1 rises linearly with the slope of Vspk (t)/Li1. The current follows the path Vs-Li1-S1- Dp-Vs, as the positive line diode Dp is in conducting state. . The voltage across the intermediate capacitor C1 starts decreasing through the switch S1 and output inductor, Lo1, providing the required load current to the flyback converter. The output diode Do1 remains in reverse bias during this interval, due to the polarity of intermediate capacitor voltage, C1.

Mode 2

This mode starts at instant t2, when switch s1is turned OFF. The output diode D01 comes into conduction and the voltage across the intermediate capacitor, starts increasing as the input inductorLi1 starts releasing the stored energy via C1 and D01. The output inductor L01 provides the required load current as it releases the stored energy through the output diode D01and DC link capacitor Ccuk.

Mode 3

This mode starts at instant t2, when switch s1is turned OFF. The output diode D01 comes into conduction and the voltage across the intermediate capacitor, starts increasing as the input inductorLi1 starts releasing the stored energy via C1 and D01. The output inductor L01provides the required load current as it releases the stored energy through the output diode D0 1 and DC link capacitor cuk.

Operation of Flyback Converter

Mode 1

During this mode,the current through the magnetizing inductance Lmf rises linearly and it stores the energy when the flyback switch Sf is made ON. The output diode, Df is reverse biased due to the dot convention of HFT, during this instant.

Mode 2

This mode begins when switch sf is turned off at instant t2. The output power is delivered to the battery as the polarity of HFT, is reversed during switch OFF instant and the output diode Df becomes forward biased. The switch current isf and diode voltage VDf are zero.This mode ends at the instant t3.

Mode 3

This mode also known as discontinuous conduction mode, starts when both the switch and diode are turned OFF. The stored energy in the magnetizing inductance is transferred completely to the output, at the end of the switching cycle. At this instant, theoutput capacitor Cbatt provides the required battery charging current in CC mode.

III. SIMULATION OF BRIDGE TYPE CONVERTER

A. Simulation parameters of Bridge type dual input converter

TABLE I
SIMULATION PARAMETERS

PARAMETER	SPECIFICATION
Input voltage	$V_{S}1$=20v $V_{S}2$=16 V
Switching Frequency	20 kHz
Power	240 watt
Output voltage	60 volt
Capacitor	O.675miliF
Inductor	0.233miliH
Resistance	15 ohm

B. Simulation diagram and waveforms

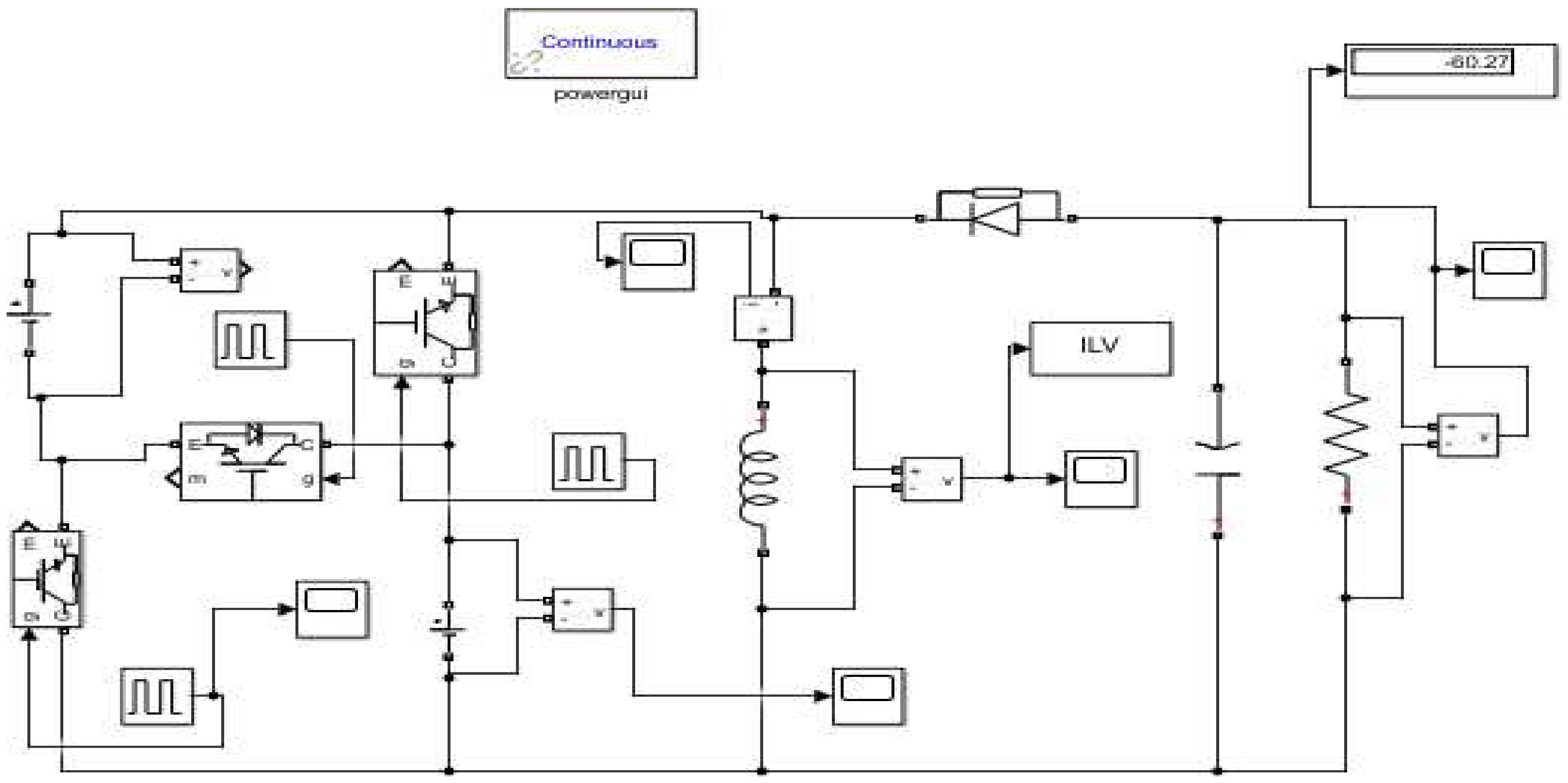

Fig.3. Open Loop Simulink diagram of dual input converter

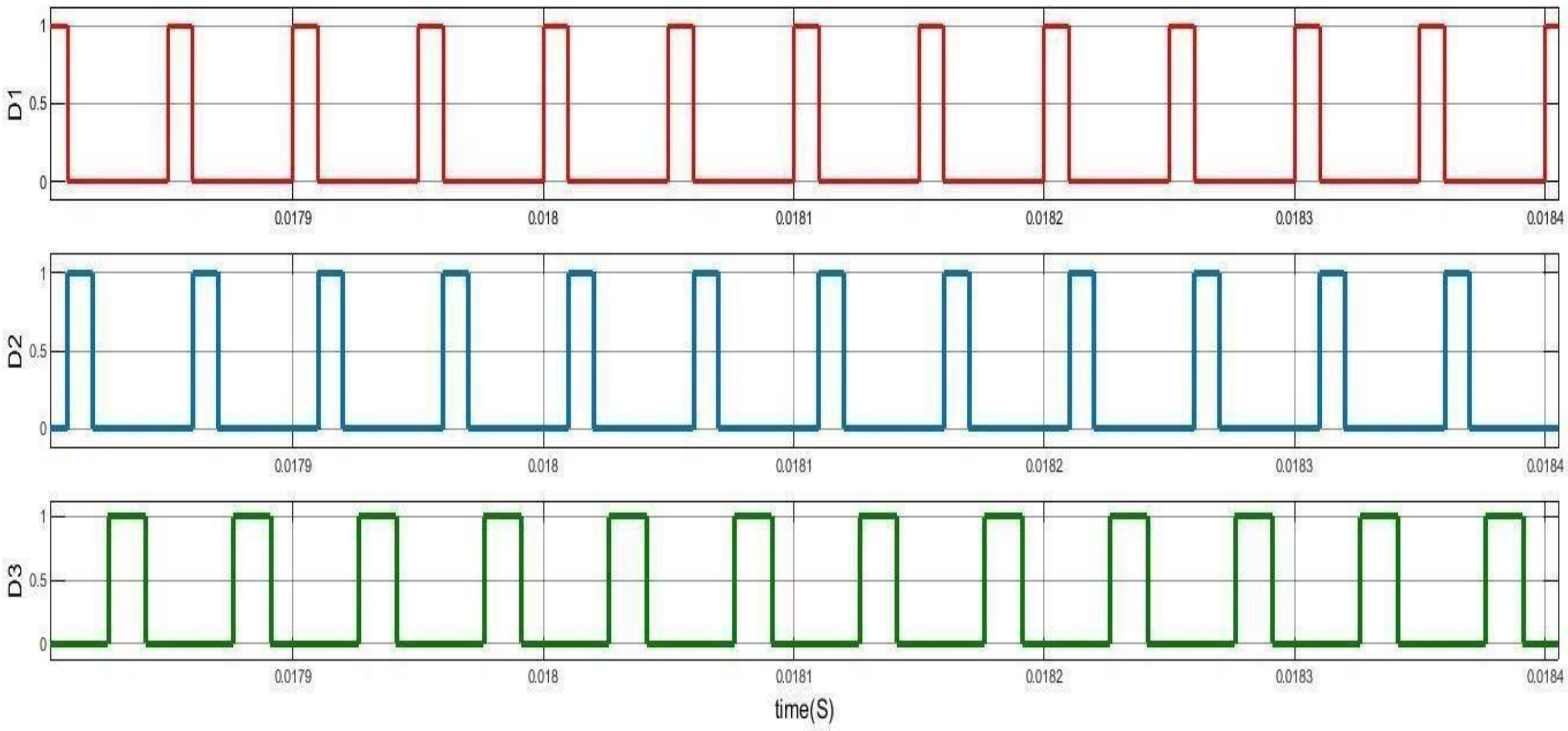

Fig.4. Pulse of 3 switches S_1 ,S_2 and S_3

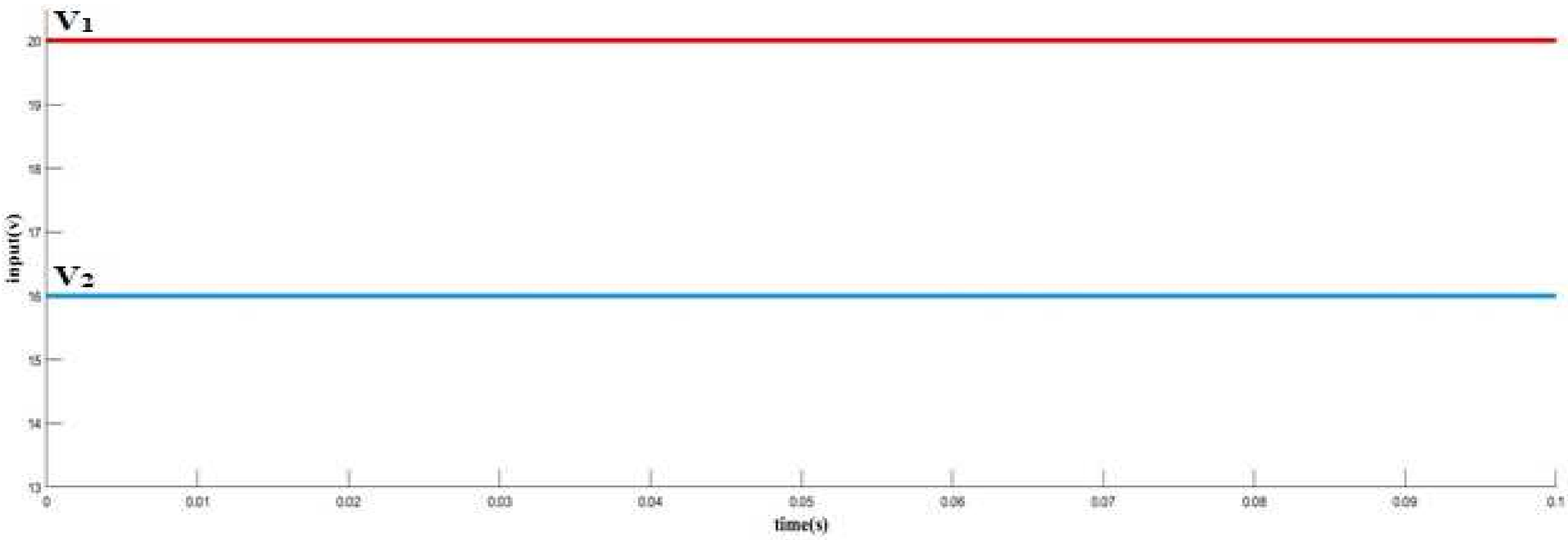

Fig.5. Input voltages V_1 and V_2

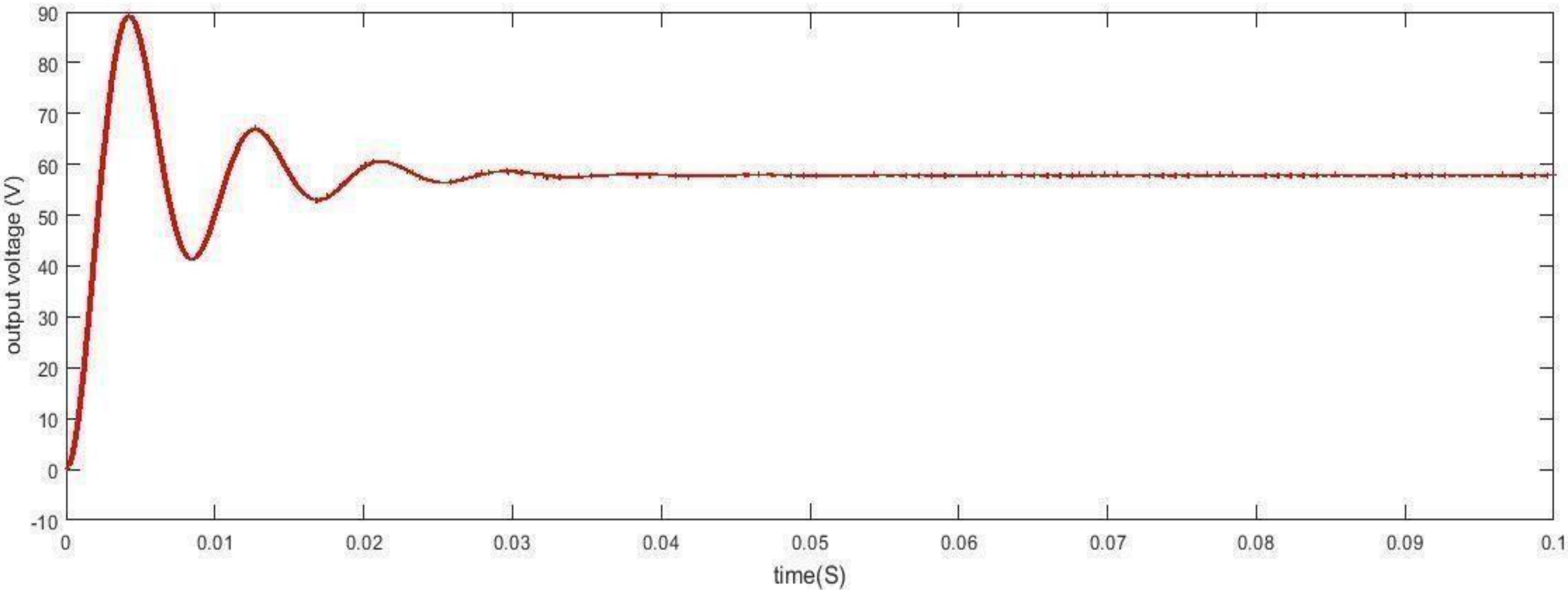

Fig.6. Output voltage

Output voltage of 60 volt obtained from Bridge type dual input converter across the load resistor by MATLAB simulation.

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IV. SIMULATION OF CUK CONVERTER

A. Simulation parameters of Cuk converter

TABLE 2
SIMULATION PARAMETERS

PARAMETER	SPECIFIACTION
Input voltage,frequency	220V,50Hz
Input inductance Li12	4mH
Output inductance LO1	150µH
Intermediate capacitor C13	3µF
Transformer turns ratio	0.33
Output voltage	65V

B. Simulation diagram and waveforms

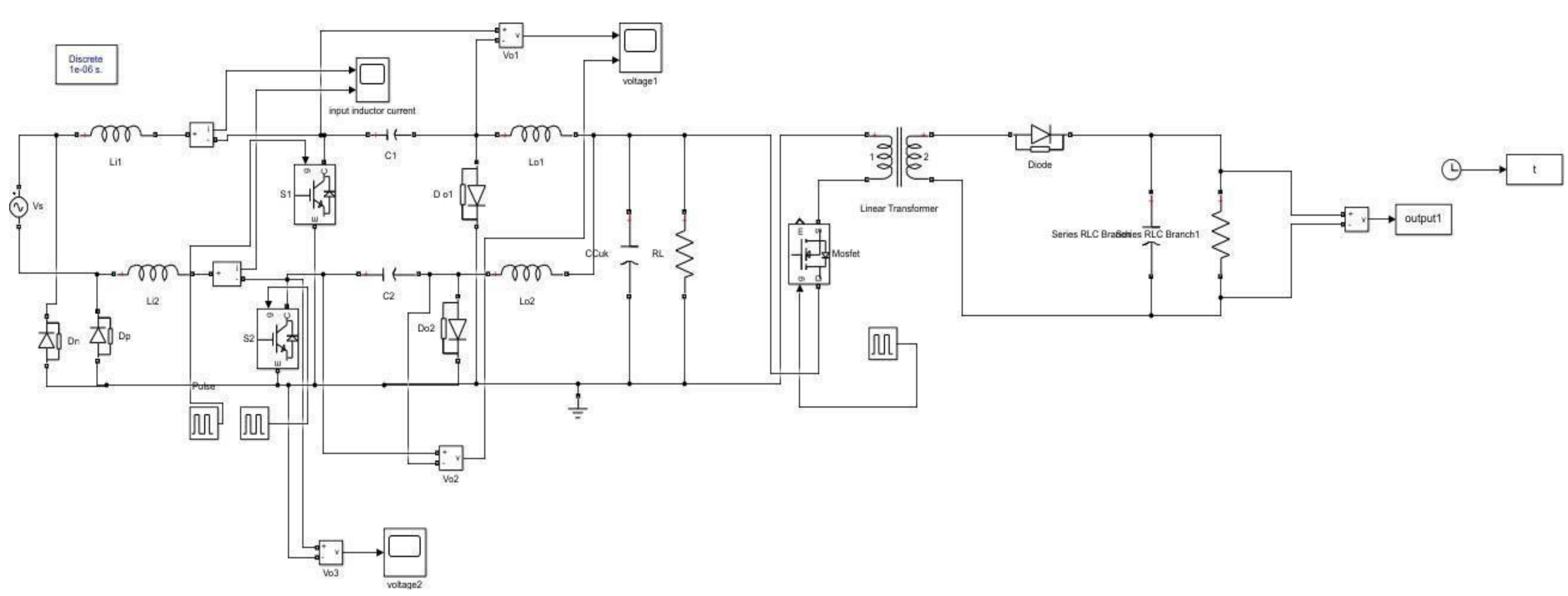

Fig.7. Open Loop Simulink diagram of Cuk converter

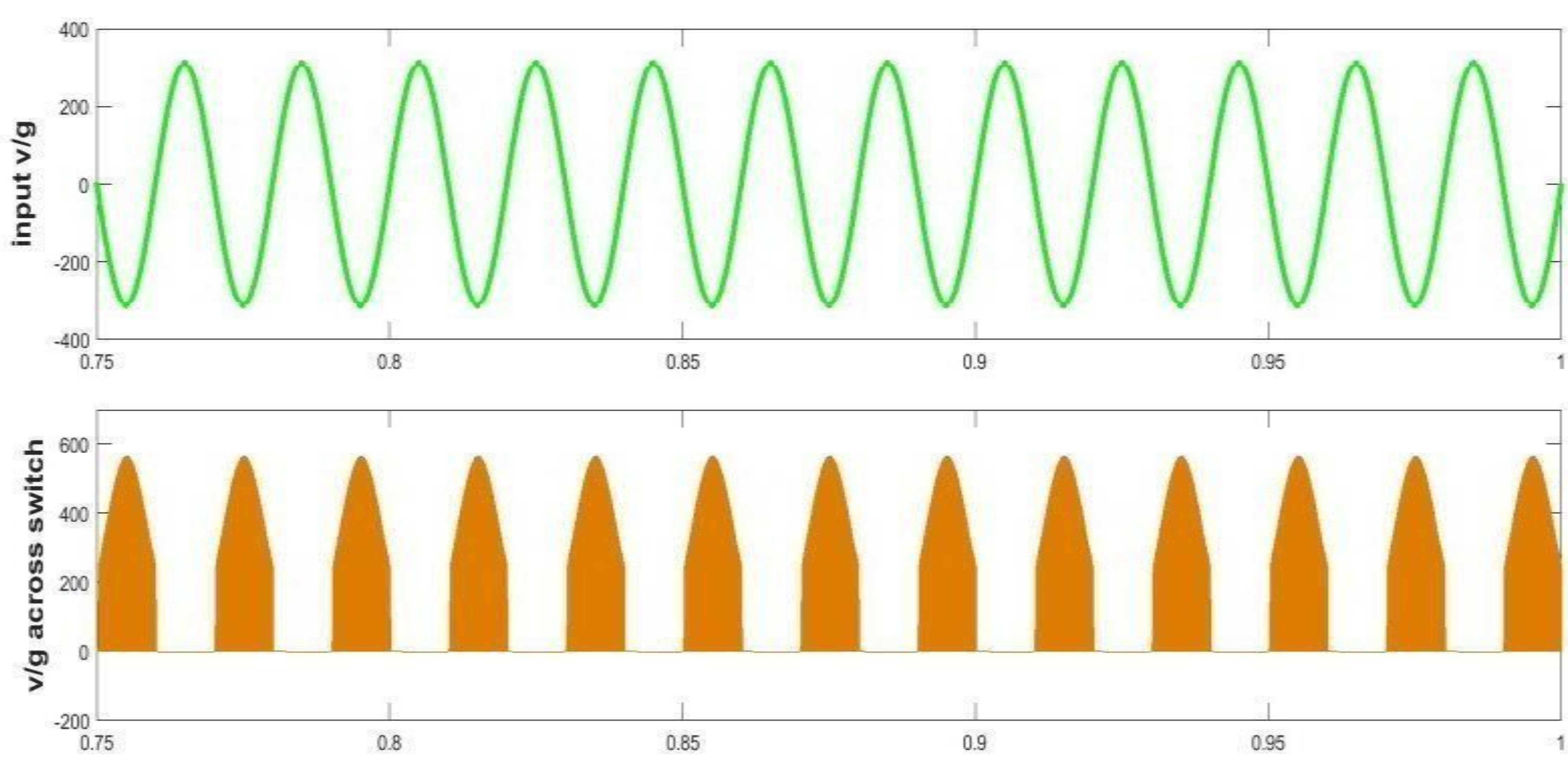

Fig.8. Input voltage and voltage across the switch

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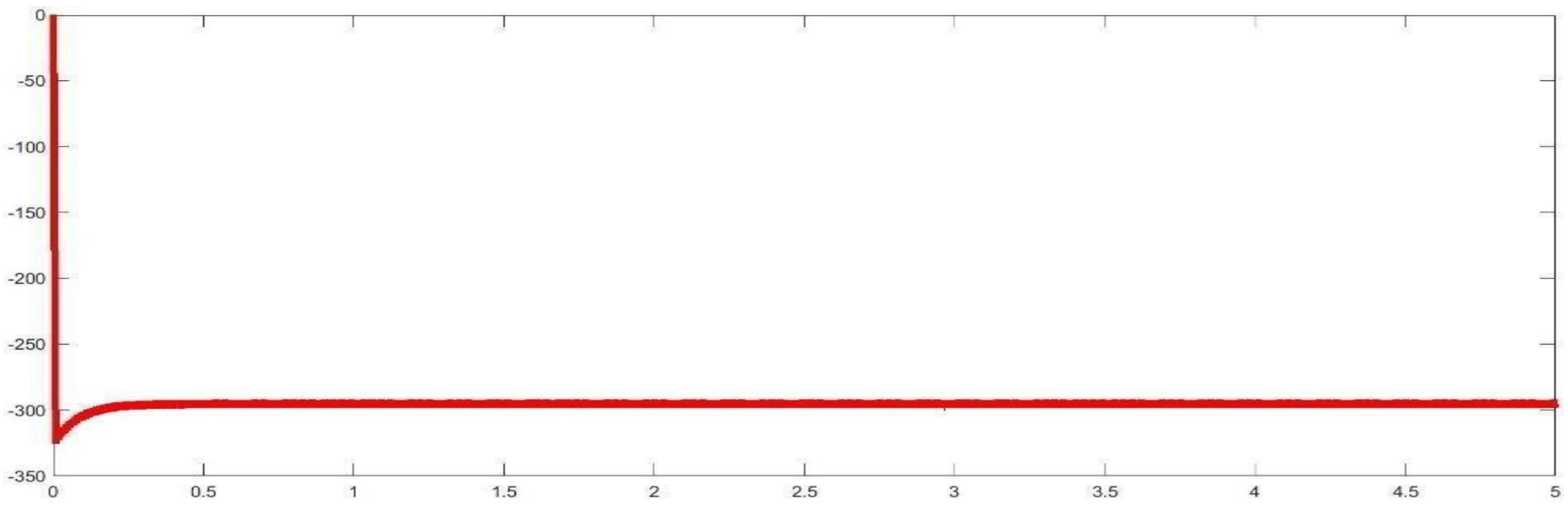

Fig.9. Output voltage across Cuk converter

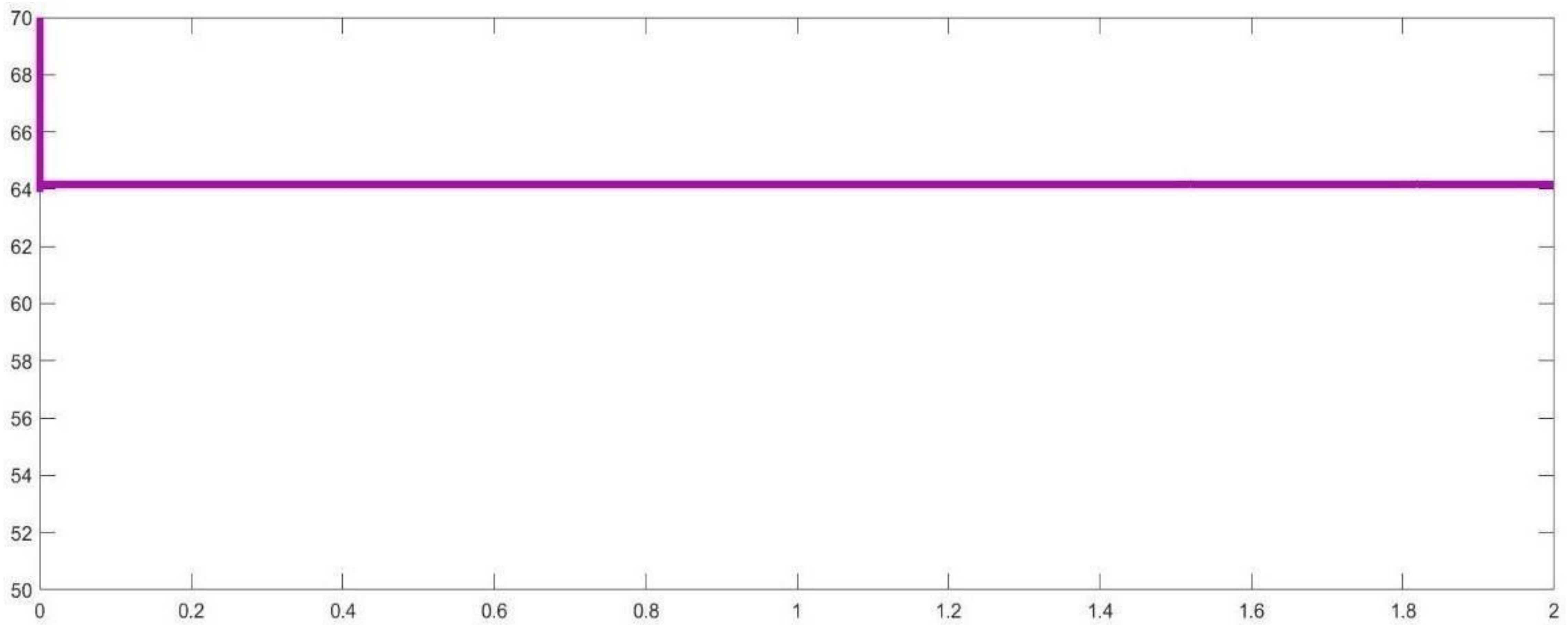

Fig.10. Regulated voltage across Flyback converter

V. COMPARISON BETWEEN CONVERTERS

TABLE II
COMPARISON BETWEEN CONVERTERS

	Bridge type dual inputconverter	Cuk converter basedcharger
Application	Electric vehicle, UPS, Hybridenergy integration system	Electric vehicle batterycharger
Structure	Compact	Complex
Design Procedure	Easy	simple
No of sources	2 source – can AC or DC	1 source – 230 Volt 50 Hz Acsupply
Conduction loss	Less	Less
Power factor	Unity	Unity

VI. CONCLUSION

Comparative analysis of two converters Bridge type dual input converter and cuk converter based EV charger done on the basis of simulations done on the MATLAB SIMULINK Software. Both are power electronic converter and they play a crucial role as power electronic interface in various applications .Both the converter can be used in different EV application according to our requirement. Cuk converter is used as battery charger in EV. But at the same time application of dual input converter is high it can be used to drive the vehicle or to as battery charger, Uninterruptable power supply, hybrid energy integration systems.

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Reduced Components Multifunctional PEC for Charging Electric Vehicles

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Abstract: This paper deals with a Power Converter (PC) which enables charging of a battery from both solar power and grid power. The Integrated Converter used can function in various vehicle modes such as charging from solar and grid modes, running mode and V2G operation mode. The vehicle battery can be charged from either solar power or grid power.The battery uses both power sources simultaneously when the power supply from one source is not sufficient. The Integrated Power Converter acts as an isolated SEPIC converter during charging mode from grid power and as a non-isolated SEPIC converter in solar power charging mode. In propulsion and regenerative braking modes, it acts as boost topology and buck topology respectively. The Integrated Converter acts as a ZETA converter for Vehicle -to-Grid (V2G) mode.

Keywords:Electric vehicles,V2G and G2V mode, SEPIC,solar PV,PP and RB mode

I. Introduction

A major feature of Electric Vehicles (EVs) is that they can be plugged in to an off-board electric power source for charging [1]. Off-board chargers are located outside the EVs. They can transfer higher units of power. This helps charge the EVs faster. On the flipside, off-board chargers are heavier and larger..

Single stage charger is one type of on-board chargers, which directly transfers power from the AC source to the battery, thus eliminating the bulky electrolyte capacitor in a traditional two-stage charger. Since two-stage chargers require more components for charging,it is not widely used [3]. Single stage charging system requires only a few components and is hence cost effective.

In conventional charging setup,a bidirectional DC-DC converter is placed between Inverter-DC link and battery in the running mode [4]. An integrated converter [5] which can perform all the functions by interfacing power supply and battery has been developed.

Some of the topologies use plug-in charging mode and is not cost effective. The charger [6] uses only solar PV for charging the battery, when the solar power source is unable to generate the required power, leading to reduced system efficiency. The work [7] leads to the development of an integrated converter which uses both solar PV and grid supply for charging.

When vehicles are parking for long duration, the battery is charged through solar PV charging, but the energy is not being used [1]. If this power is fed back to the grid, it will increase the efficiency of the entire system. With proper addition of controlled rectifier and utilization of bidirectional converter topology, energy can efficiently flow from vehicle to grid (V2G mode) [8].

Based on the above literature, a new dual-power single-stage multifunctional integrated converter is presented for EVs. The block diagram (figure 1) shows that the integrated converter is capable of performing multiple functions including rectification stage,bidirectional DC- DC converter and MPPT converter stages. The features of the integrated converter topology can be summarized as follows (a) it uses both solar and grid power for charging of battery, which increase the reliability of system. (b) It enhances the safety of the vehicle due to provision of isolation. (c) It is more cost effective due to reduction in the number of components. (d) It can achieve various modes of vehicle operation, and finally (e) the topology can use the solar power generated for implementation of V2G mode of operation.

The integrated converter functions as a non-isolated and an isolated SEPIC converter during the two charging modes. It operates as a boost converter during propulsion mode and as a buck converter in regenerative braking mode. The converter acts as an isolated ZETA converter during V2G mode of operation as shown in Fig. 2. The semiconductor switches S_{a1}, S_{a2}, S_{a3} and S_{a4} control the charging and running modes by providing proper PWM.

The remaining sections of this paper are organized as follows. Converter operations and different modes are discussed in section II. Section III deals with switching stress present in semiconductor devices. Section IV discusses the design and analysis part. Section V deals with the control algorithm used for proper control of modes. Finally, the simulations, parameters and the results are discussed in section VI.

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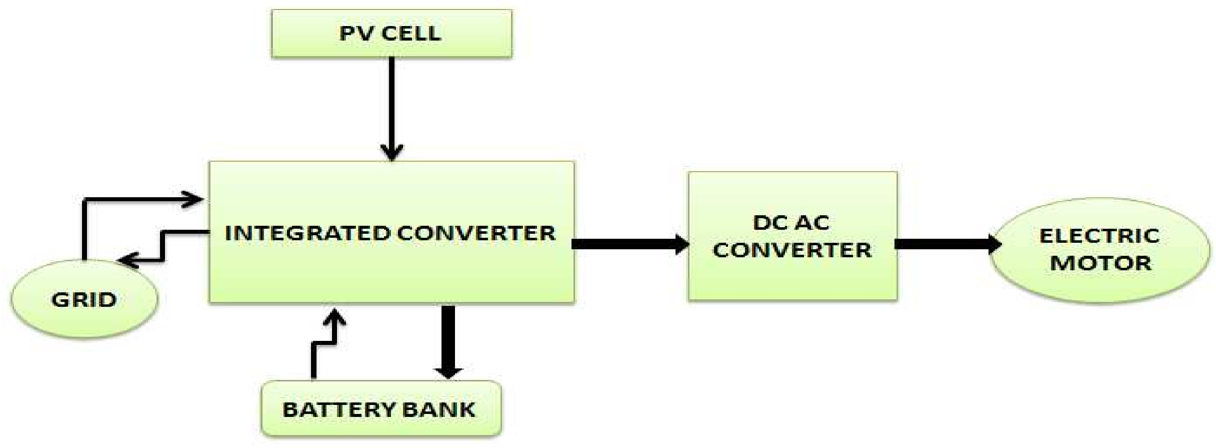

Fig.1. Block Diagram of Charging System

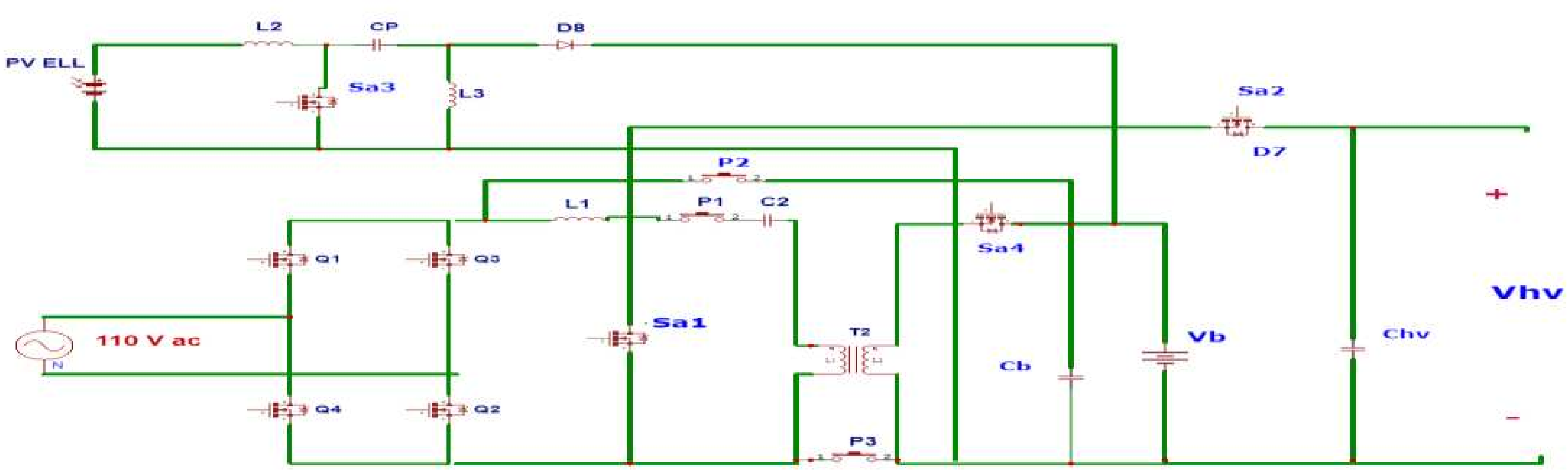

Fig.2. Circuit Diagram of the Topology

II. MODES OF OPERATIONS OF THE POWER CONVERTER

The block diagram of the system shown in Fig.1 consists of the two power supply sources – the grid and the PV. The integrated converter is connected to both sources for charging the battery. The direction of arrows indicates the charging of battery and V2G mode respectively.The circuit diagram of the topology is explained inFig.2. The switching states in each mode is tabulated in Table Ⅰ.

A. Solar PV Mode

In situations where solar power is sufficient to charge the battery, it uses the Solar PV System to charge. The Solar PV system is connected to the battery through non-isolated SEPIC converter. The Perturb and Observer-based Maximum Power Point Tracking (MPPT) controller is implemented using dspic30f2010throughthis non-isolated SEPIC converter for the optimal performance of the converter.The electrical schematic of MPPT controller is shown in Fig. 18.

When switch S_{a3} is turnedON, the solar power is supplied to inductor L_2.L_2stores the energy and capacitor Cp discharges its stored energy to inductor L_3. Thus inductors$L_2$and L_3 are charging. During this time diode D_8 is reverse-biased so that capacitor C_b provides sufficient energy to the battery. When$S_{a3}$is turned off,L_2 charges capacitor Cp and L_3 charges the battery through diode D_8which is forward-biased as shown in Fig. 3.

B. Grid Mode

When solar panel is unable to provide the required power for charging, the converter uses power from the grid. When switchS_{a1} turns ON, the active rectifier rectifies the AC voltage and the rectified DC voltage is given to$L_1$and C_s charges magnetizing inductance L_m of high frequency transformer and C_b provides the required energy for the battery. When$S_{a1}$is in OFF state, energy stored in L_m is transferred to the battery through diode D_6as shown in Fig. 4.

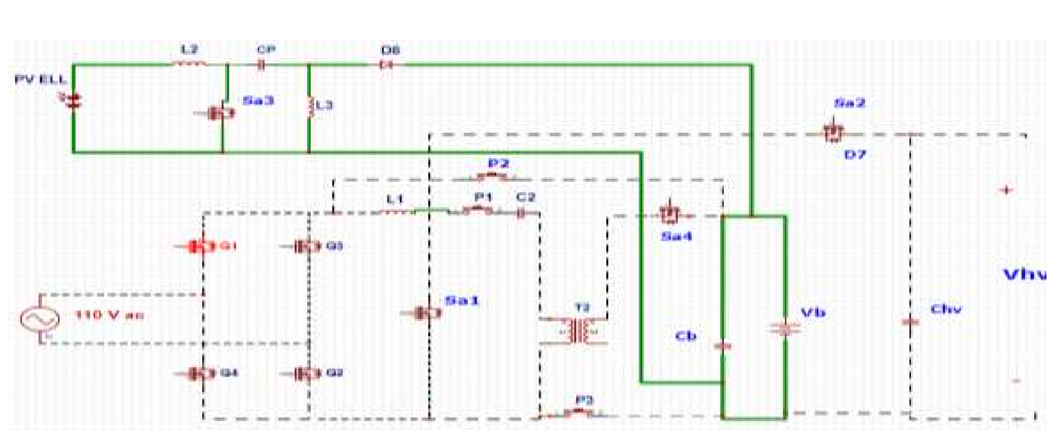

Fig.3.Solar PV Mode

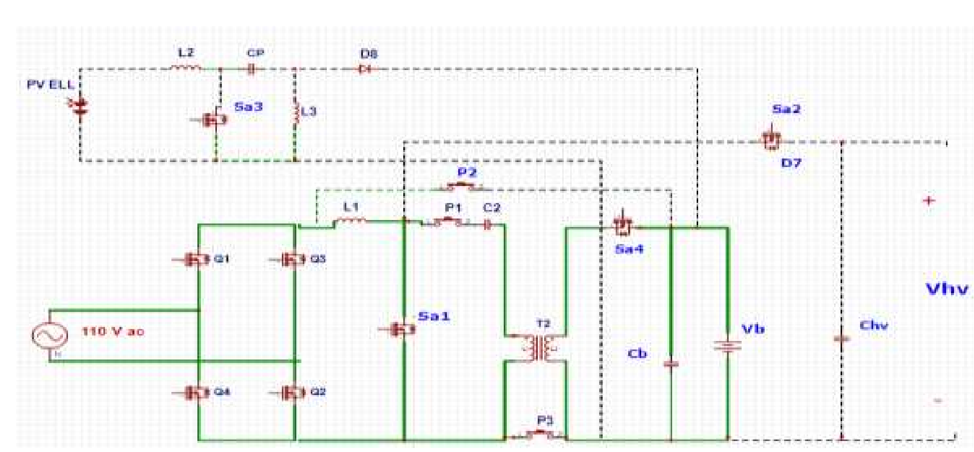

Fig.4.Grid Mode

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C. Solar PV and Grid Mode

When solar power is not sufficient, grid power supports the chargingof the battery.The grid supplies the remaining power. In this mode,battery is charged from both supplies simultaneously. The switches$S_{a3}$and S_{a1}control this mode.S_{a1}controls the charging of battery from grid power and S_{a3}controls the solar power charging of battery using proper PWM as shown in Fig. 5

TABLE I

SWITCHING STATES IN ALL MODES

Mode of operation	**Sa1**	**Sa2**	**Sa3**	**Sa4**	**P1**	**P2**	**P3**	**D5**	**D6**	**D7**	**D8**	**D9**
Grid mode	PWM	OFF	OFF	OFF	ON	OFF	OFF	OFF	ON	OFF	OFF	OFF
Solar PV mode	OFF	OFF	PWM	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF
Solar PV and grid mode	PWM	OFF	PWM	OFF	ON	OFF	OFF	OFF	ON	OFF	ON	OFF
PP mode	PWM	OFF	OFF	OFF	OFF	ON	ON	OFF	OFF	ON	OFF	OFF
RB mode	OFF	PWM	OFF	OFF	OFF	ON	ON	ON	ON	OFF	OFF	OFF
V2G mode	OFF	OFF	OFF	PWM	ON	OFF	OFF	ON	ON	OFF	OFF	OFF

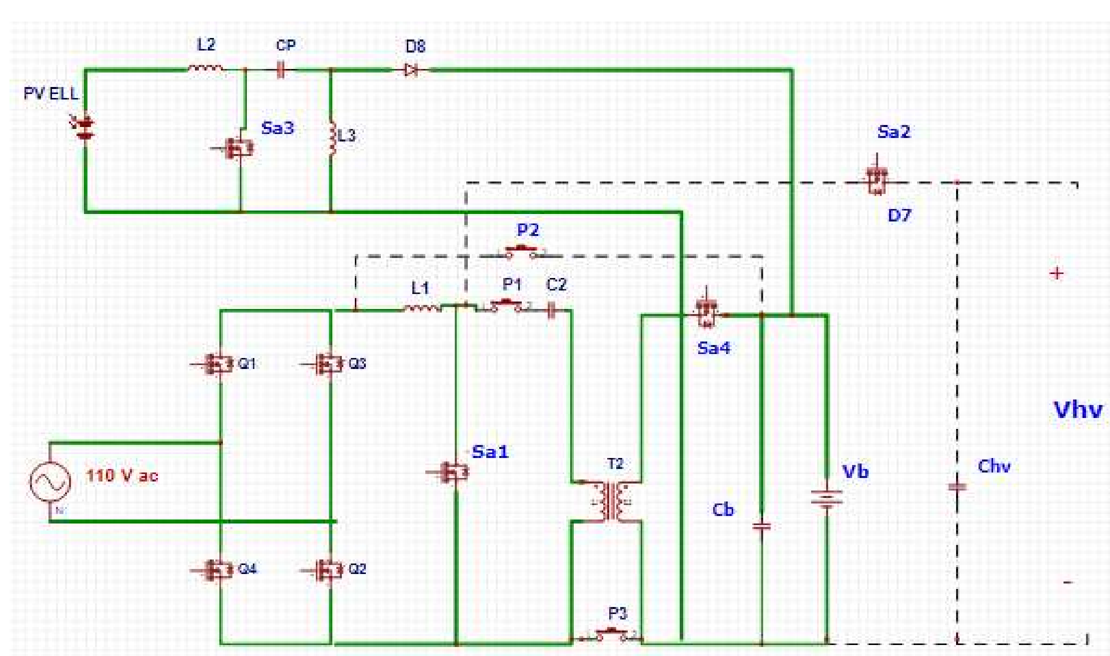

Fig.5. Solar PV and Grid Mode

D. Propulsion Mode

The system acts as a boost converter as the energy stored in the battery is boosted in to DC link voltage during the running mode. The switch S_{a2}controls the mode by giving the appropriate PWM signal. The mechanical switches $P_2$and $P_3$are permanently ON in this mode. During turn ON of S_{a2},the battery energy charges the inductor $L_1$and during turn off period, L1 discharges its stored energy to C_{hv}. This DC link voltage V_{hv} can be transferred to run the motor through an inverter setup.

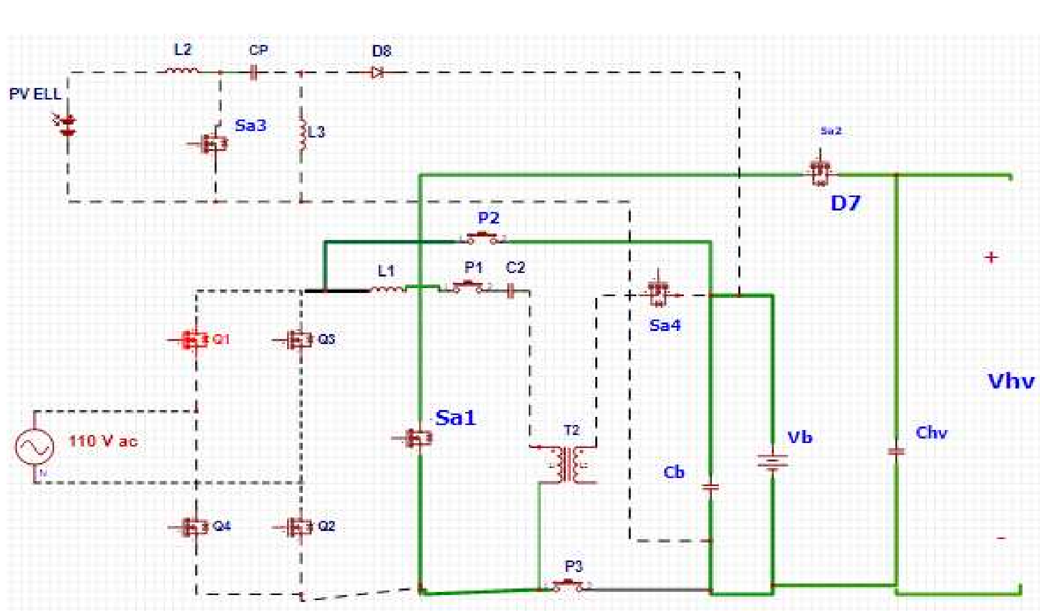

Fig.6.Propulsion Mode

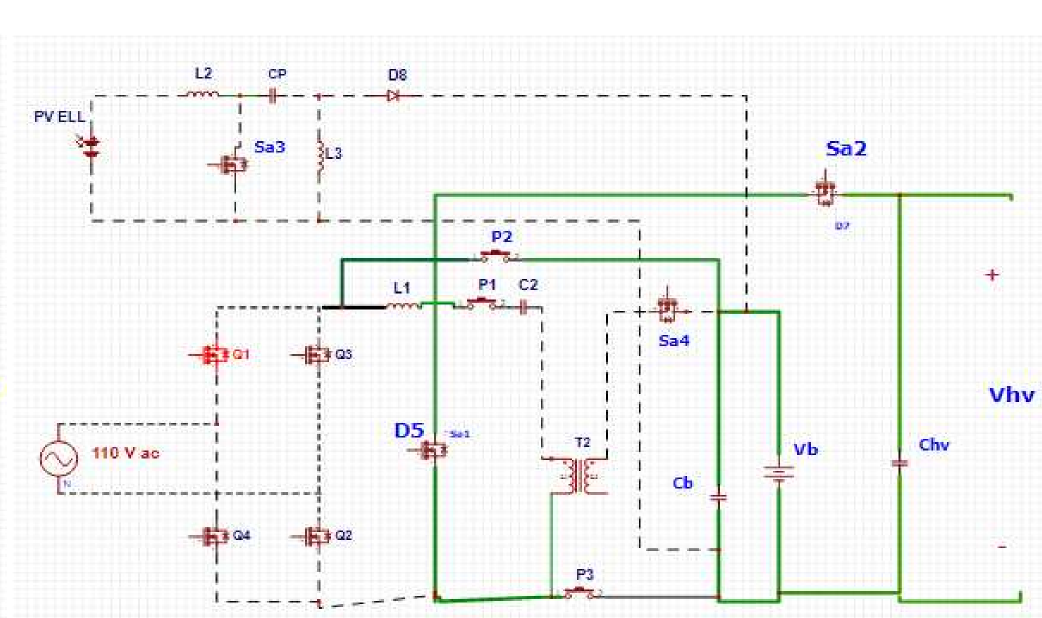

Fig.7. RB Mode

E. Regenerative Braking(RB) Mode

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The battery can be charged in running mode by using the kinetic energy of the wheels. Hence this mode is called RB mode. In this mode, the integrated converter is working as a buck converter. Switch S_{a2} controls the mode and P_2,P_3 are permanently ON as in the propulsion mode. During turn ON period,L_1 store the energy and this stored energy will be supplied to load duringturn-off as shown in Fig.7.

F. V2G mode

The power converter acts as ZETA where switch S_{a4} controls this mode. During turn ON period of S_{a4},capacitor $C_s$is charging and during the urn-off period, the energy stored in capacitor will be given to inductor L_1as shown in Fig.8.

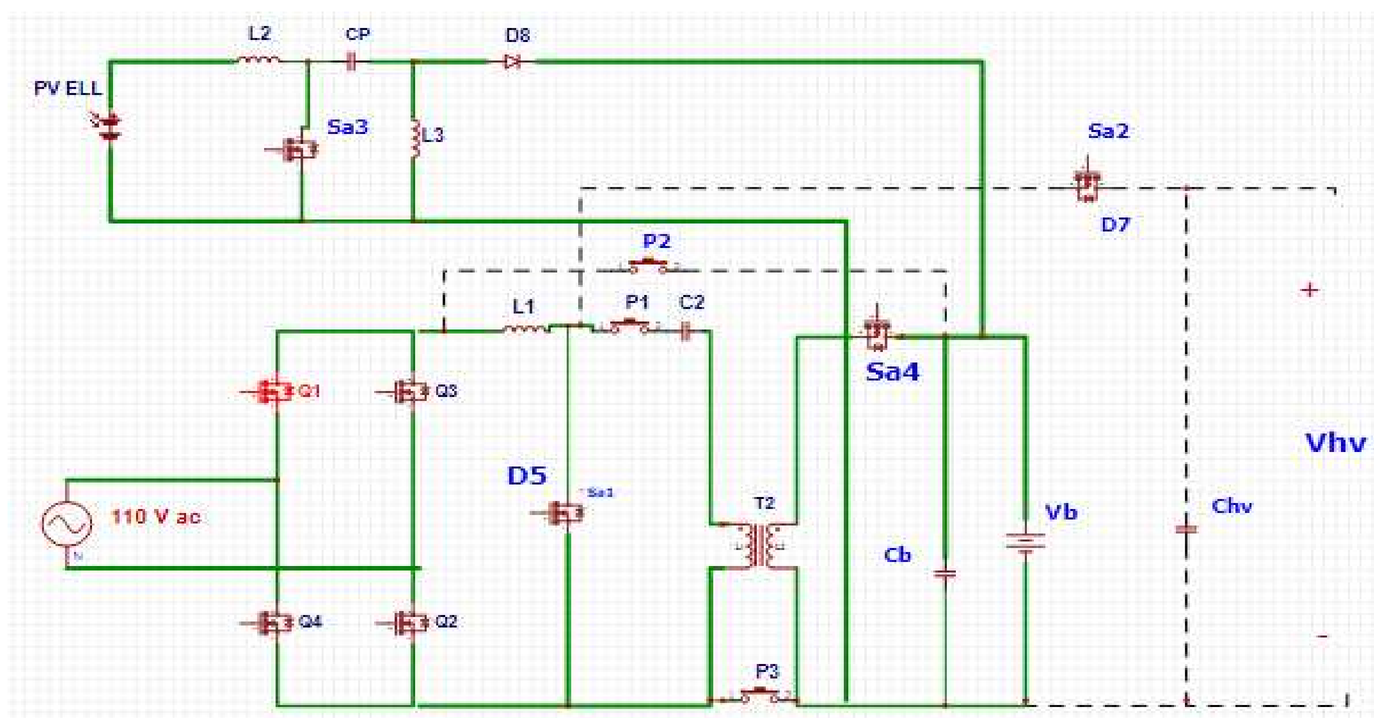

Fig.8. V2G Mode of Power Converter

III. VOLTAGE STRESS ON POWER DEVICES

The peak voltage stress is analyzed and tabulated in Table II. Some of the semiconductor devices are made to operate and work in multiple modes, for example, switch S_{a2} is operated in propulsion mode and in running mode. Hence the rating of the components is taken as the maximum rating as derived from Table II.

TABLE Ⅱ
VOLTAGE STRESS ON SEMICONDUCTOR DEVICES

Switching devices	Grid mode	PV mode	PP mode	RB mode	V2G mode
Sa1	Vg + Vb	-	Vb	Vb	-
Sa2	-	-	Vhv	Vhv	-
Sa3	-	Vpv +Vb	-	-	-
D6	Vg +Vb	-	-	-	Vg + Vb
D8	-	Vpv + Vb	-	-	
Sa4	-	-	-	-	Vg +Vb

IV. DESIGN OF PASSIVE COMPONENTS

A. Inductance L_1

In grid mode,the value of inductance can be calculated by analyzing the working of isolated SEPIC converter. The design part is as given below:

Since the average voltage across an inductor is zero for periodic operation,the equations arecombined to get

$$|V_g|(\mathrm{DT}) - \mathrm{Vb}\,((1-\mathrm{D})\mathrm{T}) = 0$$

where D is the duty ratio of the switch. The result is

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$$\mathrm{Vb} = |V_g|\frac{D}{1-D}$$

which can be expressed as

$$\mathrm{D} = \mathrm{d1} = \frac{Vb}{Vb+|Vg|}$$

Solving for average inductor current, which is also the average source current,

$$V_{L1} = \mathrm{Vg} = \mathrm{L1}\,\frac{di_{L1}}{dt} = \mathrm{L1}\,\frac{\Delta i_{L1}}{DT}$$

$$\Delta i_{L1} = \frac{VgD}{L1fs} \tag{1}$$

In PP mode,the value of inductance L1 can be calculated by analyzing the boost converter

$$\mathrm{V_{hv}} = \frac{Vb}{(1-D)}\ ;\mathrm{L1} = \frac{VbD}{\mathrm{fs}\,\Delta i_{L1}} \tag{2}$$

InRB mode,the value of L1 is calculated from equations given below

V_b = D Vhv; D= d_2

From peak to peak inductor current,the value of L1 is summarized as

$$\mathrm{L_1} = \frac{Vhv(1-D)}{\mathrm{fs}\,\Delta i_{L1}};\ \mathrm{D{=}d_3} \tag{3}$$

In V2G mode of operation,the value of L_1 can be find out from the expression

$$\mathrm{D{=}\ d_4} = \frac{Vg}{Vb+Vg}$$

$$\mathrm{L_1} = \frac{1}{2}\frac{VbD}{\mathrm{fs}\,\Delta i_{L1}} \tag{4}$$

From these expressions of inductance L_1 obtained from (1), (2) and (3), (4)the maximum value of L_1 can be selected for thepassive element L_1.

The value of magnetizing inductance Lm can be found out by using the expression

$$\mathrm{L_m} = \frac{Vg^2}{Pg}\frac{1}{€fs}\frac{Vb}{Vg+Vb} \tag{5}$$

Where € is% ripple of the grid current ig.

B. Capacitors Cs, Cb and Chv calculation

From the definition of capacitance andconsidering the magnitude of charge,solving for Cs ;

$$\mathrm{Cs} = \frac{Vbd1(t)}{kVgRLfs} \tag{6}$$

Where k is the % ripple in v_{cs} and R=$\frac{Vb^2}{Pb}$

In V2Gmode, Cs can be found out using the expression,

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$$Cs = \frac{igd4}{\Delta Vgfs} \tag{7}$$

The capacitor Cb is chosen based on second harmonic (100 Hz) voltage ripple experienced by it,

$$Cb = \frac{Pb}{2\omega\delta Vb^2} \tag{8}$$

Where δ is the ripple present and ω= 2∏f where f= 50Hz

And Cb obtained from V2G mode (ZETA) is,

$$Cb = \frac{igd4}{fs\Delta Vg} \tag{9}$$

The value of capacitance Chv is calculated by considering Propulsion mode, so that

$$Chv = \frac{d2}{Rfs\frac{\Delta Vhv}{Vhv}} \tag{10}$$

The non-isolated SEPICconverter used for charging of battery from solar PV can be designed using the same analysis done in the previous section. For the given specifications used for simulation, the corresponding parameter values are calculated and listed in Table III.

TABLE III

PARAMETERS AND POWER STAGE COMPONENT SPECIFICATION

Design Parameters		**Design Specifications**	
Parameters	**Values**	**Component**	**Values**
Grid voltage	110 V	battery	48 V,26 Ah
Solar PV voltage	18 V	capacitors	330/1/1200 μF
DC link voltage	400 V	Inductor L1	2 mH
Reference power	800 W	Inductor Lm	2 mH
Switching frequency	20 kHz	Motor	Rotor type,squirrel cage,3HP,230 V

V. CONTROL TECHNIQUES

Control techniques of the integrated modes are explained in this section.

A. *Control Technique for grid and Solar PV Modes*

The battery is charged from both Solar PV and the grid, with priority to solar power. It is a two-loop control strategy. The energy supplied by the grid is calculated using the error detector and the output is fed to the PI controller. The DC signal produced by the PI controller is compared with the sawtooth waveform and the pulse generated is given to switch S_{a1} to control the grid mode as shown in Fig.9.

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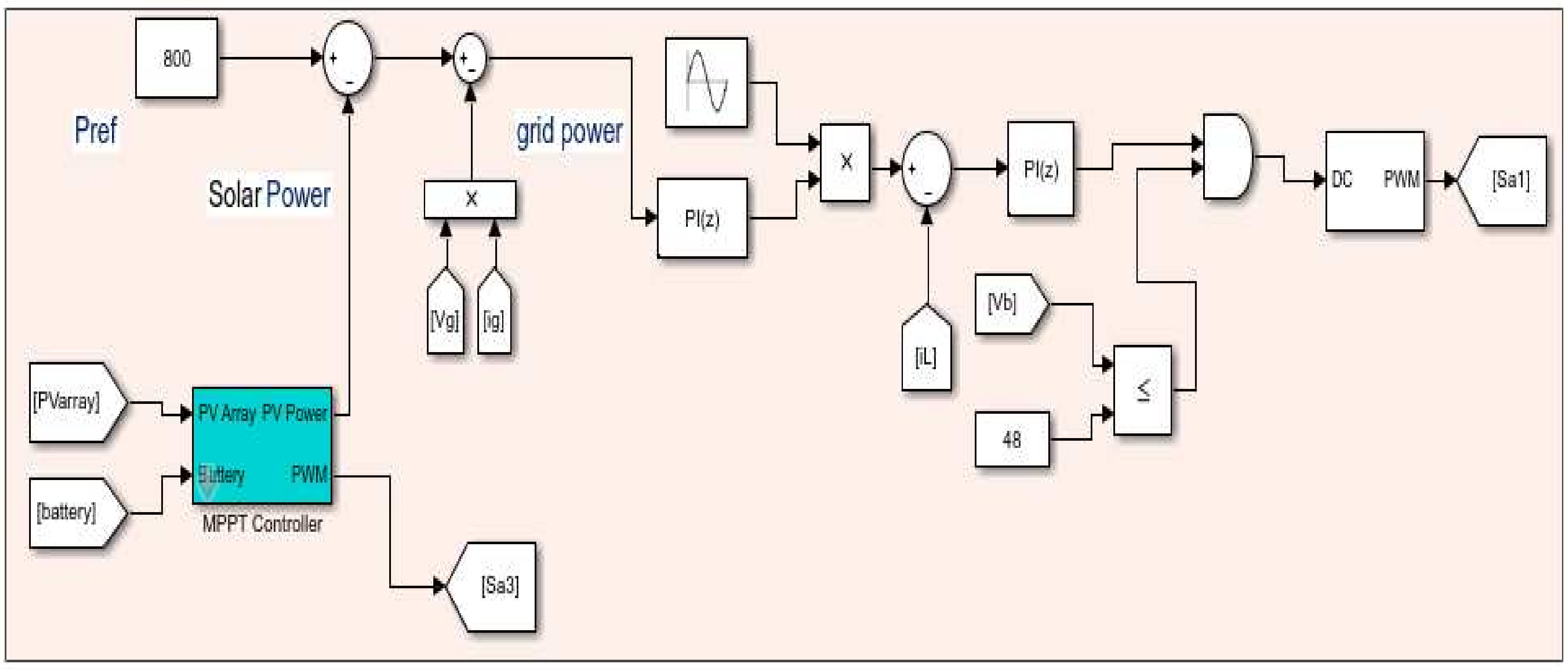

Fig.9.Control of Solar PV and Grid Modes

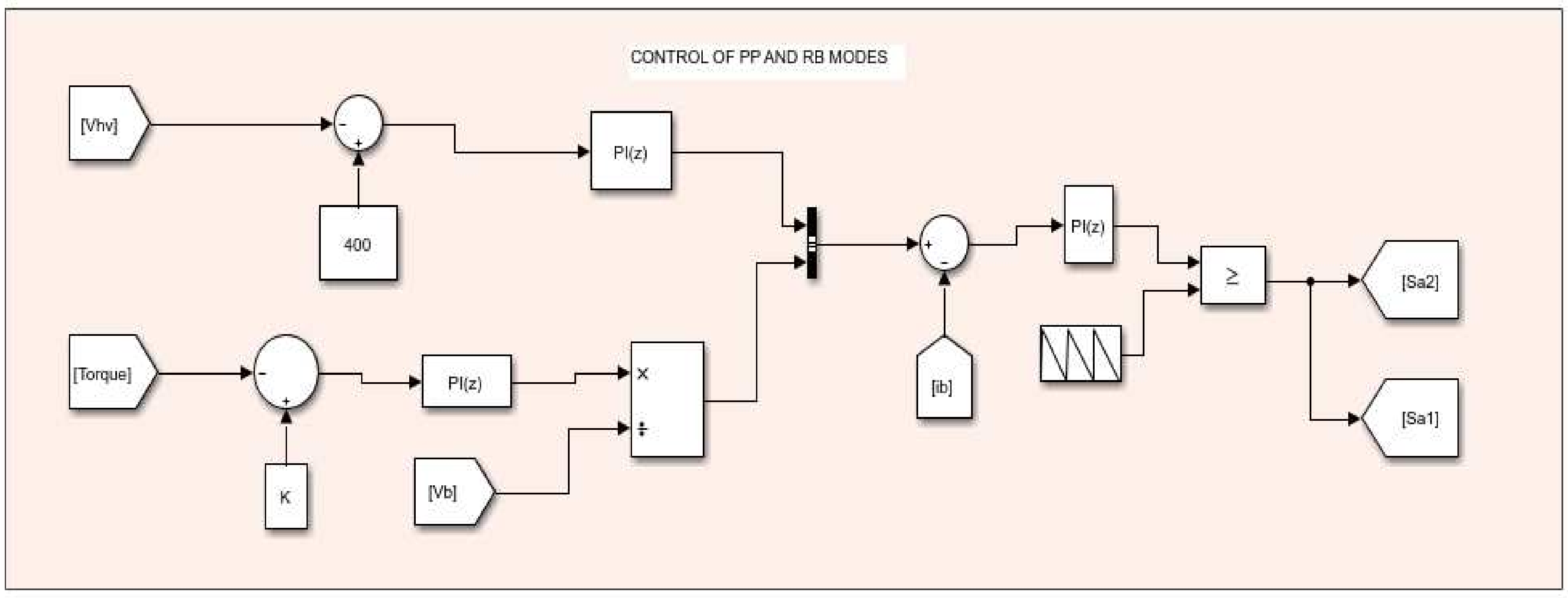

Fig.10.Control of PP and RB Mode

The solar mode is controlled using Perturb and Observer-based algorithm as shown in Fig. 18. Microcontroller-based charge controller design is feasible for performing complex tasks. dspic30F2010microcontroller used in this charge controller is central in coordinating all system activities.Port A is used for voltage sensing of battery and solar voltage whereas port B controls disconnect or reconnect operations for PV panel or load.Port B also controls generation of PWM signal which in turn controls the SEPICconverter as shown in the electrical schematic diagram Fig.18.

B. Control Technique for PP and RB Modes

The control technique for PP and RB modes are shown in Figure.10. Maintaining a constant DC link voltage is the purpose of PP mode.There are outerloop and inner loop controls as shown in Fig. 10. Theouterloop of both the modesproduce reference battery current.It is compared with the actual battery current and the error signal is fed to the inner PI controller. The controller produces DC signal which iscompared with a sawtooth signal produced by high frequency sawtooth generator and the generated pulse isprovided to switch S_{a2}.

C. Control technique for V2G Modes

The control strategy is a two-loop technology. The outer loop compares the actual and the reference voltages of the battery and the error is given to the outer PI controller which produces the reference current for V2G operation.The error detector feeds the difference between the measured and the reference battery currents tothe inner PI controller which produces PWM signal for the operation as shown in Fig. 11.

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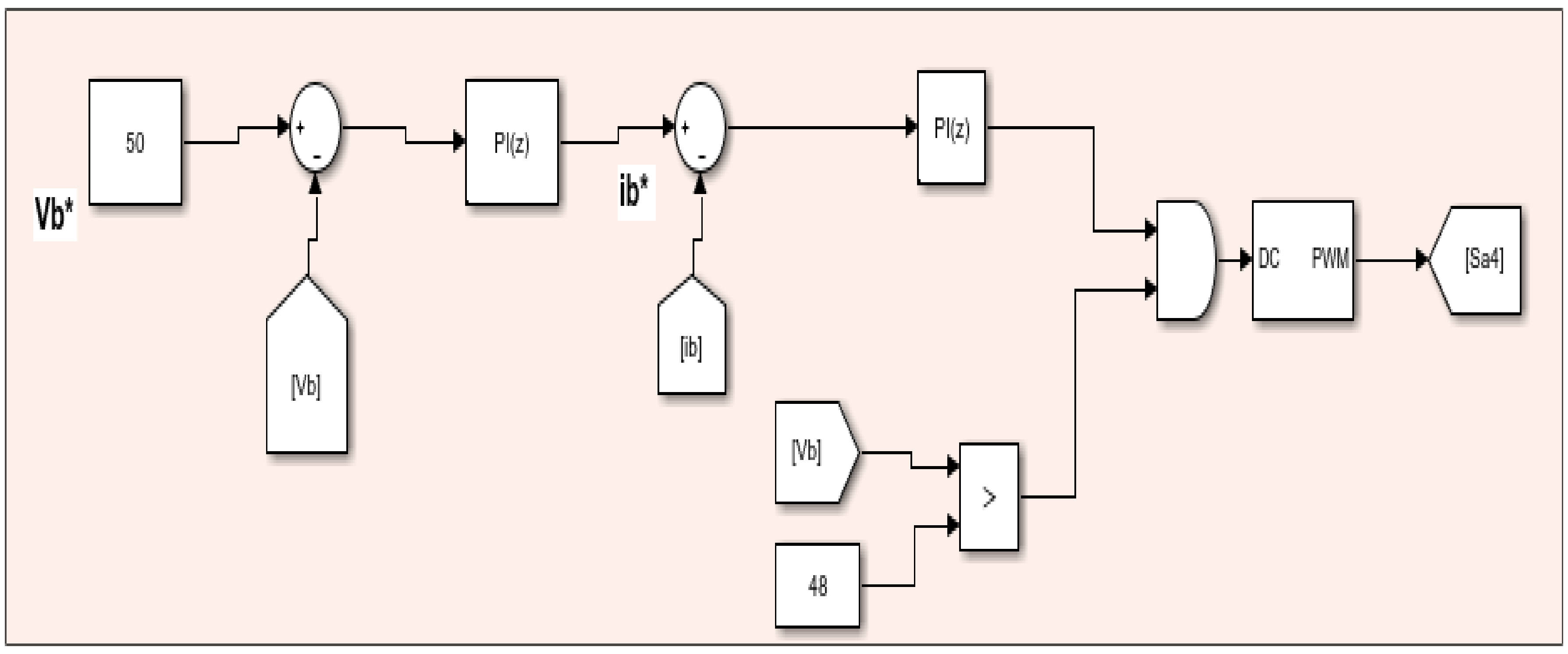

Fig.11.Control of V2G and G2V Modes

VI. RESULTS AND DISCUSSION

The integrated power converteris simulated on MATLAB SIMULINK 2018 software and the results are validated for a 48 V,26 Ah battery and a DC link voltage of 150Vshown in theFig. 12.The table Ⅲexplains the parameters used for simulation as obtained from design section. All modes are simulated and results are explained below.

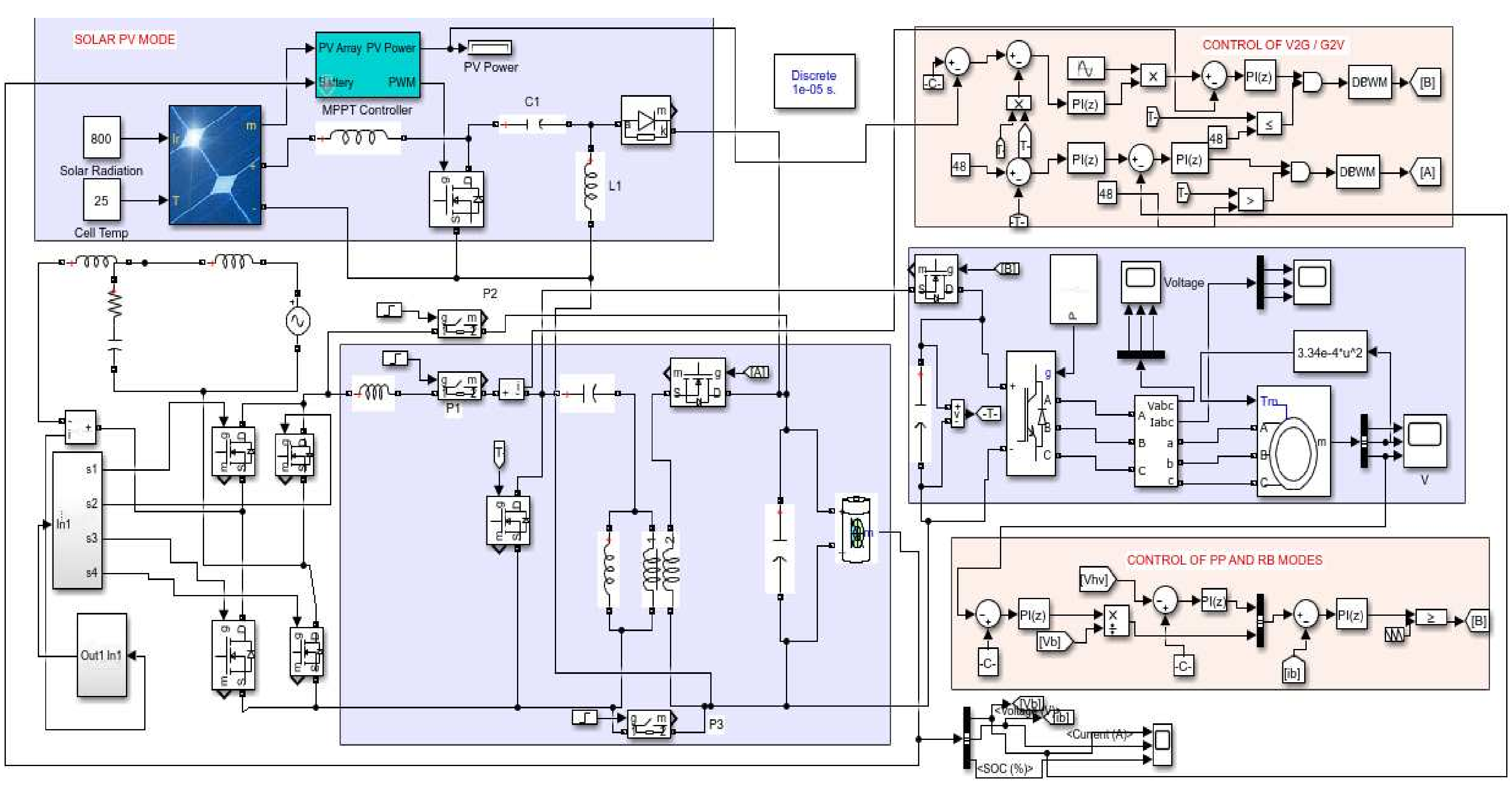

Fig.12.Simulink Diagram of the Entire System

A. Solar PV mode

When Solar PV alone supplies the required power to the battery, the measured Solar PV voltage at Maximum Power Point (MPP) is 60 V and current is 12 A, as shown in Fig. 13. The solar PV power, battery voltage and battery current are shownin Fig. 14. The measured battery current in this mode is 16 A and power at battery side is 800W. The overall efficiency of both converters (SEPIC isolated and SEPIC non-isolated) is 90.6%.

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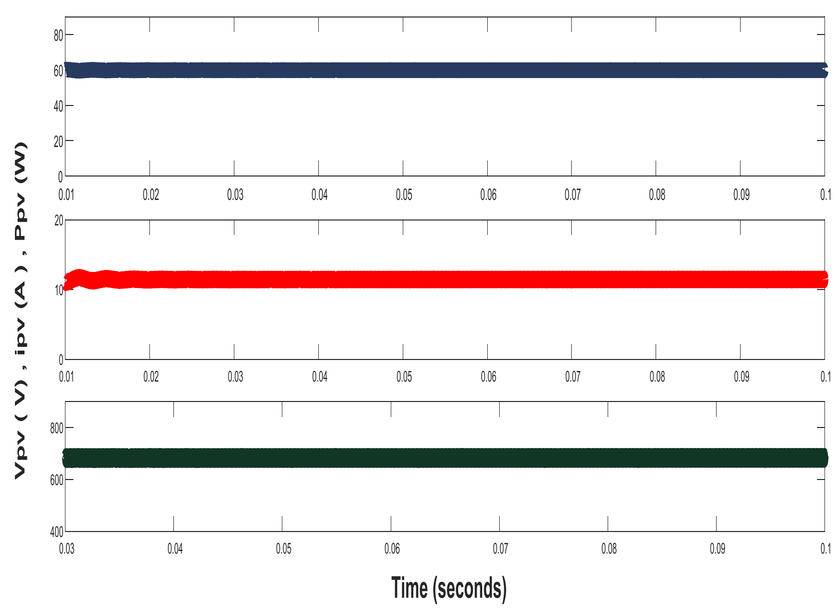

Fig.13. Solar PV Voltage and Current

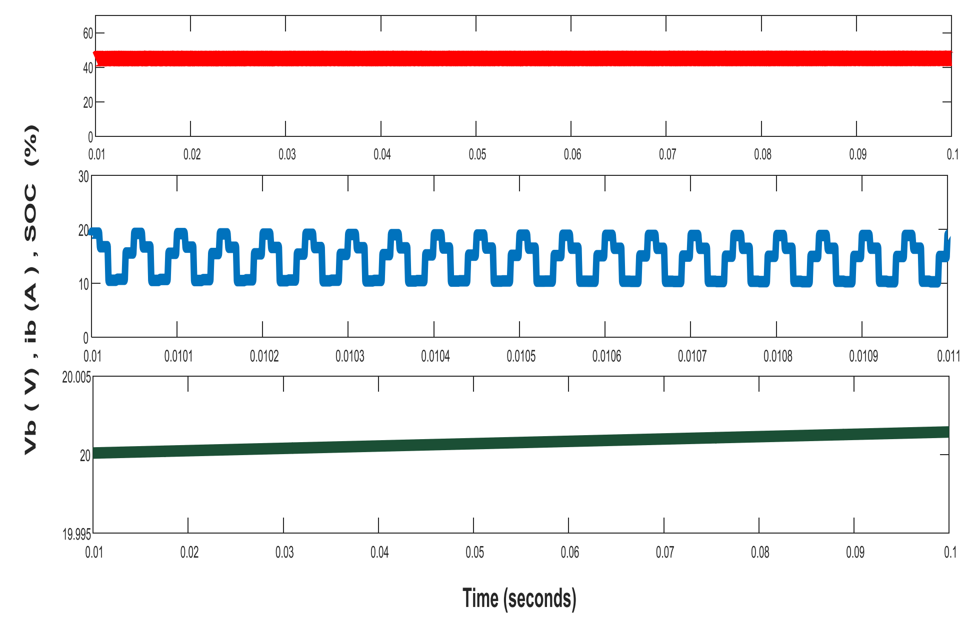

Fig.14.Battery Voltages and Currents in PV Mode

B. Solar PV and Grid Mode

In Solar PV and Grid mode, Solar PV system is set to operate at 400 W/ m^{2}solar irradiation, and the reference poweris setas 800 W.Here solar PV system provides 400 W and the remaining power is supplied by the grid.The grid voltage and current V_g and $i_g$are in the same phase as shown in Fig. 15.

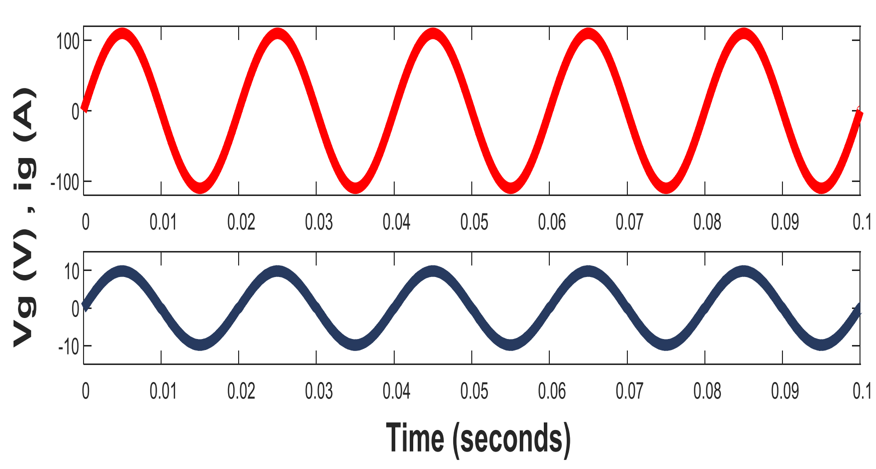

Fig.15.Grid Voltage and Current

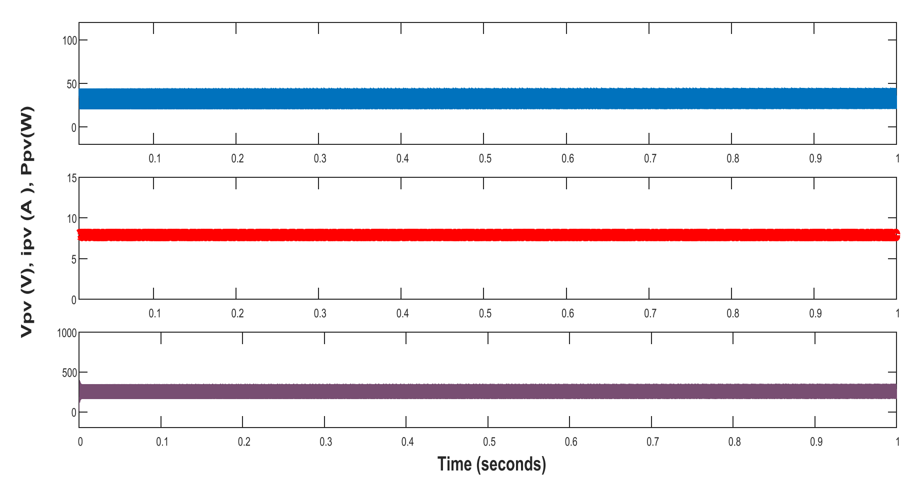

Fig.16.Solar Voltage and Current

The measured Solar PV voltage at Maximum Power Point (MPP) is 48 V and current is 9 A. The Solar PV power,voltage andcurrent are shown in Fig.16. The measured battery current in this mode is 15 A and power at battery side is 750Was shown in Fig.17. The overall efficiency of both converters (SEPIC isolated and SEPIC non-isolated) is 93.75%.

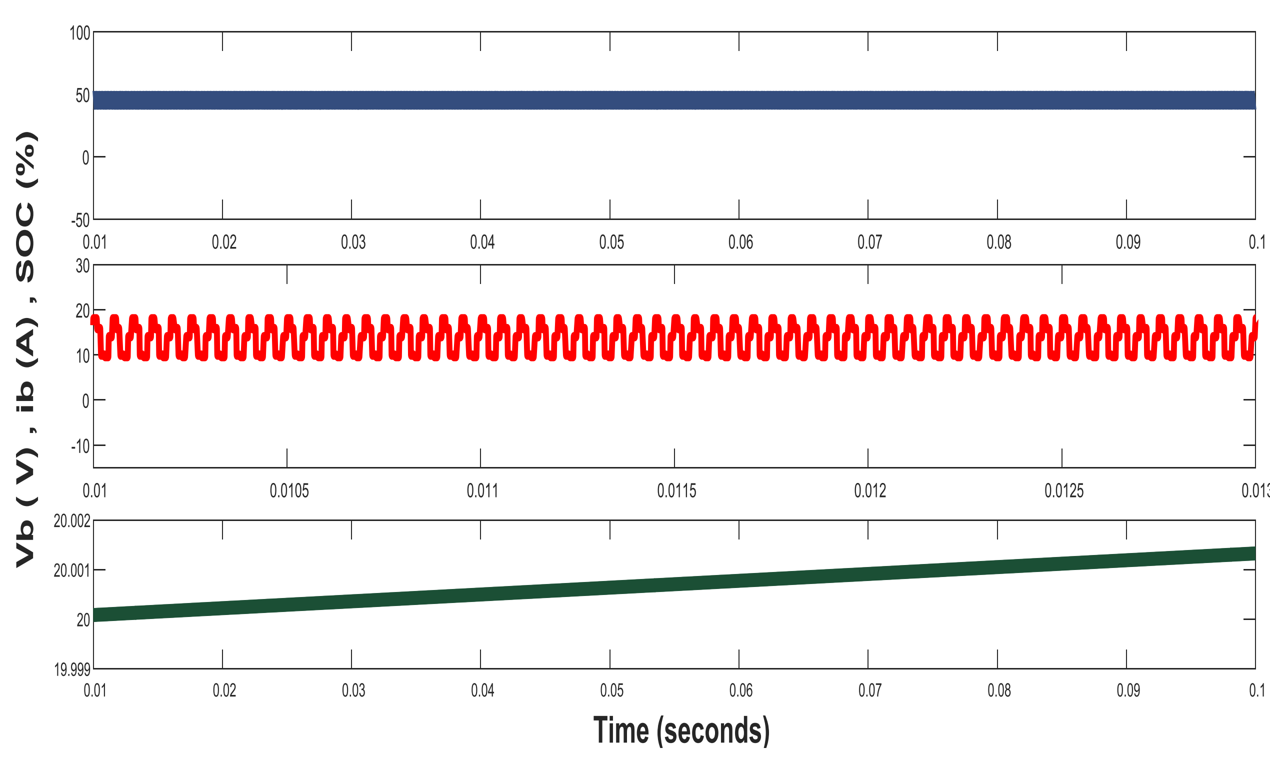

Fig.17. Battery voltage and current

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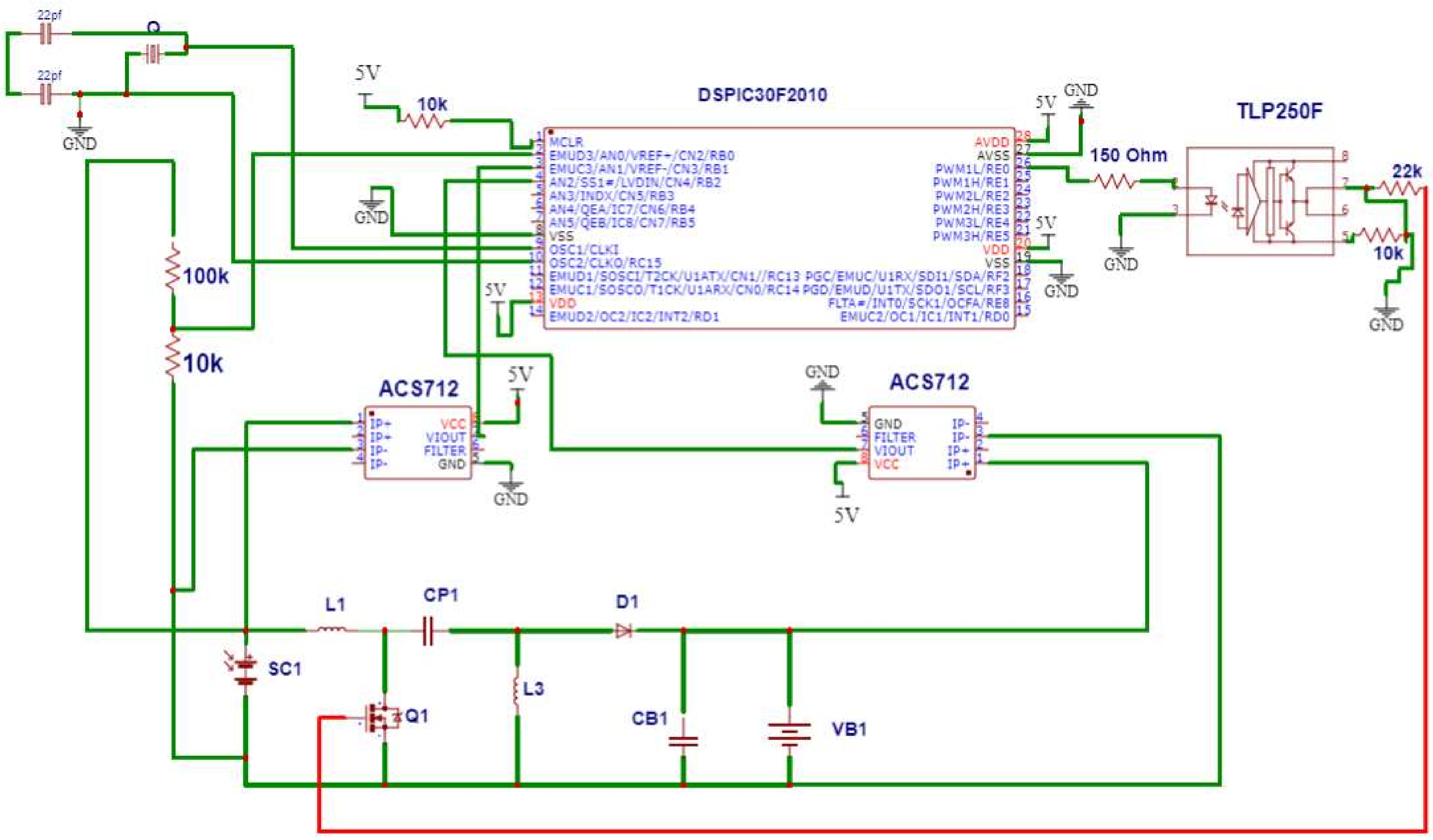

Fig.18. Electrical schematic of MPPT controller

C. Propulsion and Regenerative BrakingModes:

The simulatedwaveforms of Propulsion mode are as shown in Fig.19.The reference DC-link voltage is 400 V and the objective of PP mode is to regulate the DC-link voltage at the reference value. The DC link voltage and SOC of battery waveforms are shown in Fig.19. Speed of the motor decreases when brakes are applied.Hence the generated voltage, i.e., DC link voltage decreases. This regenerative braking mode is tested by reducing DC link voltage from 400 V to 250V.The battery is charged through a currentof 20 A and voltageof50 Vas shown in Fig. 20.

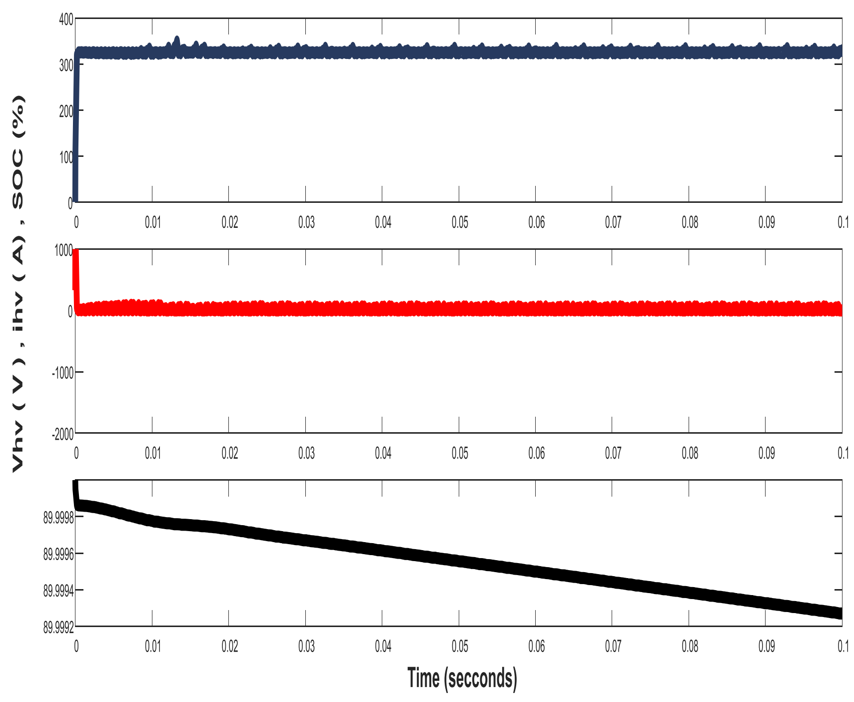

Fig.19.DC link voltage and battery discharging in PP mode

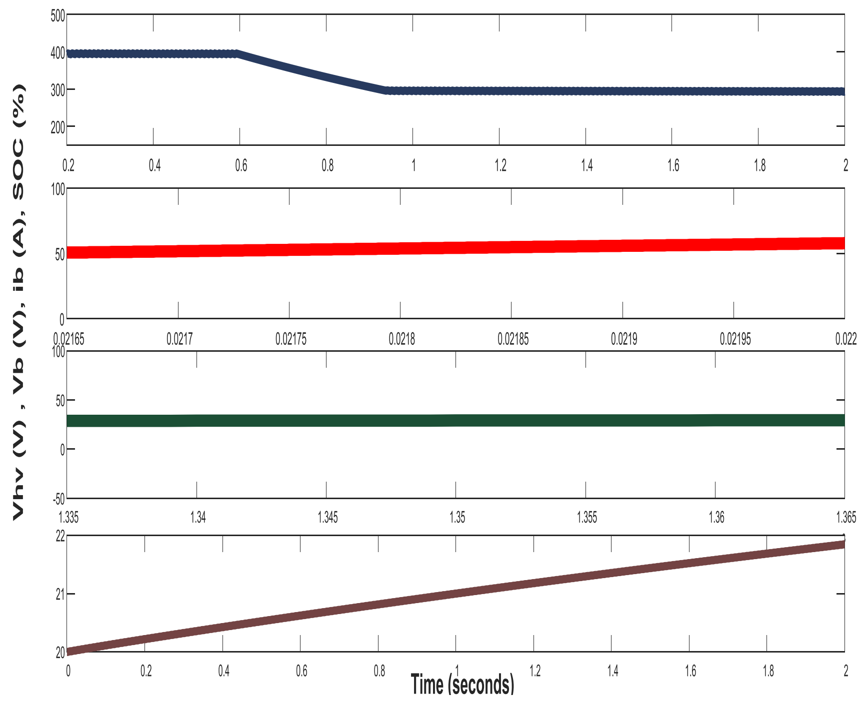

Fig.20.DC link voltage and battery charging in RB mode

D. V2G Mode

The energy stored in battery during parking period is utilized for V2G operation. The simulation is carried out by controlling the semiconductor switch S_{a4} by giving a proper PWM signal,and the waveforms obtained are shown in Fig.21

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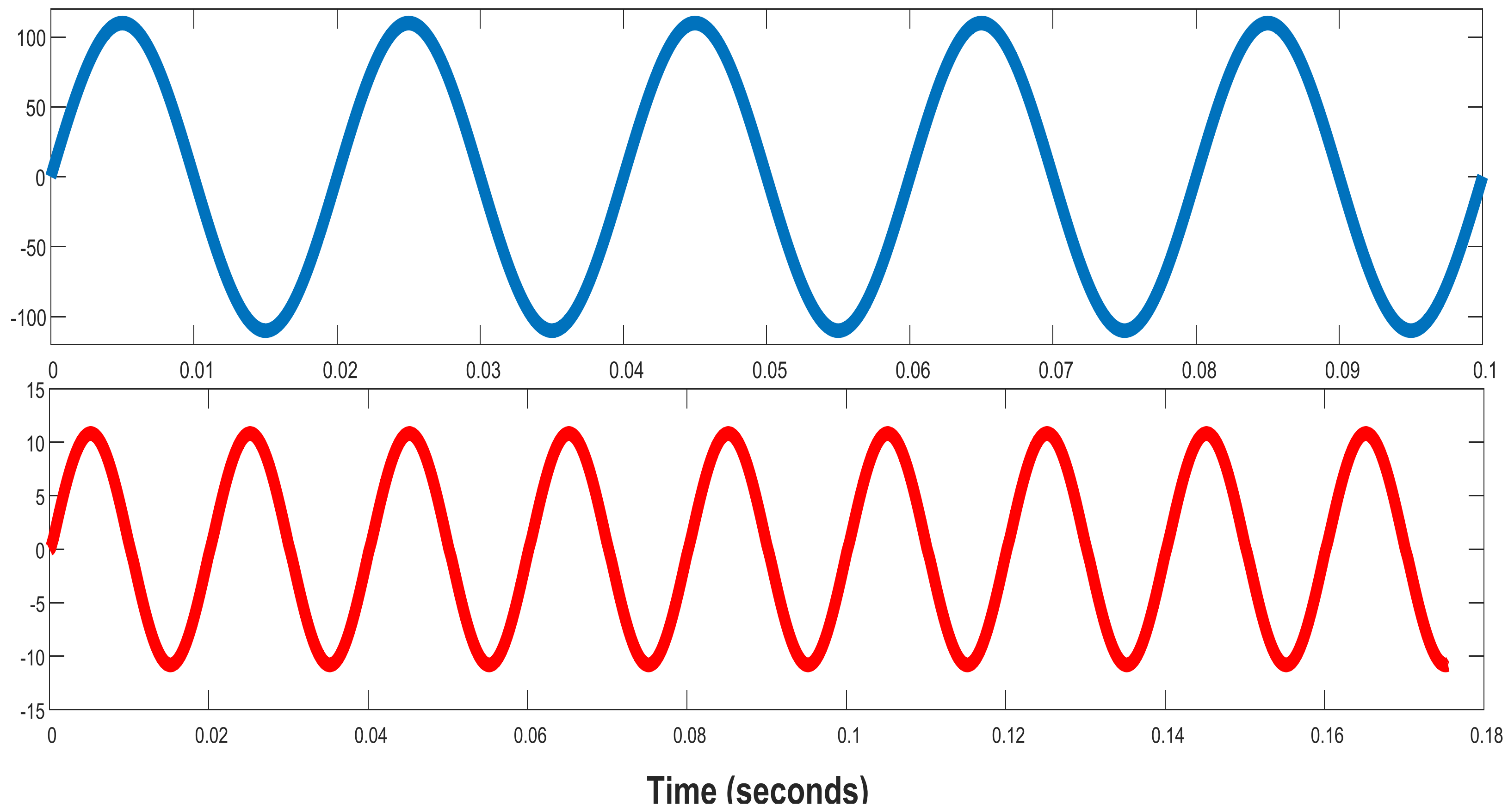

Fig.21. Grid voltage and current during V2G operation

VII. CONCLUSION

In this work,a new Integrated Power Converter is introduced and its various modes of operation are discussed. The Converter can operate in various modes of vehicle operation and the topology is simulated using the parameters obtained from the analysis of the converter.The results are verified for 800 W reference power and grid supply of 110V / 10 Aand battery capacity of 48 V,26 Ah lead acid battery. The topology is working as SEPIC converter during its charging, as conventional boost and buck converters during running modes.The charge in the battery during long parking periods is used to implement V2G operation and this is achieved by working the converter as a ZETA.Various modes of operations and analysis of converter stages are carried out and designed values of parameters are used for simulation using MATLAB 2018.The efficiency of each mode is calculated and controlled.The addition of the V2G mode improves the performance of the overall system.

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A High Gain Cascaded DC-AC Converter for Renewable Energy Applications

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Abstract: With the rapid advancement of power electronics technology, various converter topologies for renewable systems have been created. A high gain dc-ac converter system for solar PV applications is presented in this paper. A symmetric dual switch dc-dc converter and a single step five stage PWM inverter are used to create the proposed converter. A dual switch high step-up DC/DC converter has a basic circuit configuration and can achieve a high step-up voltage gain by working in parallel charge and series discharge. As compared to a conventional complete bridge three level PWM inverter with equal supply dc voltage and switching frequency, the five level PWM inverter will minimise harmonic components. Multilevel inverters are used in a variety of industrial and renewable energy applications. The construction of a cost-effective dc-ac converter with fewer components is a major challenge for researchers and engineers. A boosted ac voltage is given by the proposed topology. MATLAB simulations are used to verify the validity of the proposed system. The proposed converter is tested with a 48 V input voltage and a 1 kW load.

Keywords: Photovoltaic, DC-DC converter, Pulse width modulation, Multilevel inverters

I. INTRODUCTION

With the large usage of fossil fuel such as oil, coal and gas results in environmental pollution and greenhouse effect. There is a big conflict between global energy demand and fossil fuel supply. For human being development major interference is energy shortage and environmental pollution. Because of exhaustion of the global fossil energy sources, the emergence of renewable energy is the best solution. As a result, renewable energy sources are becoming increasingly relevant. PV is one of the most notable of these sources, and it will contribute the most to electricity generation due to its cleanness, emission-free nature, and high reliability [1]. Since the generation voltage level in a solar energy conversion device is low, a transformer is required to step up the voltage. However, due to the existence of a transformer, it increases device volume and losses, reduces reliability, and is large in size. So, in order to avoid transformer high step-up gain converters are used. To provide high step up, various topologies have been come out but it is difficult to attain both high voltage conversion ratio and high efficiency at the same time [2].

In both isolated and non-isolated topologies there are many high step-up DC-DC converters investigated and developed to obtain high voltage gain. A series connected forward-flyback converter topology refine the weakness of insulation type converters, such as high-volume low efficiency and high cost [3]. It has series connected output for high boosting voltage gain. But large turns ratio may increase the leakage inductance of the transformer and cause voltage spike and high voltage stress of power devices. In this circumstance non isolated DC-DC converters are preferred because of some advantages of simple electric energy conversion process, high efficiency, and low cost [4]. Cascaded DC-DC converters have high gain due to multistage power conversion. But in this topology output diode reverse recovery problem is large and has problem of system instability and high voltage stress on power devices [5]. In high step-up DC-DC converter with active coupled inductor network, a passive lossless clamped circuit are put in to reduce voltage spikes and to recycle leakage energy. Due to this it causes additional cost of components. [6]. The switched capacitor/switched inductor-based DC-DC converters can attain unlimited gain and has lower energy in the magnetic element which give on to weight, size and cost savings for the inductors. But in these structures, the number of capacitors and diodes also significantly increase with the increase of the voltage gain ratio. Also, in the working states there arise problems of current spikes and also causes problems of EMI [7]. Then a symmetric dual switch high step-up DC-DC converter was developed recently, with simple structure, which overcomes the disadvantages of another dc-dc converter. It has dual output and low voltage stress on components [8].

In case of inverters, there are many multilevel inverter topologies incorporate a large number of levels have been there and they have advantages of improved output waveform, lower EMI, smaller filter size etc. In the traditional full bridge type three level PWM inverters, output voltage has three values, zero, positive and negative supply dc voltage levels. Besides the harmonic reduction of them is limited to somewhat.[9] A cascaded multilevel H-bridge type any number of voltage levels are series connected to form an inverter phase leg. The frequent drawback of usual multilevel inverters is the requirement of components count. It is corresponding to the number of output voltage level, so the necessary of driver circuits, heat sinks, and protection circuits are increased [10]. To solve these problems researchers introduced several multilevel inverter topologies with reduced switch counts. Among them a single phase five level PWM inverter has simple structure and reduced switch count. Output voltage of them has five values-zero, half, and full supply dc voltage levels. It can decrease harmonic components compared with that of traditional full-bridge three level PWM inverter [11].

This paper describes a high voltage gain DC-AC converter system for photovoltaic applications that combines two separate existing converters, a DC-DC converter and a multilevel inverter, to produce boosted ac voltage at the output. The DC-DC converter is a symmetric dual switch converter with dual output that operates in parallel charge and series discharge to achieve high step-up voltage [8]. The inverter in this system is a single phase five stage inverter [11], which has a simple structure and fewer switches. The problem with the inverter is that it has two dc sources at the input, necessitating the use of a symmetric dual switch converter with dual outputs. The circuit overview, operating principle of symmetric dual switch DC-DC converter, and single phase five stage inverter will be addressed in the following sections. Finally, the simulation and its effects are shown.

II. METHODOLOGY

DC-DC converter topologies are developed to meet the demands of particular DC loads. Buck, boost, and buck-boost are some of the DC-DC converters that can be used as switching regulators to regulate unregulated DC voltage by converting it to suitable utilisation voltage by increasing or decreasing the DC output voltage with the help of a PWM switching technique which operates at a fixed frequency. When a converter is required, it needs power switching devices to turn on and off. Depending on the parameters and applications of the circuit design, power switching devices such as thyristors, BJTs, MOSFETs and IGBTs are used. Appropriate gate drive signals produced by a gate driver circuit must be considered when triggering power switching devices Pulse Width Modulation. PWM switching is used to regulate the voltage frequency and phase delay of the DC-DC converters.

A. *Proposed approach*

Generally, the solar PV converter system requires high gain DC-AC Converter system. The proposed converter method, which consists of two steps, is depicted in Fig. 1. In the first stage, a symmetric dual switch DC-Converter is used to increase the input voltage range [8]. In the second stage, a single phase five level inverter [11] with LC filter is used to generate a pure sine wave. Both converters in two stages have a simple circuit configuration. In both the steady and volatile states, the symmetric dual switch converter has voltage balance of switches and capacitors. The voltage stress of power devices is low with this DC-DC converter. It has a higher voltage gain than most conventional converters. It has been advantageous to minimise device EMI due to the balanced structure.

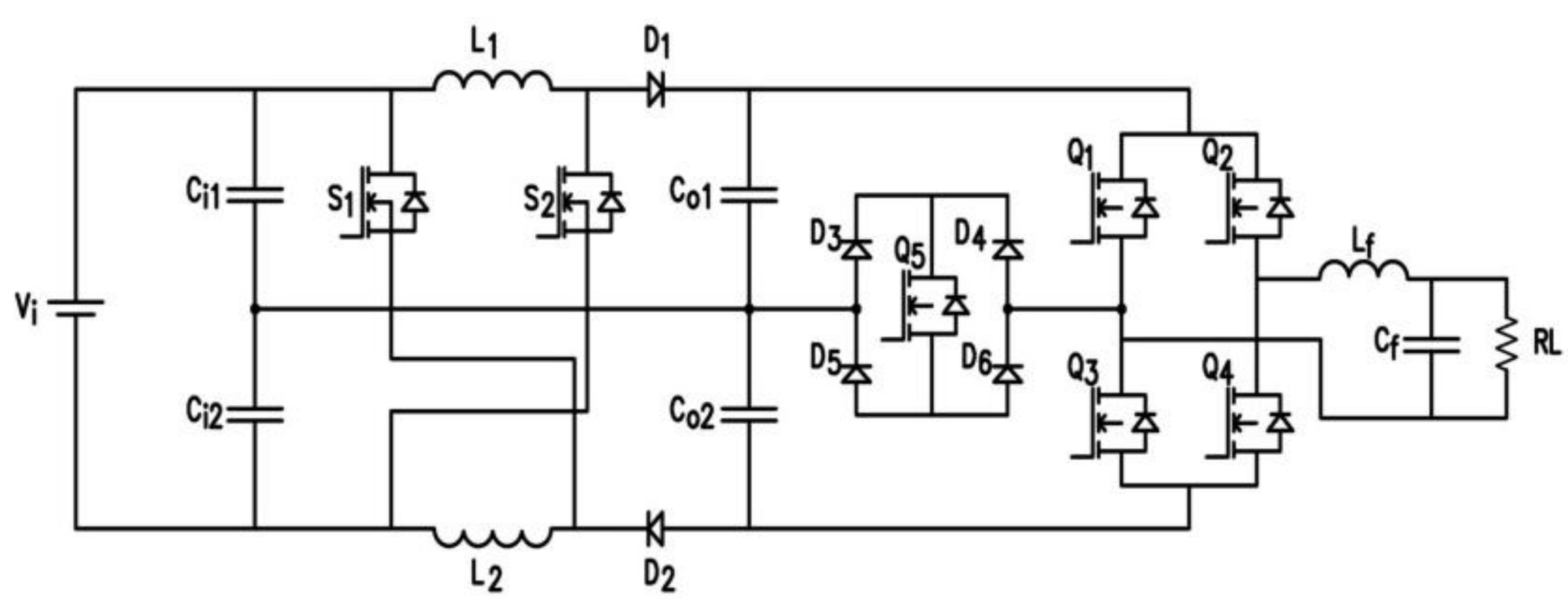

Fig. 1. Proposed DC-AC Converter System

The five-level inverter in the second stage has functions of regulating dc bus voltage, and converting dc power to ac power. It is lighter & more compact compared to other multilevel topologies. The topology also has less switching power loss, reduced harmonic distortion and reduced EMI.

B. *Symmetric dual switch dc-dc converter*

The circuit diagram of a DC-DC converter [8] is shown in Fig. 2. This contains Vi input dc, controlled switch S1, S2, L1, and L2 inductors, input capacitors C_{i1},C_{i2},output capacitorsC_{o1} ,C_{o2},and load resistance R. In mode1, $[t_0, t_1$] when the switches are ON and the diodes are off, the inductors $L_1, L_2$are charged by the input powerV_i and the current in the inductors will increase linearly. Voltage across inductors can be given as:

$$L_1 \frac{di_{L1}}{dt}=L_2 \frac{di_{L2}}{dt} = V_i \quad (1)$$

In mode 2 $[t_1, t_2$] at t_1 the switches are turned off and diodes are ON power in an induction system is discharged through a diode into load. Voltages across the inductors are:

$$V_{L1}=V_{Ci1} - V_{Co1} \quad (2)$$
$$V_{L2} =V_{Ci2} - V_{Co2} \quad (3)$$

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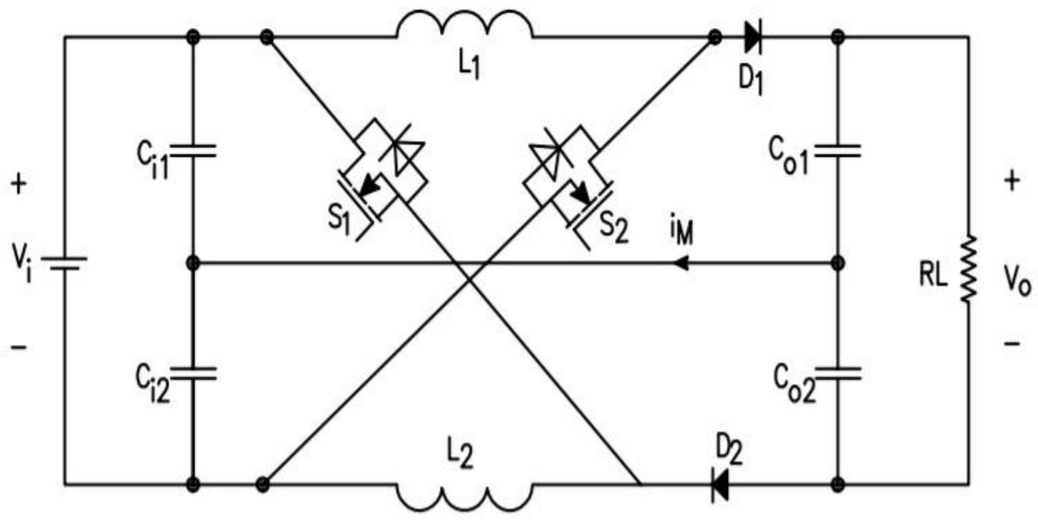
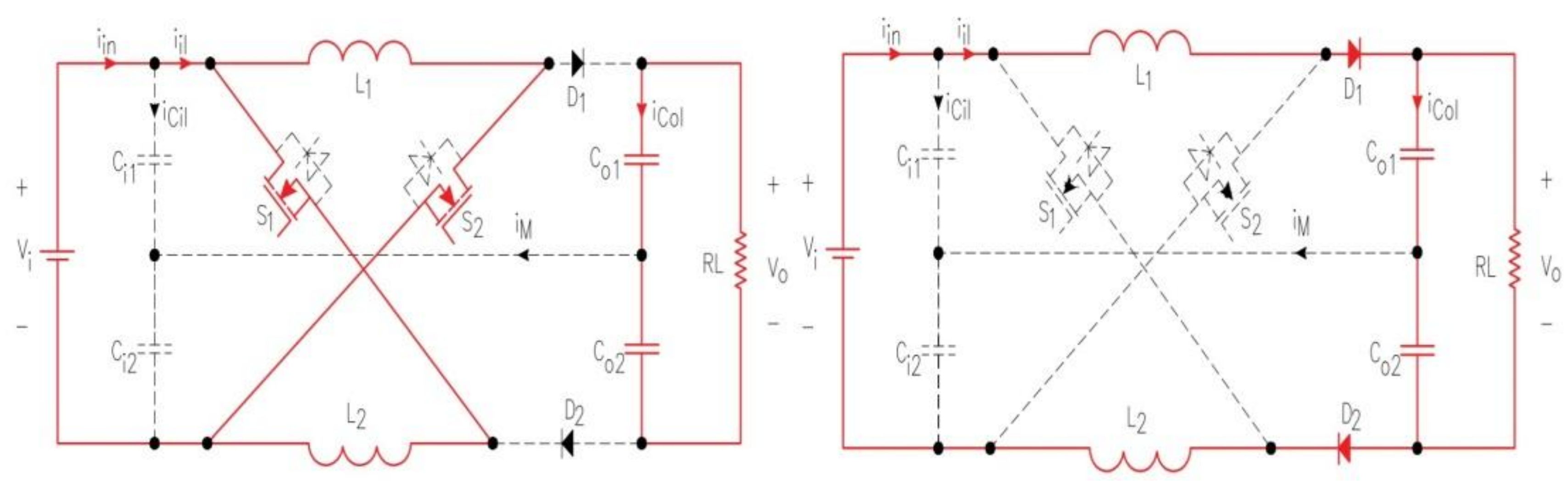


Fig.2. Symmetric dual switch Converter

The equivalent circuits of mode 1 and mode 2 of DC-DC converter are shown in Fig. 3(a), and Fig. 3(b). The wave forms of Continuous Conduction Mode (CCM) is shown in Fig. 4



(a) (b)

Fig.3. Operating modes of symmetric dual switch DC-DC converter (a) mode1 (b) mode2

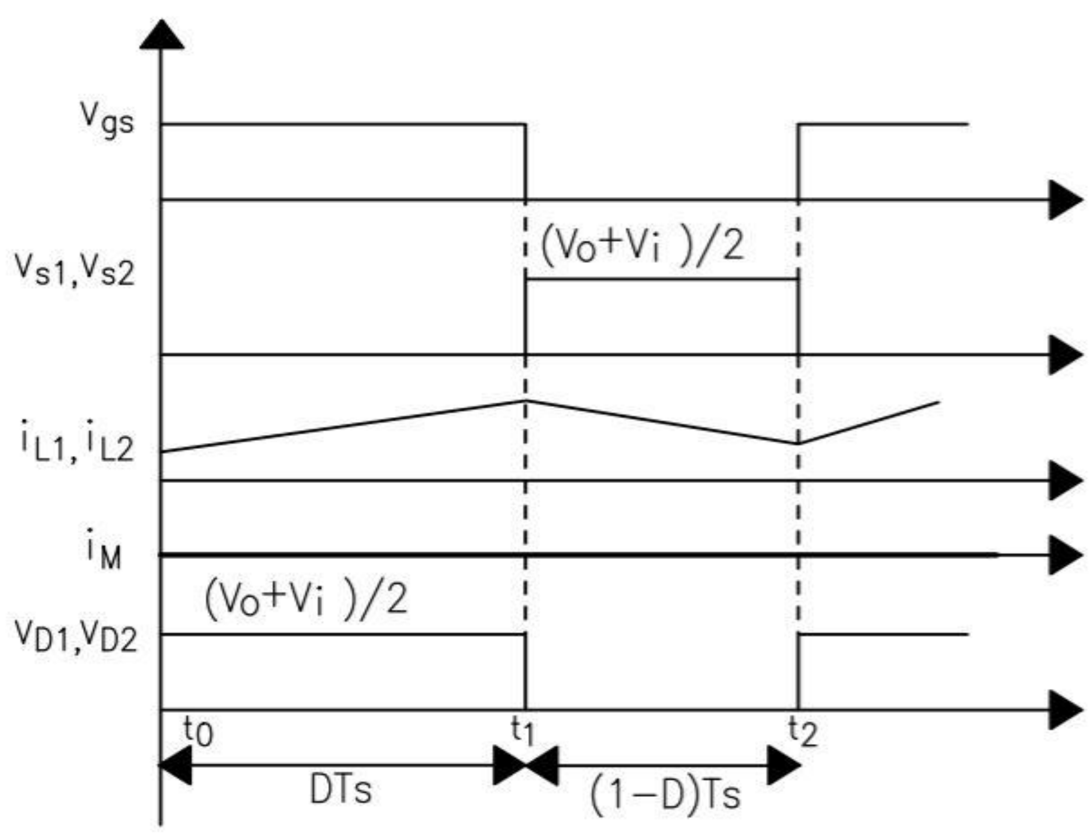


Fig.4. Waveforms of CCM Operation

C. *Single phase five level inverter*

Single phase 5 level PWM inverter [11] to reduce the harmonic components of output voltage and load current are used in the proposed system. PWM inverters have able to control output voltage and frequency simultaneously. It has simple structure and reduced number of switches. The circuit diagram of single phase five level inverter is shown in Fig 5. It consists of one switching element and four diodes which is added to the conventional full bridge inverter and is connected to the centre tap of dc power supply. It can generate half level of dc supply voltage by proper switching control of auxiliary switch. The output voltage has five values: zero, half and full supply dc voltage levels. So, it is called a single phase five level PWM inverter. The output voltages according to the switch ON-OFF conditions are shown in TABLE I.

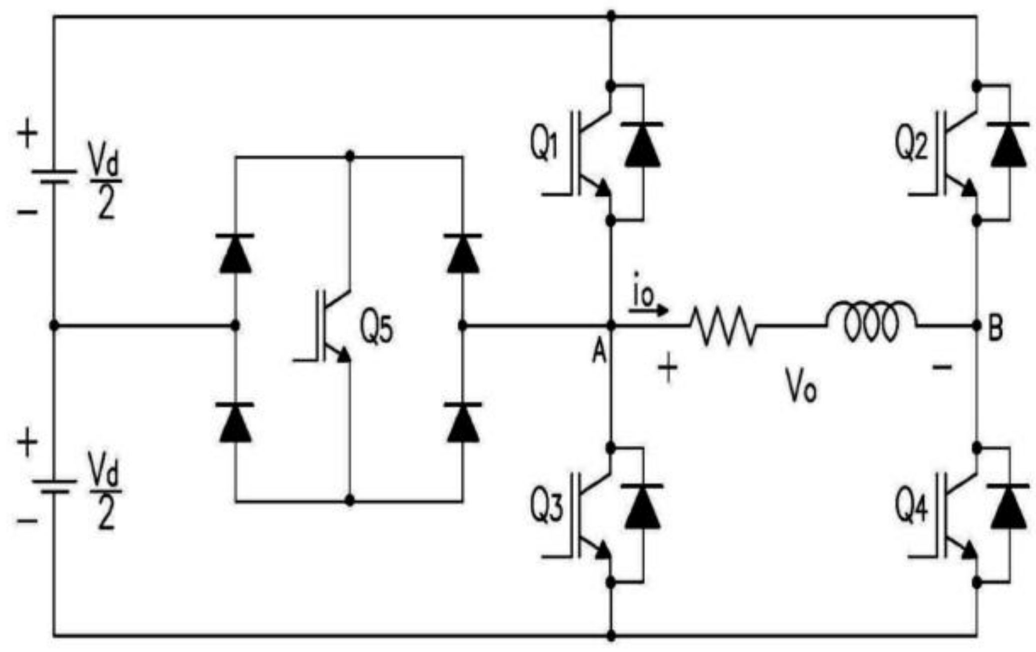


Fig.5.Single Phase Five Level PWM Inverter

When switches Q_1 and Q_4 are turned ON, the positive terminal of source is connected to node A and the negative terminal of the source is connected to node B. This generates output voltage V_o=$V_d$across the load terminal. The output voltage V_0=$\frac{V_d}{2}$is produced by switching ON switches Q_5 and Q_4. Zero states output is obtained by switching ON switchesQ_3 , Q_4 or Q_1, Q_2.Similarly to obtain the negative half cycle in the next states, switches Q_5, and Q_2 are turned ON. The negative terminal of the input source is connected to node A and positive terminal of the source to node B and so output voltage V_o=$-\frac{V_d}{2}$. By switching ON Q_2&Q_3an output voltage V_o=$-V_d$ is obtained. So a five-level step wave is generated at the output terminals as in Fig. 6.The gate pulses to the inverter switches can be generated using SPWM technique.

TABLE I
SWITCH ON-OFF STATES

SWITCHESON	NODE A VOLTAGE	NODE B VOLTAGE	OUTPUT VOLTAGE
Q_1 Q_4	V_d	0	V_d
Q_5 Q_4	$V\frac{d}{2}$	0	$+V\frac{d}{2}$
Q_3 Q_4 or Q_1 Q_2	0 or V_d	0 or V_d	0
Q_2 Q_5	0	$V\frac{d}{2}$	$- V\frac{d}{2}$
Q_2 Q_3	0	V_d	$- V_d$

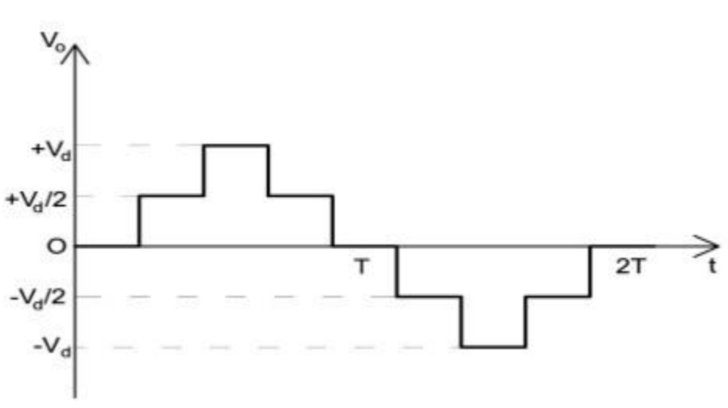


Fig.6. Output waveform of five level inverter

III.DESIGN

A. Selection of duty cycle

Applying voltage-second balance on the inductors L_1 ,L_2

$$D.V_i+(1-D).(V_{Ci1}-V_{Co1}) = 0 \tag{4}$$

$$D.V_i + (1 - D).(V_{Ci2}-V_{Co2}) = 0 \tag{5}$$

By simplifying equations (4), (5) the voltage gain is given by

$$G=\frac{V_O}{V_i}=\frac{1+D}{1-D} \tag{6}$$

The DC-DC converter duty cycle can be calculated as follows:

$$D=\frac{G-1}{G+1} \tag{7}$$

B. Design of inductor

The inductor selection depends on duty cycle(D), switching frequency, inductor ripple current(Δi_L), and inductor voltage (V_L).The input inductance L_1 and L_2has voltage equal to V_i.Therefore the inductance value can be written as:

$$V_L= L\frac{di}{dt} \tag{8}$$

$$L_1\frac{di_{L1}}{dt}=L_2\frac{di_{L2}}{dt}=V_i \tag{9}$$

$$\Delta i_L = \frac{V_i D T_s}{L} \tag{10}$$

$$L_1 = L_2 \geq \frac{V_i D T_s}{\Delta i_L} \tag{11}$$

C. Capacitor selection

The output capacitor value depends on output power of the converter P_o, output voltage V_o voltage ripple ΔV_o and switching frequency f_s which can be obtained by using following equation:

$$C_0 = \frac{(1-D)T_s I_0}{\Delta V_0} \tag{12}$$

The output capacitor consists of two capacitors,C_{o1},C_{o2} the value of C_{o1} and C_{o2} are same, so it can be written as :

$$C_{01}=C_{02} \geq \frac{2(1-D)T_s I_o}{kV_o} \tag{13}$$

IV. SIMULATION AND RESULTS

The circuit is simulated in MATLAB/Simulink to verify the system performance. Simulation parameters were obtained using design equations and outputs were obtained as expected. The TABLE II shows the simulation parameters of proposed system.

TABLE III
SIMULATION PARAMETERS

COMPONENTS	SPECIFICATIONS
Input voltage	48V
Output voltage	350 V
Rated power	1 kW
Switching frequency	50 kHz
Inductors (L_1,L_2)	240 µH
Input capacitors (C_{i1},C_{i2})	1000 µF/50 V
Output capacitors (C_{o1},C_{o2})	470 µF/250 V
Load resistor	125 Ω

The proposed converter system was designed for a power rating of 1 kW, input voltage 48 V, output voltage 350 V and switching frequency of 50 kHz. The duty cycle of the converter under the operating condition is 0.7. Simulation diagram of proposed converter system is shown in Fig. 7The Fig. 8 shows the input and output voltage waveforms, switching pulses and inductor currents of the symmetric dual switch DC-DC converter. Fig. 9 shows the switching pulses to inverter by SPWM technique. The sinusoidal waveform at 50 Hz is obtained at the inverter output terminal as shown in Fig.10.

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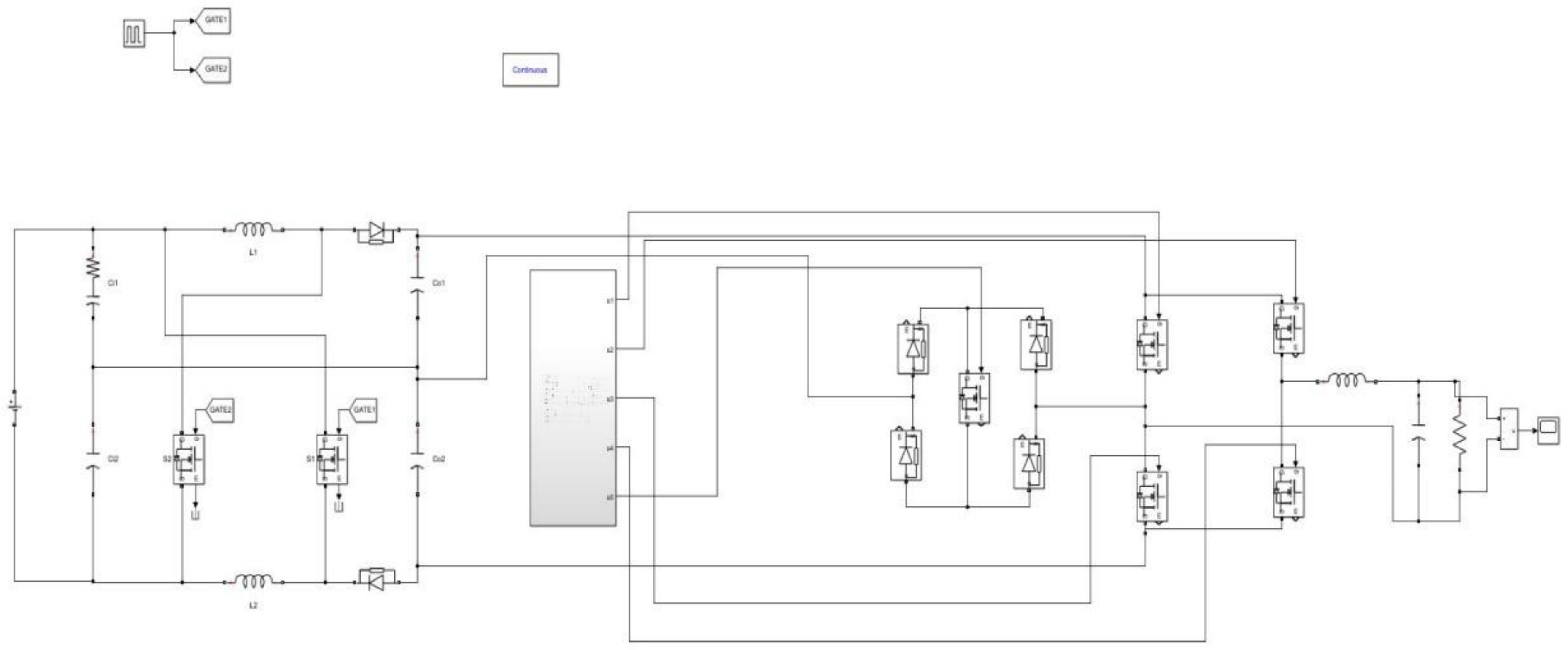

Fig. 7. Simulation diagram of proposed DC-AC converter system

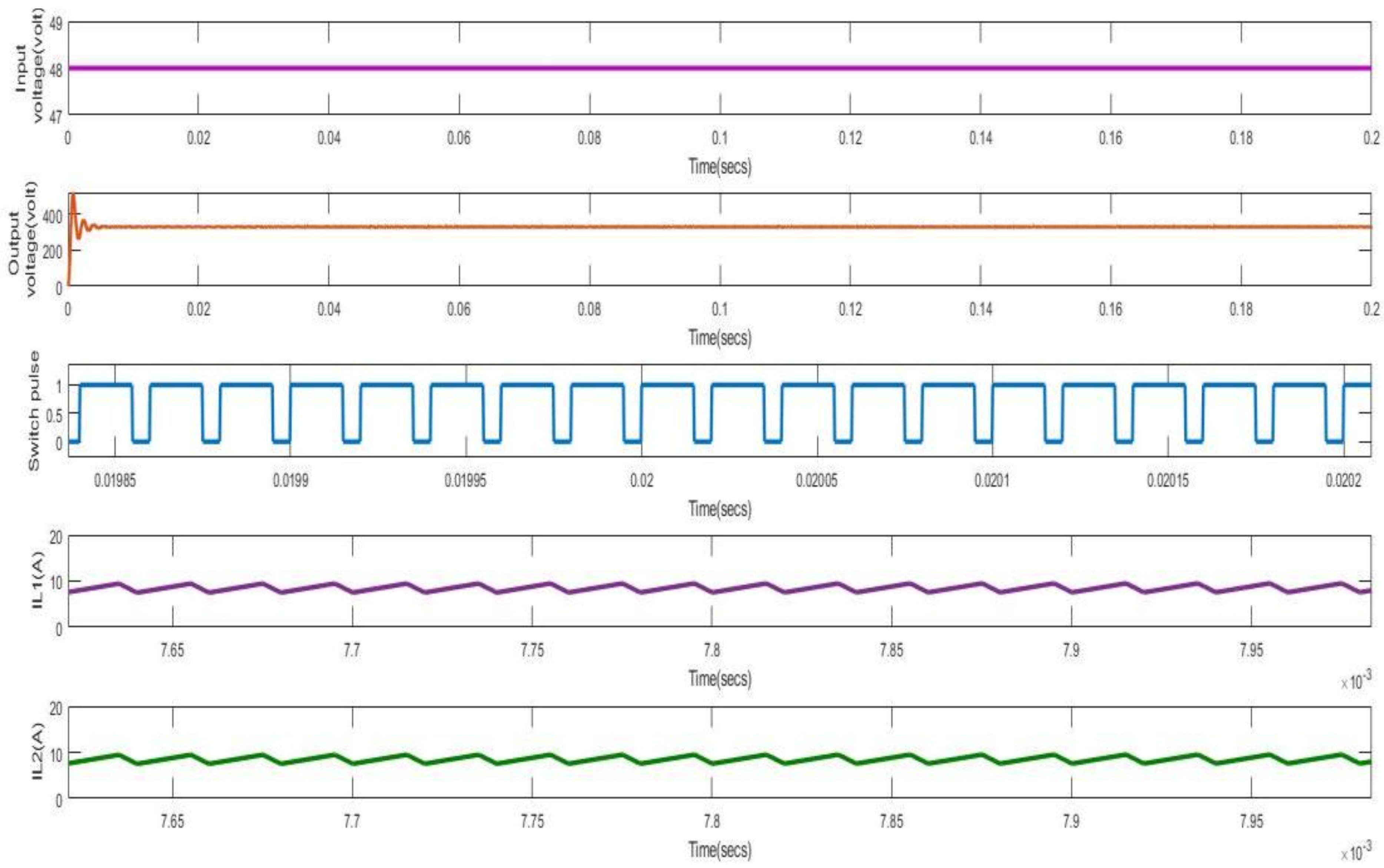

Fig. 8. .Input voltage, Output voltage, Gate pulses ,Inductor currents of DC-DC converter

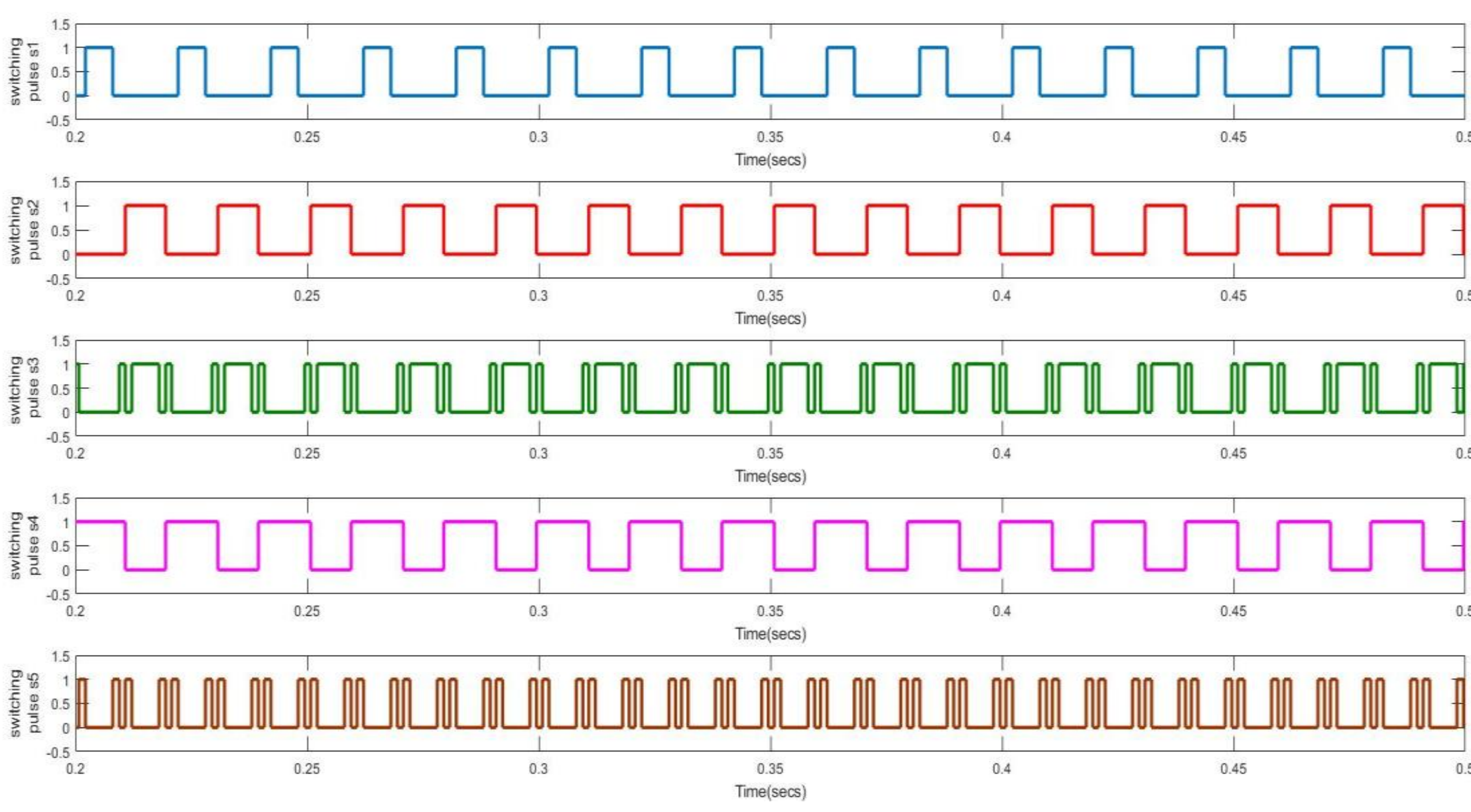

Fig. 9. SPWM pulses to inverter switches

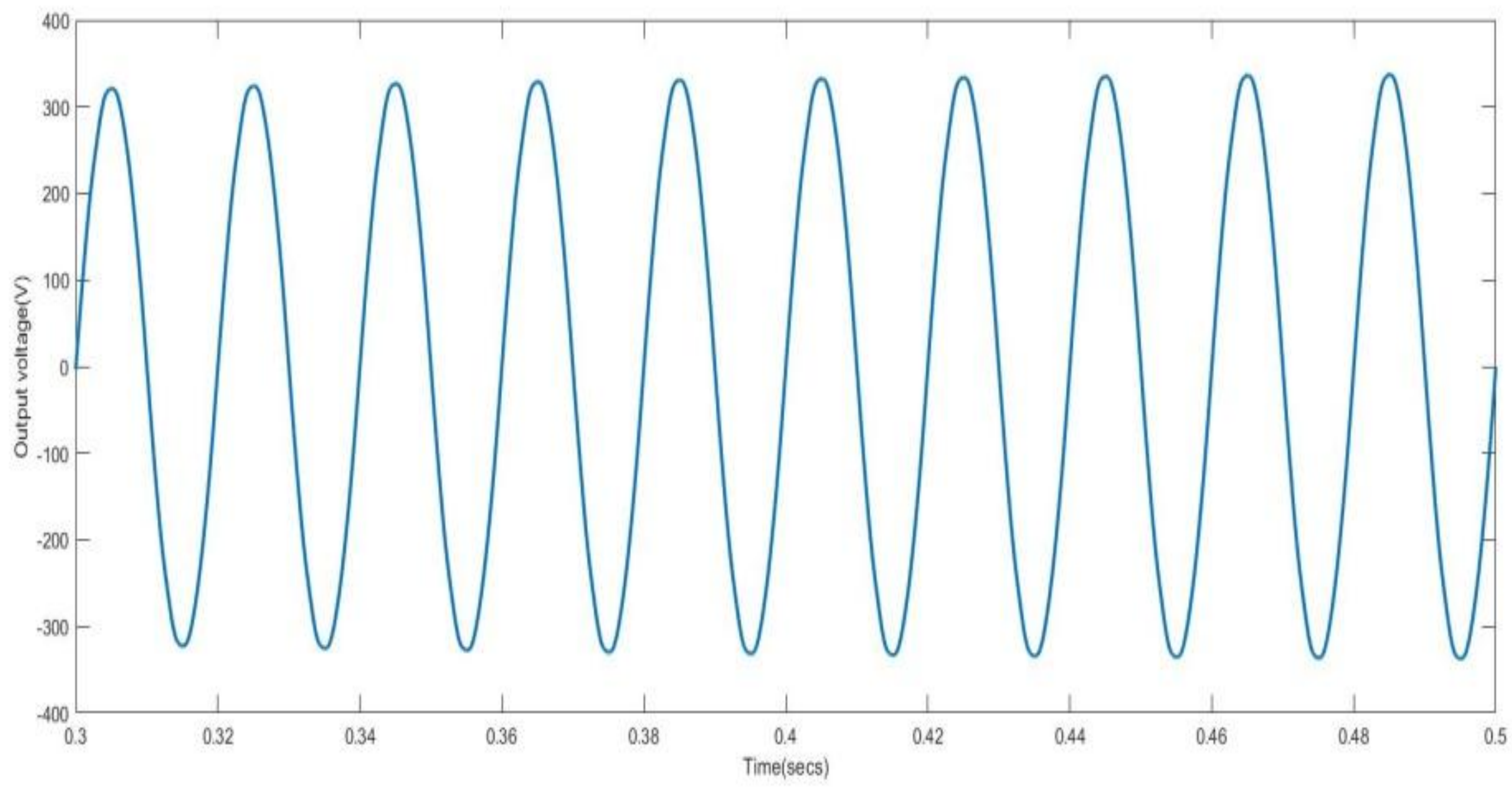

Fig. 10 Sinusoidal output voltage wave form of converter

V. CONCLUSION

The paper presents a high voltage gain DC-AC converter system which can be used for renewable energy applications. A High step-up DC/DC converter with symmetric topology is used in first stage, and a single phase five level PWM inverter is cascaded in the second stage of proposed system. The DC-DC converter can keep low voltage stress of the power devices and makes the switches realize voltage balance in steady and dynamic states, which reduces voltage stress. The output voltage of the proposed system is sinusoidal of required frequency and is generated from low voltage DC input. The performance of converter is analysed and verified by simulation in MATLAB/SIMULINK for a 1kW system. The proposed converter system is suitable for renewable energy applications especially for solar PV systems.

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Modified Transformer less Boost Inverter for Grid-Tied PV Systems

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Abstract:This paper proposes a modified single phase transformerless Photovoltaic (PV) boost inverter for grid connected PV systems. The proposed topology is having a leakage current about zero as the neutral of the AC grid is directly connected to negative terminal of PV panel which is known as common ground configuration. The boost inverter can enhance the efficiency of the system that will be useful for low power applications. The voltage stress on the Power switches are minimized and the life of the switches will get improved. The simulation results were presented and the harmonics in the injected current to grid were analysed. Since the circuit does not having a transformer, the size, weight and price of the inverter can be reduced significantly.

Keywords: Leakage current, Photovoltaic (PV), Inverter, Common Ground configuration.

I. INTRODUCTION

Since the world is getting more electrified day by day, the power demand also increased. In order to meet the power demand environmental friendly renewable energy sources has to be used. Solar energy is the best and widely available option. So a lot of researches are ongoing on interconnection of PV sources and Grid. Inverters plays an inevitable role here. Since the transformers makes the circuit bulky and costly, trasformerless inverters are preferred. Transformer less inverters does not provide galvanic isolation between PV and PowerGrid. Usually the neutral line of AC network is grounded. So a parasitic capacitance will be formed between PV panel and ground [1]. The paracitic capacitance, filter inductance and impedance of grid forms a resonant circuit and it causes for a leakage current. The path for leakage current is shown in Fig. 1. The variying Common Mode Voltage (CMV) causes leakage current through ground. This leakage current can harm the circuit in the form of Harmonics, EMI and power-losses.The leakage current can be harmful to human when they touch the PV Panel[2]-[4]. The varying CMV depends on different circuit configurations. The CMV has to be constant and minimum to reduce the leakage current.
The differential mode voltages (DMV) and CMV can be calculated by,

$$V_{DM} = V_{AN} - V_{BN} \tag{1}$$

$$V_{CM}=(V_{AN} + V_{BN})/ 2 \tag{2}$$

Many trasformerless inverter topologies that eliminate leakage current were studied all over the world. Some major topologies are discussed below. Full bridge inverter along with bipolar switching were studied, which is a very common inverter topology [5]. The bipolar switching reduces the CMV and thereby low leakage current. But when it comes to unipolar the CMV is varying [6] . Later H5 topology were proposed in [7]-[8]. H5 is almost similar to FB topology and there is an additional switch at DC side. The DC decoupling switch separate grid and PV module during freewheeling period. HERIC topology in [9]-[10] can't reduce the CMV considerably even though the decoupling is provided at AC side.

Connecting neutral point of AC side with negative terminal of PV module can bring down the leakage current to almost zero [11]. So the common ground type configuration got attention. The capacitor switching can produce an alternating output as in [12]. All these configuration needs a high voltage DC supply of 400V. A stepup converter having high voltage gain has to be used for low power applications. A boost inverter can overcome this problem and thereby the overall efficiency of the system can be improved.

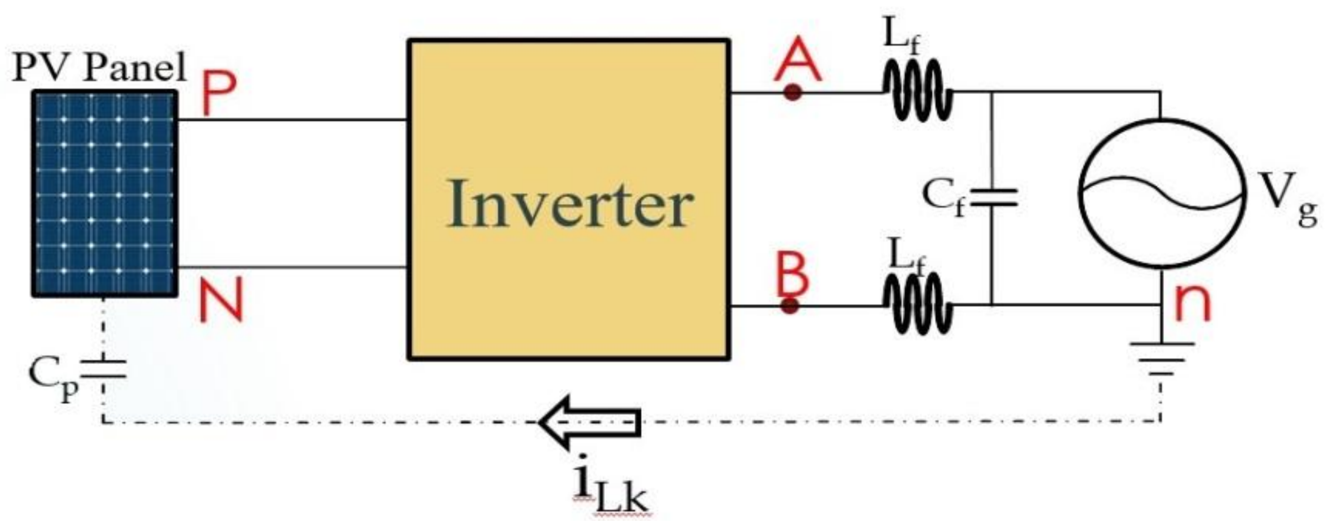

Fig. 1Path for leakage current in transformer less inverter

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A boost inverter configuration was proposed by [13], that is having 6 switches. This configuration can provide around zero leakage current. But the switching voltage stress were found to be very high and almost twice the output voltage. The proposed converter can eliminate these problems. The P&O algorithm can be used to transfer maximum power by the MPPT. The modes of operation, Design and simulation and result analysis are presented on sections II, III and IV respectively

II. CIRCUIT DESCRIPTION AND MODES OF OPERATION OF MODIFIED BOOST INVERTER

The overall common-grounded configuration that connecting PV to the grid is represented in Fig. 2, where the path for leakage current isrepresented as dotted line. As the parasitic capacitances of the solar panel is shorted, no leakage current passes through the ground and C_P. Therefore the leakage current is completely eliminated.

The proposed transformer less inverter represented in Fig. 3 ishaving, eight power switches, two capacitors and an inductor as a filter. As Switched Capacitor based module is incorporated in the circuit, the topology can boost the PV voltage within a single stage. The three involved power switches does not having body diodes and rest are with body diodes. The switch S_8 is bidirectional which can withstand peak inverse voltage on both negative and positive half cycles. The operation in one cycle of grid frequency can be divided to four. First two modes are in positive half cycle and next two are in negative half cycle.

A. MODE 1:

In the first mode of operation where grid voltage (V_g)is positive the power switches S_1 and S_7, are turned ON condition as shown in Fig. 4(a). In this positive state, the capacitor C_1 discharges. $C_1$is in series with the input voltage so the output voltage (V_{out}) will be twice the input voltage. The output current flows through the inductor which can reduce the ripples and supply a sinusoidal current to grid.

B. MODE II:

In the second mode, the grid voltage is still positive and the inverter is in zero state as shown in Fig. 4(b). The inductor current freewheel through the bidirectional switch $S_{8,}$ and so V_{out}will be zero. At the same time the capacitor C_1 charges by turning the switches S_1 and S_2 ON.

C. MODE III:

The third mode is occurred when grid voltage is negative. The charge stored in the capacitors $C_1$and C_2 together produces a negative output voltage of $2V_{PV}$by discharging to the grid through the switches S_5 and S_6 as shown inFig. 4(c).

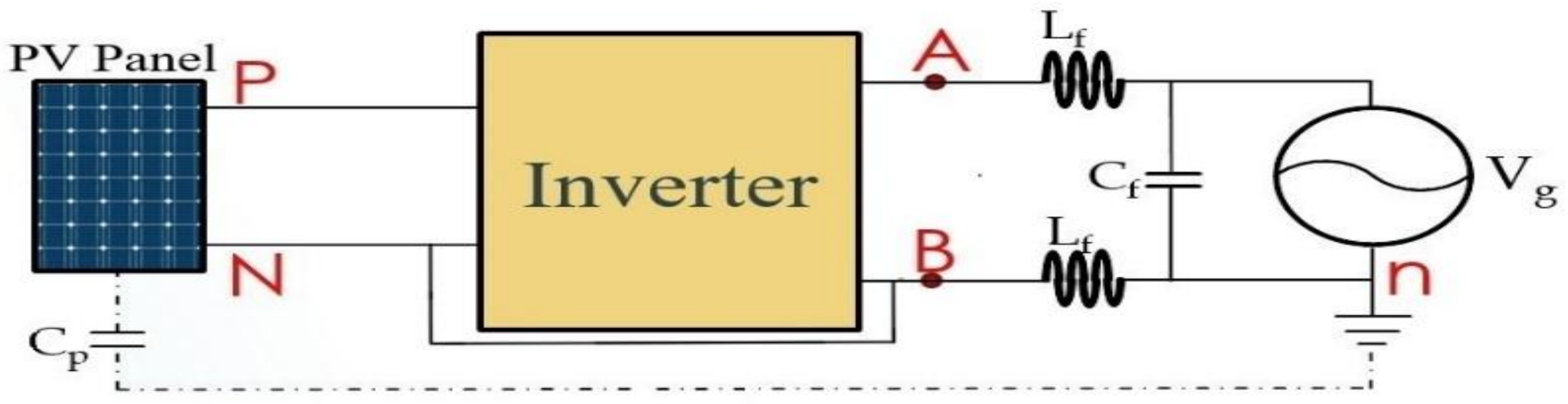

Fig. 2 Common grounded transformer less inverter configuration.

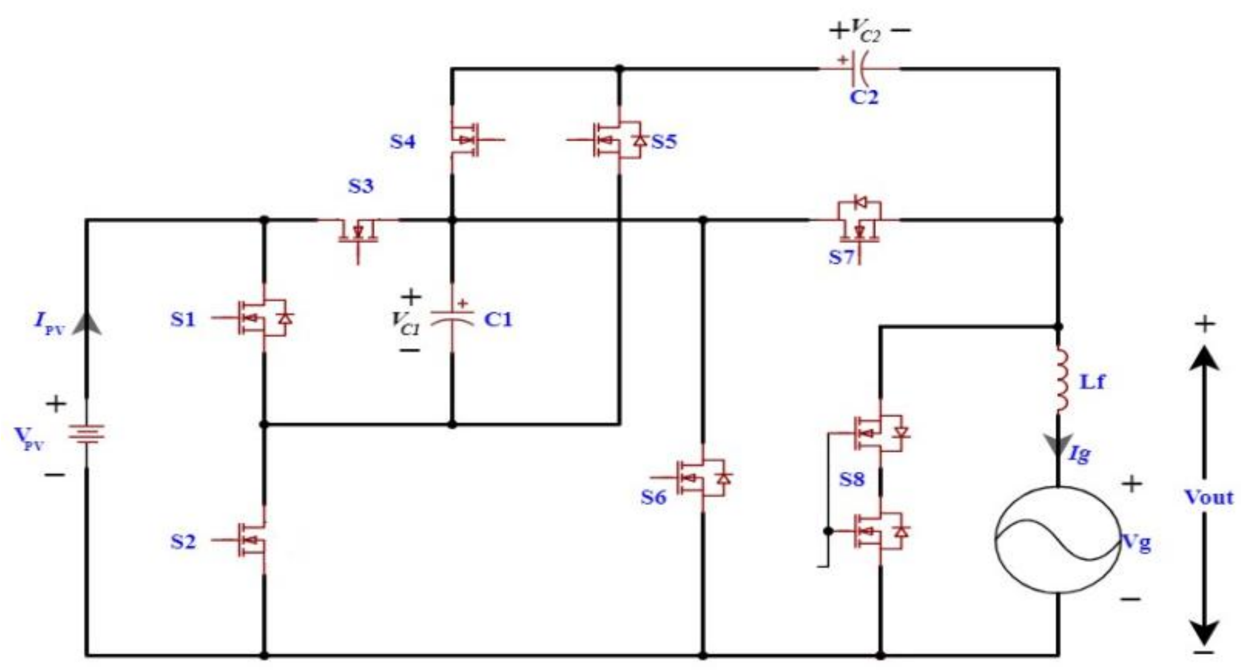

Fig. 3 Circuit diagram of modified boost inverter.

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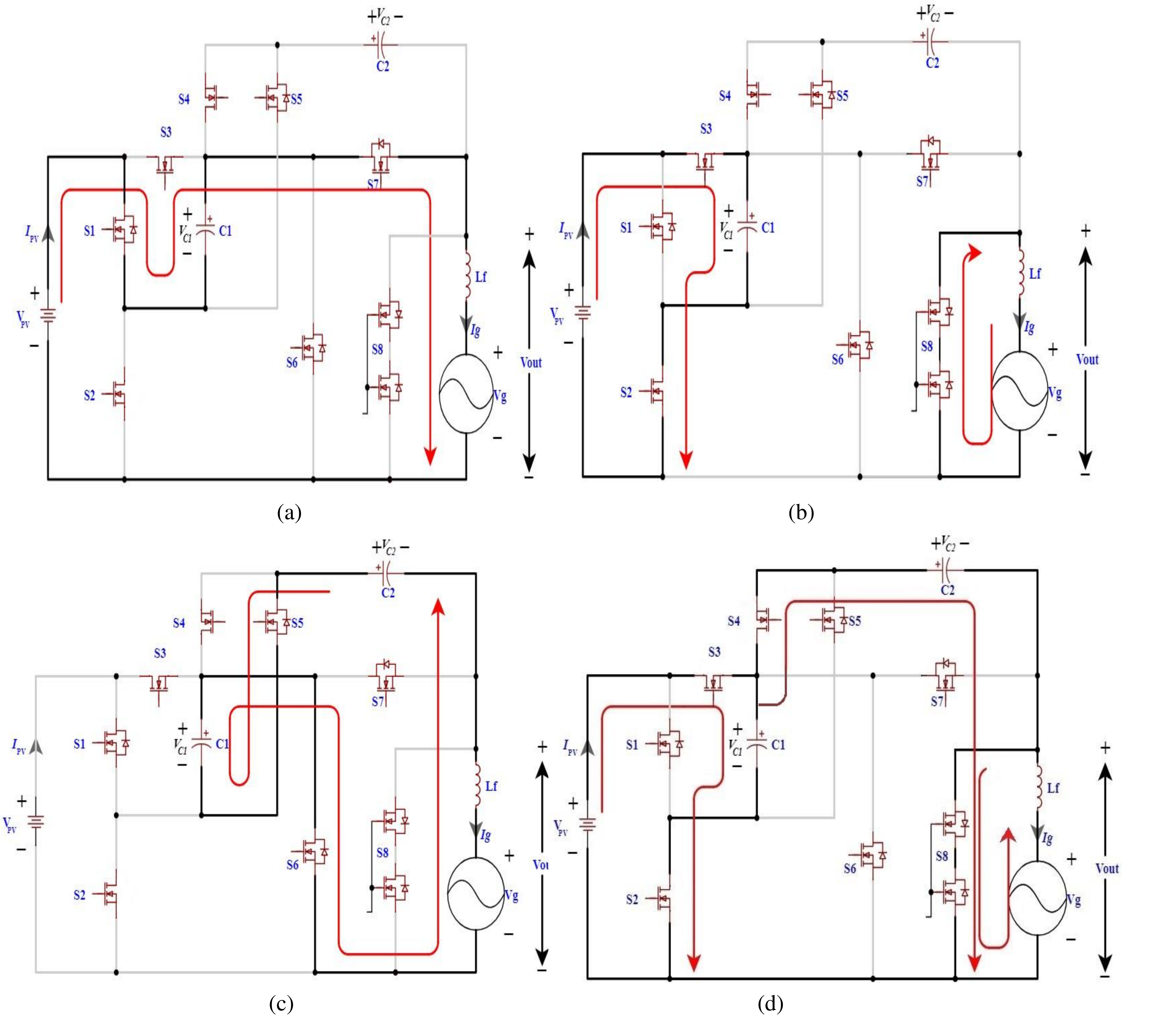

Fig. 4 Operating modes of modified boost inverter (a) in the first mode (b) in the second mode (c) in the third mode (d) in the fourth mode.

D. MODE IV:

The fourth Mode is similar to the second and here the capacitor C_2 also charges by turning the switch S_4 and S_8. The current free wheel through S_8. The fourth mode is depicted as in Fig. 4(d).

INVERTER CONTROL STRATEGY:

The hysteresis current control [14]-[15] and unipolar PWM method is used in this paper for controlling the inverter and injecting current to the grid. The MPPT with P&O algorithm generates a switching pulse for the front end boost converter in such a way that the maximum power output is produced.The reference current amplitude is calculated using the Power measured from the output of PV panel and generate a sine wave which is in phase with the grid voltage.The MPPT ensures injection of maximum active power into the grid. The control of the inverter is in such a manner that the injected current (I_g) follows the reference current (I_{ref}).The modes are selected and gate pulses are generated by logical states of grid voltage (V_g), injected current, and reference current. The pulses are generated as represented in the Fig. 5.

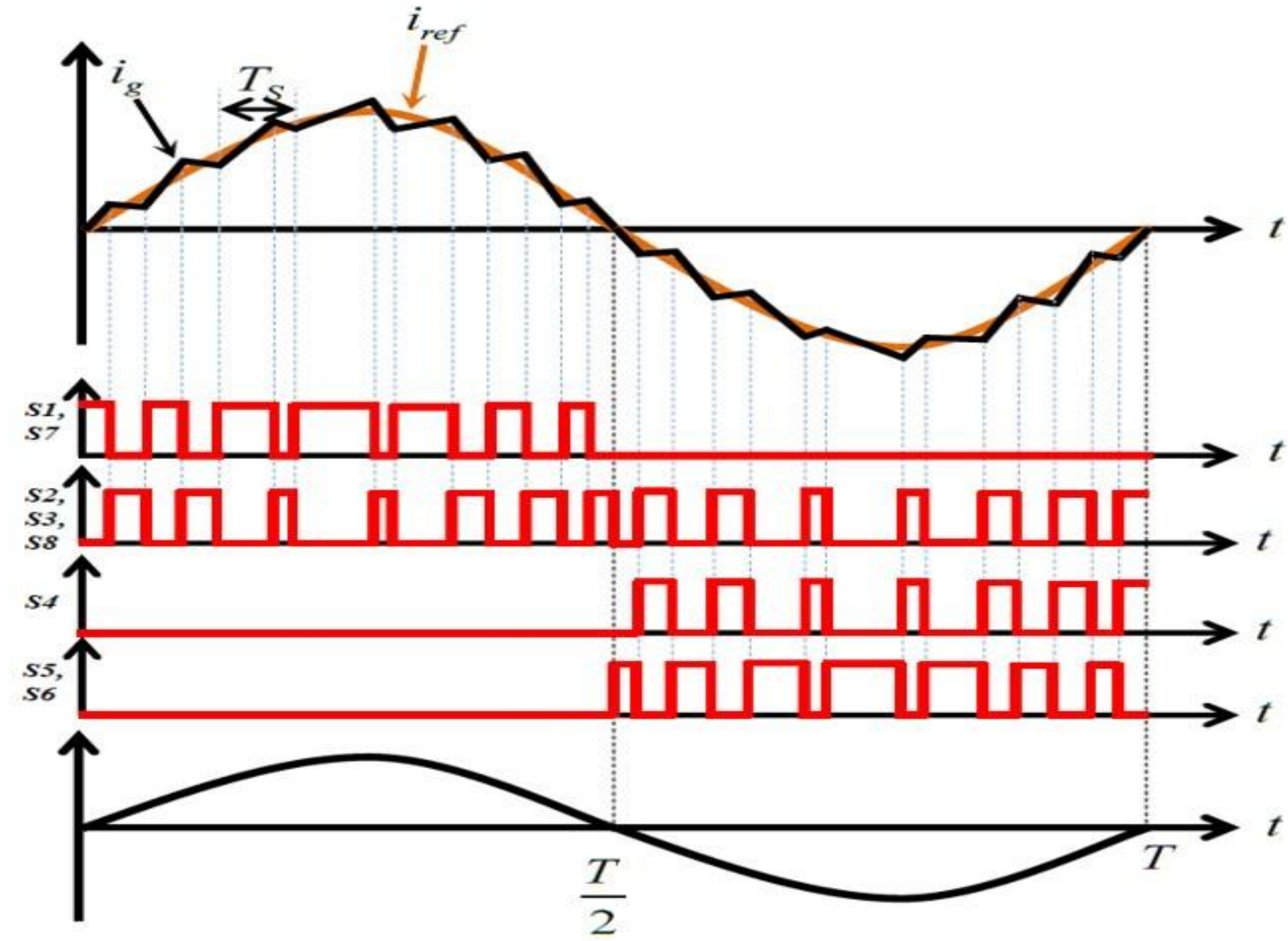

Fig. 5 Inductor and Reference current waveforms forms switching pulses.

III.DESIGN GUIDELINES

The gain of the inverter can be calculated using Volt-second Balance Equation for a switching cycle of operation. The same will be obtained in negative half cycle also.

$$(V_{out}-V_g)DT_s - V_gT_s + V_gDT_s = 0 \tag{3}$$

Where T_s is the time period of switching. The duty ratio (D) can be derived as,

$$D = V_g/2V_{PV} \tag{4}$$

The voltage gain (G) can be obtained as 2D. So the output voltage will be double as input. The inductor current ripple (ΔI_L) can be written as follows,

$$\Delta I_L = (V_{out}-V_g)DT_s/L \tag{5}$$

The filter inductance L can be calculated as,

$$L=(2V_{PV.}V_{g,m}- V_{g,m}^{\ 2})T_s/ 2V_{PV.}\Delta I_{L,m} \tag{6}$$

Where $V_{g,m}$and $\Delta I_{L,m}$are maximum values of grid voltage and current ripple. Similarly capacitance C_1 can be written as,

$$C_1=(I_{g,m}.V_{g,m}^{\ 2})T_s/ 2V_{PV.}\Delta V_{C1} \tag{7}$$

$I_{g,m}$and ΔV_{C1} are maximum values of injected current and capacitor voltage ripple respectively.

IV. SIMULATION AND RESULTS

The proposed inverter configuration is simulated using the software MATLAB Simulink. The design parameters for the simulation is shown in the Table 1. A boost converter along with a MPPT control is used to step up thePV voltage to 180V. The DC bus voltage and input power are shown in the Fig. 6.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Power	500w
PV Voltage	60 V
DC Bus voltage	180V
Output voltage	230V (rms)
Switching frequency	50kHz
Capacitors, C_1,C_2	15uF
Inductor, L	20mH

The voltage across the switches S_1,S_5,S_6 and S_7 are similar, also voltage across S_2,S_3, and S_4 are similar. The Maximum Source-Drain voltage across a switch is found to be 360V ie. twice the input voltage as shown in the Fig. 7. Where as in [13] it was four times the input. Fig. 8 depicts the Grid voltage (V_g), the Current injected to the grid (I_g) by the inverter and the Output voltage (V_{out}). V_g and I_g are in phase and maximum power nearly 500W can be transferred to the grid. The I_g is almost perfect sinusoidal as inFig. 8and current of 2.1A(rms) was injected with unity power factor.

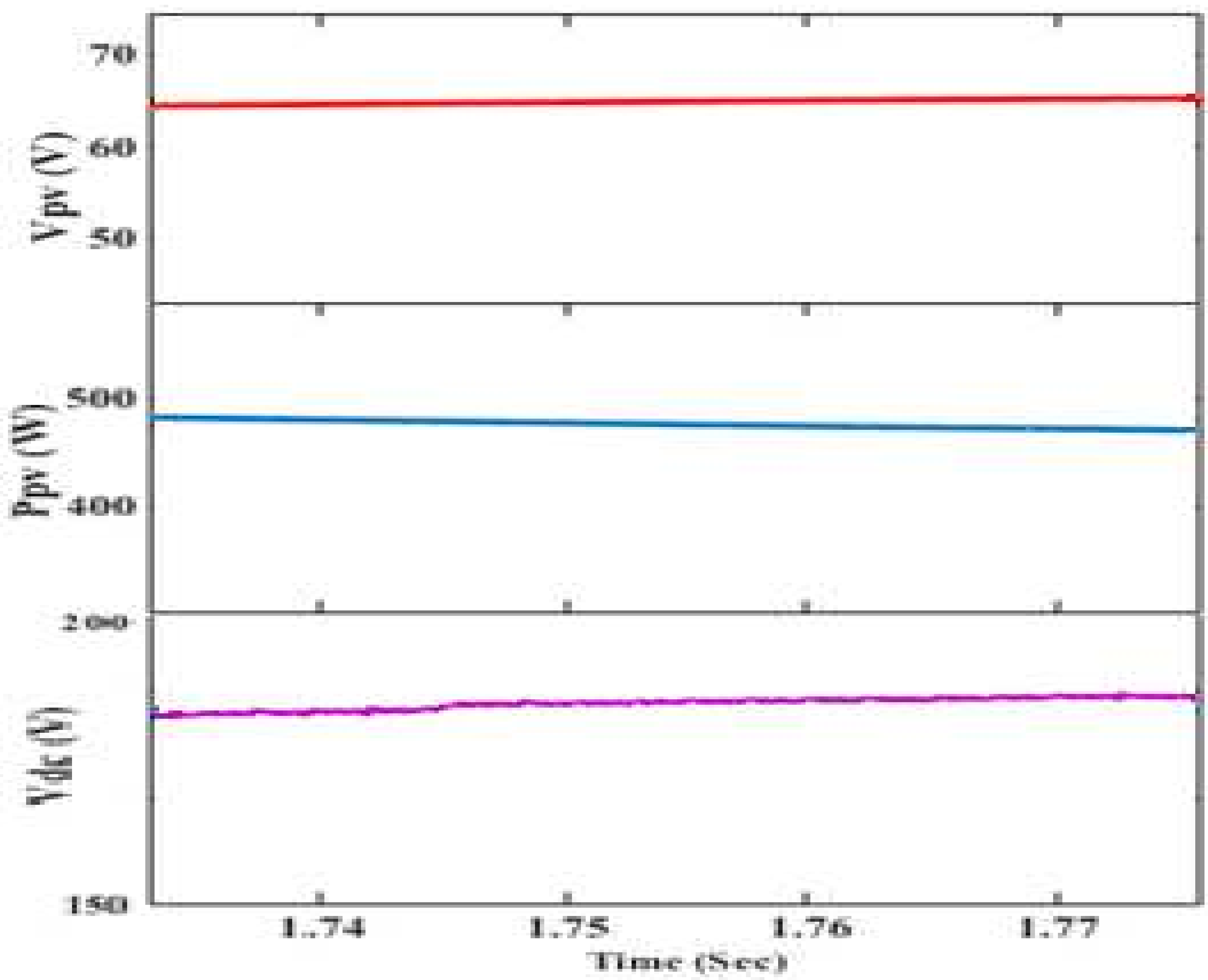

Fig. 6 PV output voltage, PV output power and DC bus voltage.

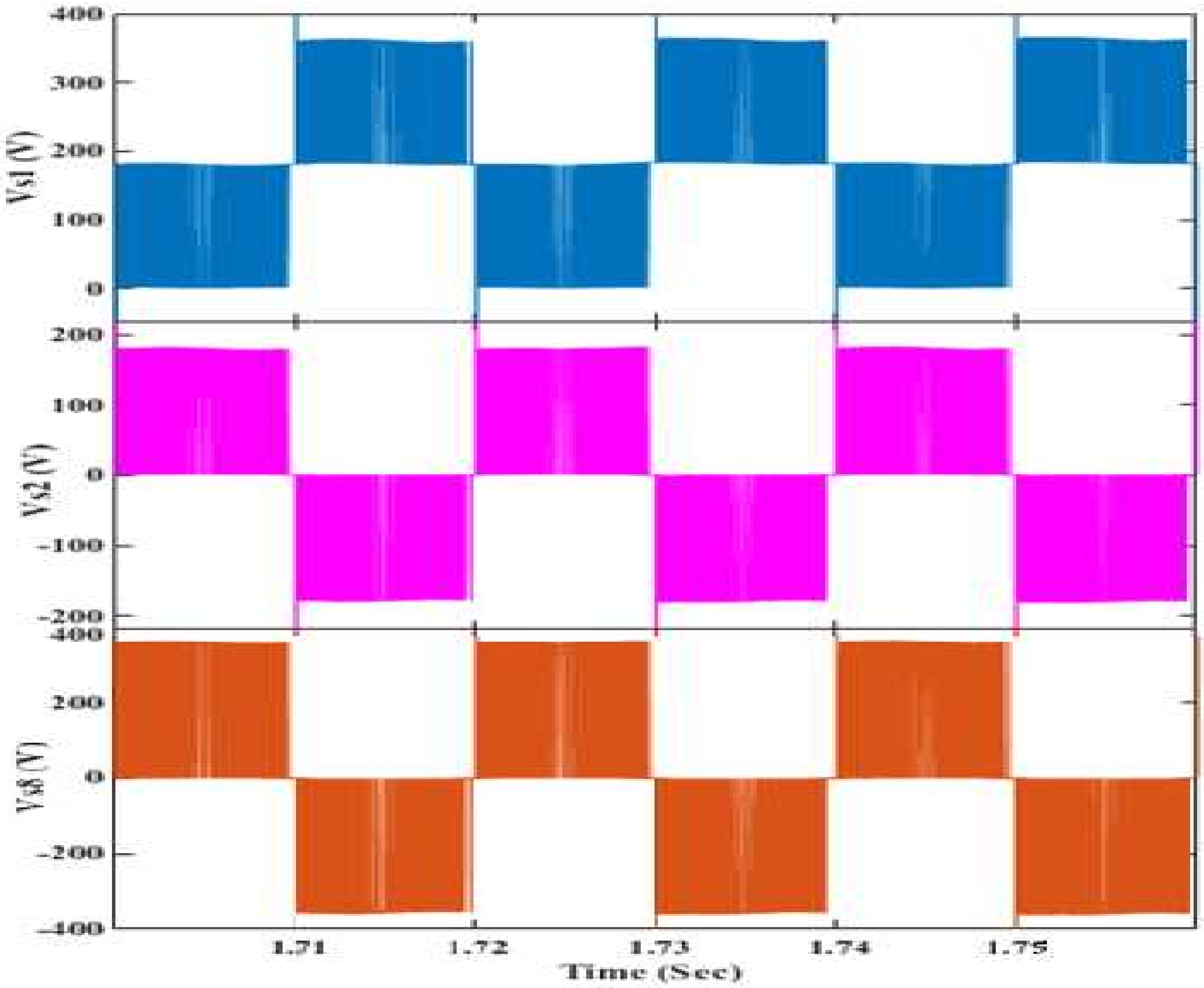

Fig. 7 Voltage stress across S_1,S_2 and S_8

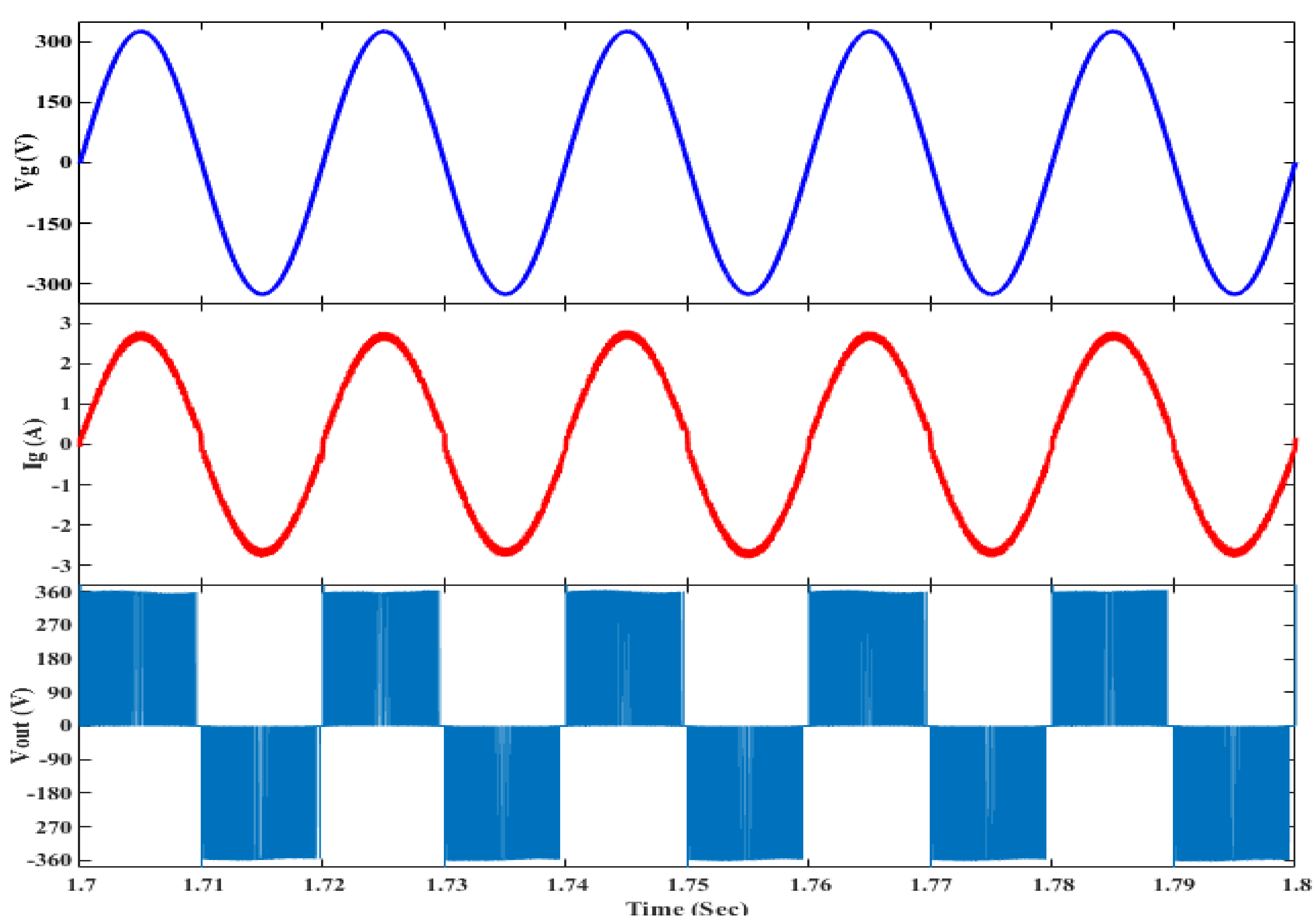

Fig. 8 V_g, I_g and V_{out} waveforms.

V. CONCLUSION

A modified single phase grid-tied PV inverter has been presented. The proposed topology offers the common ground features and boosting ability by using switched capacitors. Since the neutral of the grid and the PV panel negative terminal are shorted and grounded commonly, the leakage current issues totally eliminated. The switching capacitors can handle the power boosting in a single stage process in positive and negative half-cycle. The proposed system is able to inject a current with unity PF. Design consideration and loss analysis were studied. By minimizing the voltage stress across the power switch, cost can be minimized and life of the inverter can be improved. The proposed inverter configuration is suitable for home solarification and also for PV plants.

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A High Voltage Gain Boost DC-DC Converter for BLDC Motor Drive Applications

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Abstract: The output voltage of fuel cell cannot be used directly to drive a BLDC motor for ceiling fan application because of its low voltage and high current at the output. A high gain boost DC-DC converter with reduced voltage stress across the components will act between the fuel cell stack and the BLDC motor drive. The maximum voltage gain obtained is about 10. The output of high gain converter is given to the inverter and then to the BLDC motor. The speed of the motor is controlled by controlling the output voltage of the high gain boost converter in a closed loop. Simulation studies are done in MATLAB/Simulink.

Keywords: BLDC, Boost DC-DC converter, Fuel cell, High gain

I. INTRODUCTION

In the current situation of depletion of fossil fuels because of the unavailability of the raw materials , renewable energy resources are gaining its importance. Among the renewable energy resources fuel cells are important because of its zero emission and eco-friendly nature. One of the main drawback of fuel cells are their low voltage and high current at the output. So for obtaining a desired output voltage for a specific application a fuel cell stack containing a large number of individual fuel cells must be used. Instead of increasing the generation of electric power for meeting the demand of energy the consumption of power can be controlled. Studies show that the consumption of power is high in the house hold loads. So the maximum conservation of power is possible at the house hold loads itself. The house hold loads that consuming most of the power includes air conditioners, refrigerators, Fan ,lights etc . Among these ceiling fans contribute most part of the power consumption.

Commonly used motor for ceiling fans are the induction motors, not only for ceiling fans but for a wide variety of applications induction motors are used. Induction motors are generally used because of its advantages like simple construction, robust and can work in any environmental condition. They also have disadvantages like difficulties in the speed control, inrush current and starting torque is also poor. The use of induction motor for ceiling fan will increase the losses thus the power consumption. Instead of using induction motor the usage of a BLDC motor will reduce the power consumption. Now a days BLDC motors are gaining popularity because of the reduced power consumption. The power consumption of BLDC ceiling fans is less than half of that consumed by the ordinary induction motor ceiling fans.

The output of fuel cell is low voltage and high current and cannot be used directly to drive the BLDC motor. A boost DC-DC converter with high gain will act between the fuel cell and the BLDC motor. So even a low voltage fuel cell can drive the BLDC motor.

A conventional boost converter is commonly used to boost voltages, but they have some drawbacks due the to the parasitic elements. The voltage stress across the power semiconductor devices in the circuit is same as that of the output voltage. Many topologies are introduced to achieve a high voltage gain. Converters are cascaded to achieve high voltage gain. Converters are connected in series to achieve a high voltage gain , here buck-boost, boost, buck and cuk converters can be considered[2]. It is a simple and non isolated series connection of converters. The efficiency of series connected converter will be the product of the efficiency of each stage and the voltage stress components will also be high. High gain can be achieved by using coupled inductors also[3]. But the losses with the coupled inductors will be high. Clamp capacitor and diode is used to achieve high voltage gain and to reduce voltage stress but it will increase the complexity. To obtain high voltage gain and reduced voltage gain across switch a converter is proposed[4]. Here the additionally added capacitors will act as voltage dividers. Along with three inductors one coupled inductor is also used which will increase the circuit complexity. Isolated boost DC-DC converters topologies like three level converters are proposed but voltage gain is not that wide and in quadratic three level boost converters the inductors used will increase the losses[5]. A high gain boost converter is proposed with reduced number of components[6]. It is having single switch and one inductor. The circuit structure is simple with reduced voltage stress.

To compensate all these drawbacks and to achieve a very high gain converter with low voltage stress a converter is proposed here. The converter output is given to the inverter and then to the BLDC motor.

As shown in Fig.1 BLDC motor drive used for ceiling fan consists of a voltage source inverter and the input to the inverter is given through a high gain boost DC-DC converter. The high gain converter will boost the low output voltage of the fuel cell stack which can be given to inverter. Thus a very low voltage output of fuel cell can drive the BLDC motor. The phase currents at the motor output is used to obtain the rotor position. Only two windings of the motor will be energized at a time. Rotor position is obtained by using hall effect sensors and it can be used as feedback to drive the inverter. The speed of the motor is controlled by using a PI controller by changing the output voltage of the converter. The converter output voltage is adjusted by changing the duty ratio of the converter according to the PI controller output.

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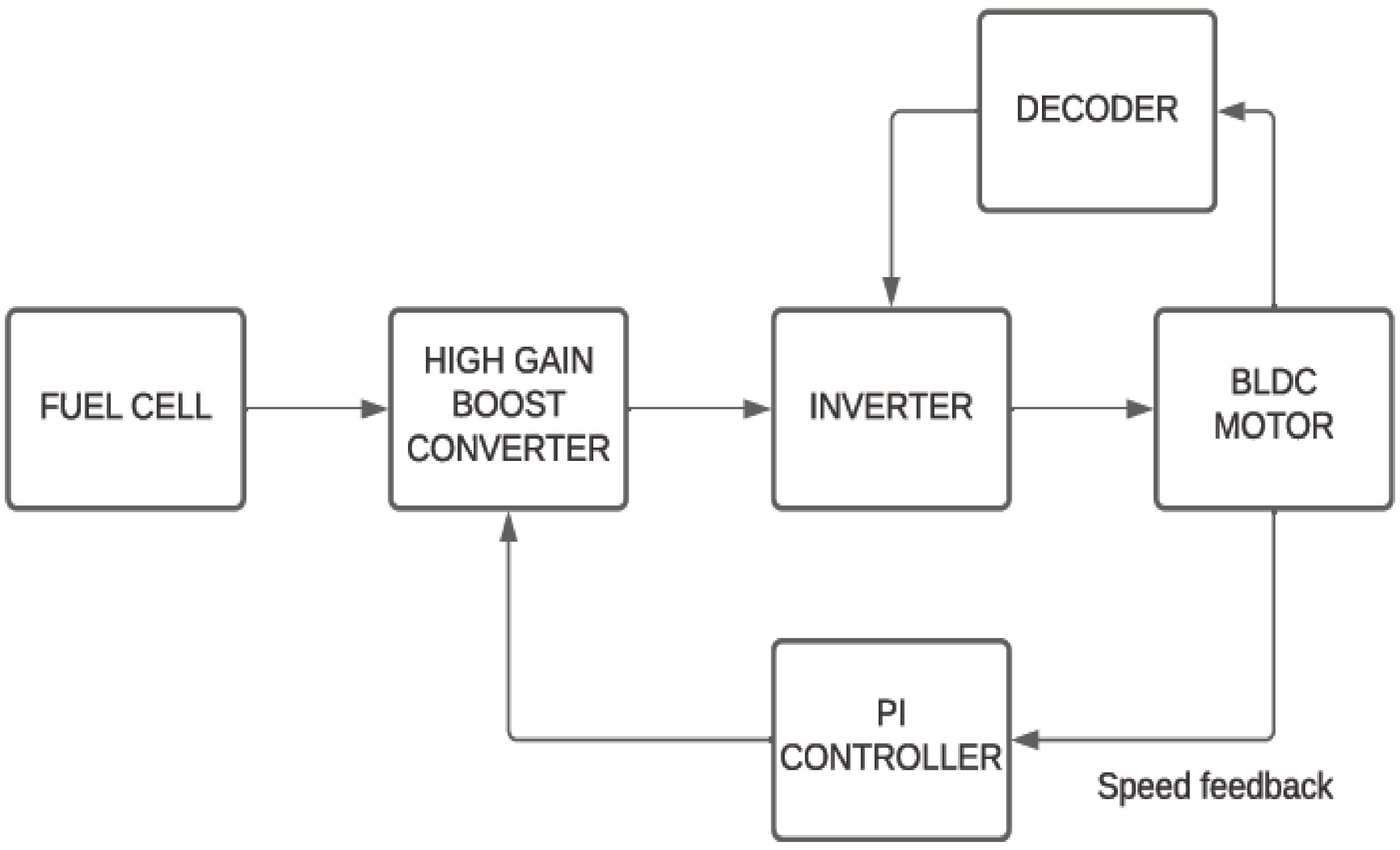

Fig.1. Block diagram representation of the proposed topology

II. HIGH GAIN BOOST DC-DC CONVERTER

A. *Circuit topology*

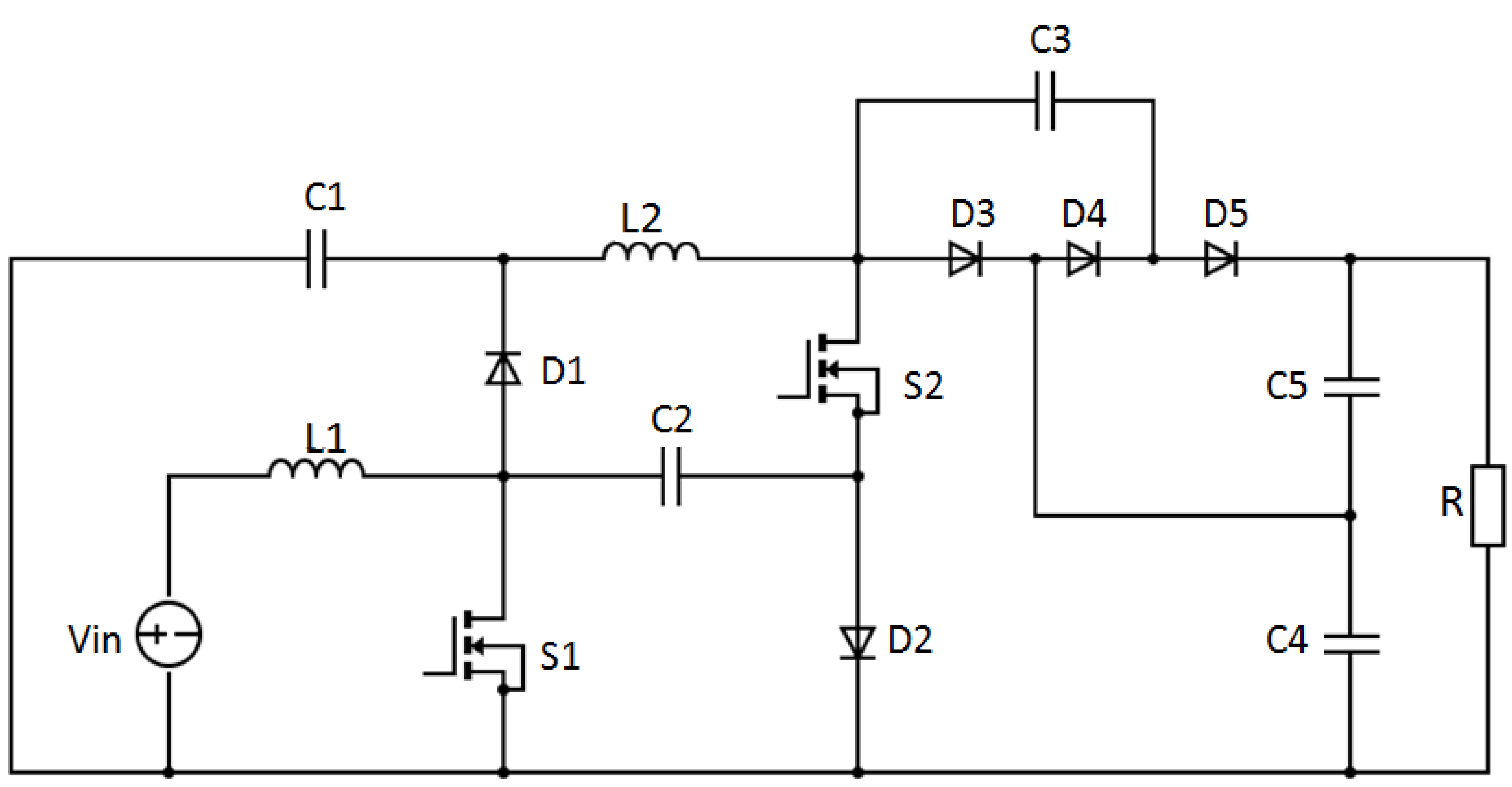

Fig.2. High gain boost DC-DC converter

The high gain converter consists of two switches S_1 and S_2. The fuel cell voltage is shown as V_{in} and the converter has two inductors , five diodes and five capacitors. A very high voltage gain of about 10 times the input voltage can be obtained at the output. Along with obtaining high voltage gain the voltage stress across the components is also reduced. The voltage stress across switches will be less than half of the output voltage. The switches S_1 and S_2 are turned on and turned off together. There will be two modes of operation. In both the modes, the inductors L_1 and L_2 are charging and discharging together.

B. *Modes of Operation*

In the two modes of operation, first mode is when both the switches are turned on at the same time and second mode is when both the switches are turned off. So the gate pulses given to them will be same. In Fig.3 and Fig.4 the circuit components shown in red colour are turned on and having current flow. The direction of current flow is also shown.

Mode 1 : In this mode both switches S_1 and S_2 are turned on as shown in Fig.3. Both inductors L_1 and L_2 are charging in this mode. L_1 is charged from the fuel cell voltage V_{in}. L_2 is charged from C_1 and C_2. Capacitors C_2 and C_4 are discharging and charging C_3 in a series path. The output voltage appearing across the load will be the voltage across capacitors C_4 and C_5.

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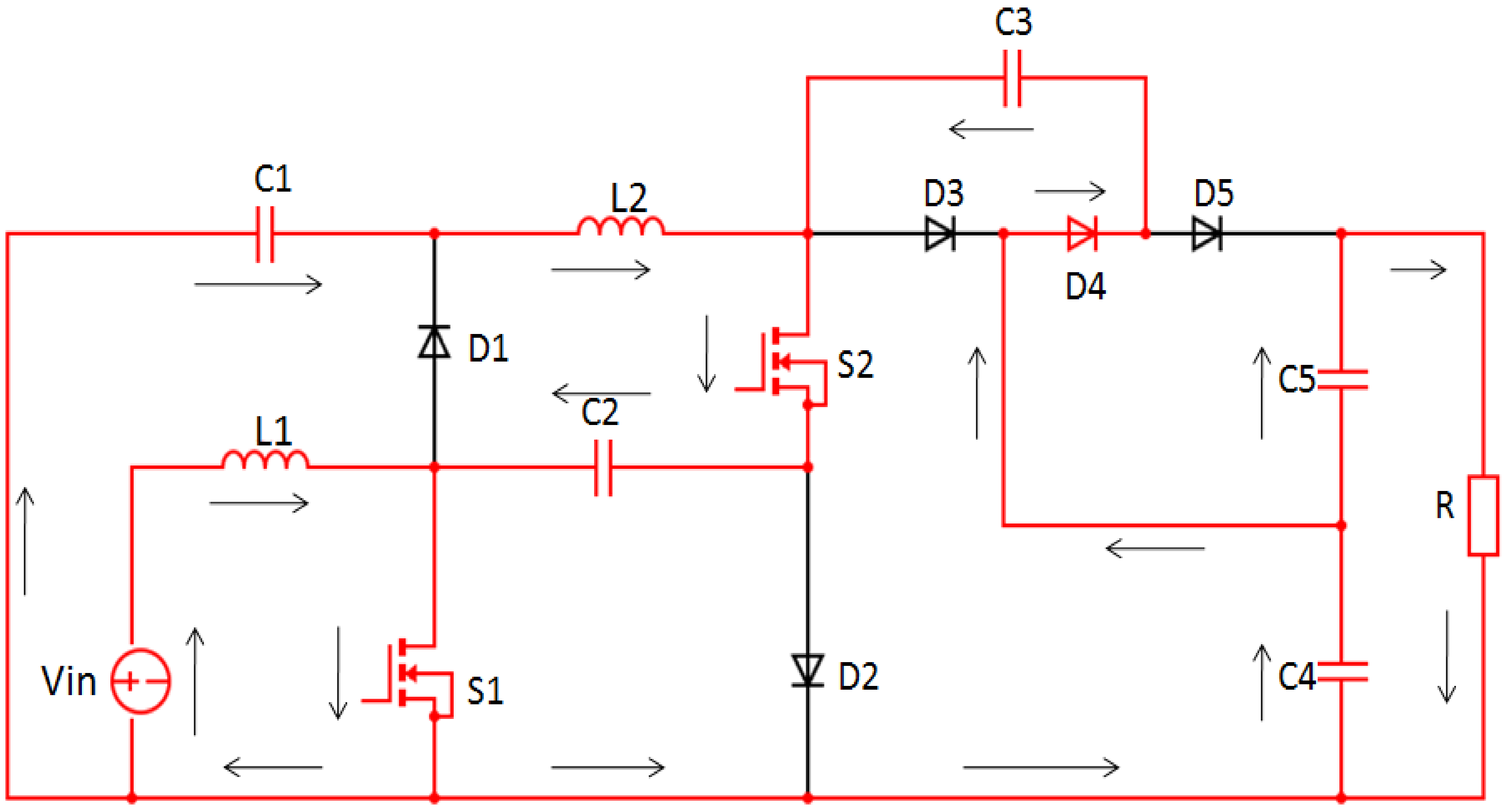

Fig.3. Mode 1

Mode 2: In mode 2 both switches are turned off and L_1 and L_2 will be discharging as shown in Fig.4. Fuel cell voltage V_{in} and L_1 will charge capacitors C_1 and C_2 . Capacitor C_4 is charged by V_{in}, L_1 and L_2. Also V_{in}, L_1, L_2 and C_3 is charging C_4 and C_5. The directions of current is shown in Fig.4.

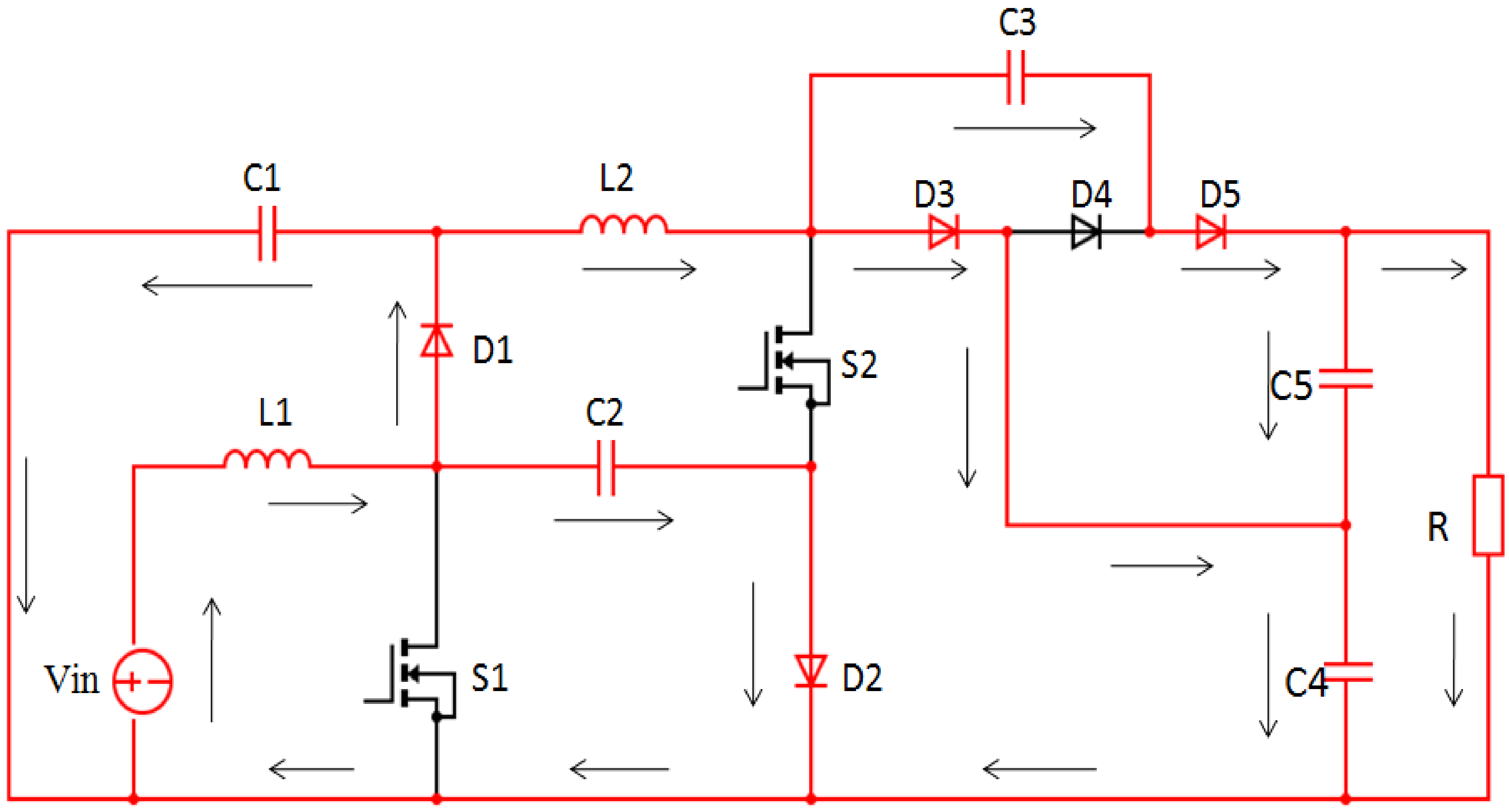

Fig.4. Mode 2

C. *Circuit analysis*

For the switches , the switching period is taken as T. On state period is taken as DT and off state period as (1-D)T. D is the duty cycle of the switches which will be same for both the switches. The on state resistance drop of the switches and diodes are not considered.

The volt-second balance equation for the inductors is written as

$$V_{in}\text{*DT} + (V_{in}\text{-}V_{C2})\text{*(1-D)T} = 0 \quad (1)$$

$$(V_{C1}+V_{C2})\text{*DT} + (V_{C2}\text{-}V_{C4})\text{*(1-D)T} = 0 \quad (2)$$

The capacitor voltages can be shown in relation with output voltages as below

$$V_{C1} = V_{C2} \tag{3}$$

$$V_{C3} = V_{C5} = V_{C2} + V_{C4} \tag{4}$$

$$V_O = V_{C4} + V_{C5} \tag{5}$$

From equation (1) to (5) output voltage V_o is given as

$$V_O = \frac{3+D}{(1-D)^2} V_{in} \tag{6}$$

$$\text{Voltage gain} = \frac{V_O}{V_{in}} = \frac{3+D}{(1-D)^2} \tag{7}$$

For the design of inductor the ripple current is taken as ΔI_L

$$\mathrm{L} = V_L \frac{DT}{di_L} \tag{8}$$

Where, $Di_L = \Delta I_L$ and $\mathrm{DT} = \frac{D}{f_s}$

$$L_1 = \frac{D*V_{in}}{\Delta I_{L1}*f_s} \tag{9}$$

$$L_2 = \frac{4D*V_{in}}{(1-D)^2*\Delta I_{L2}*f_s} \tag{10}$$

For the design of capacitor ripple voltage is taken as ΔV_C.

$$\mathrm{C} = I_C \frac{DT}{dV_C} \tag{11}$$

The capacitances are given as below.

$$C_1 = \frac{2D*I_0}{(1-\mathrm{D})\Delta V_{C1}*f_s} \tag{12}$$

$$C_2 = \frac{(1+D)*I_0}{(1-\mathrm{D})\Delta V_{C1}*f_s} \tag{13}$$

$$C_3 = \frac{I_0}{\Delta V_{C3}*f_s} \tag{14}$$

$$C_4 = \frac{(1+D)*I_0}{\Delta V_{C4}*f_s} \tag{15}$$

$$C_5 = \frac{D*I_0}{\Delta V_{C5}*f_s} \tag{16}$$

III. BLDC DRIVE SCHEME

Now a BLDC motors are more popular because of its reduced power consumption compared to other motors like induction motor. The speed control of BLDC motor is also simple. BLDC motor is a three phase motor having three windings and only two windings will be energized at a time. The third winding will be off and the two windings energized depends on the rotor position. The three hall sensors connected at the output determine the rotor position and is given as feedback to drive the inverter. The inverter output will be a three phase AC directly connected to the three phase BLDC motor windings. The output of the high gain converter is shown as input voltage to the inverter in Fig.5.

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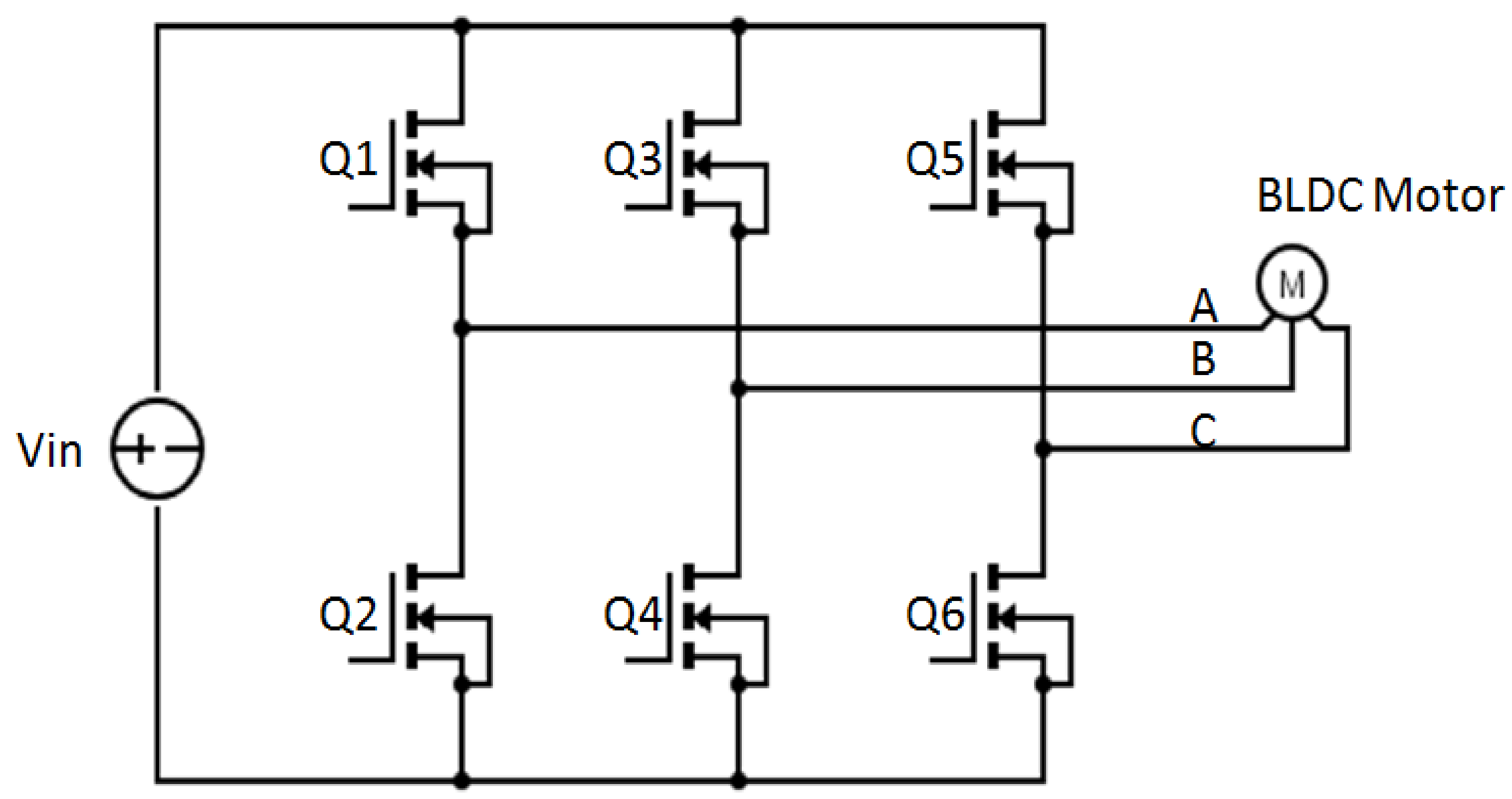

Fig.5. BLDC motor with inverter

TABLE I
SWITCHING OF INVERTER

Electrical degrees	H1	H2	H3	I_a	I_b	I_C	Switches operating	
0 - 60	1	0	1	+	-	Off	Q_1	Q_4
60 - 120	1	0	0	+	Off	-	Q_1	Q_6
120 - 180	1	1	0	Off	+	-	Q_3	Q_6
180 - 240	0	1	0	-	+	Off	Q_3	Q_2
240 - 300	0	1	1	-	Off	+	Q_5	Q_2
300 - 360	0	0	1	Off	-	+	Q_5	Q_4

The output of the hall sensors will be a three digit number output and it will change for every 60 degrees. TABLE 1 shows the switching pattern of inverter for 0 to 360 electrical degrees and the possible 6 current distributions. Out of the three windings only two will be energized at a time.

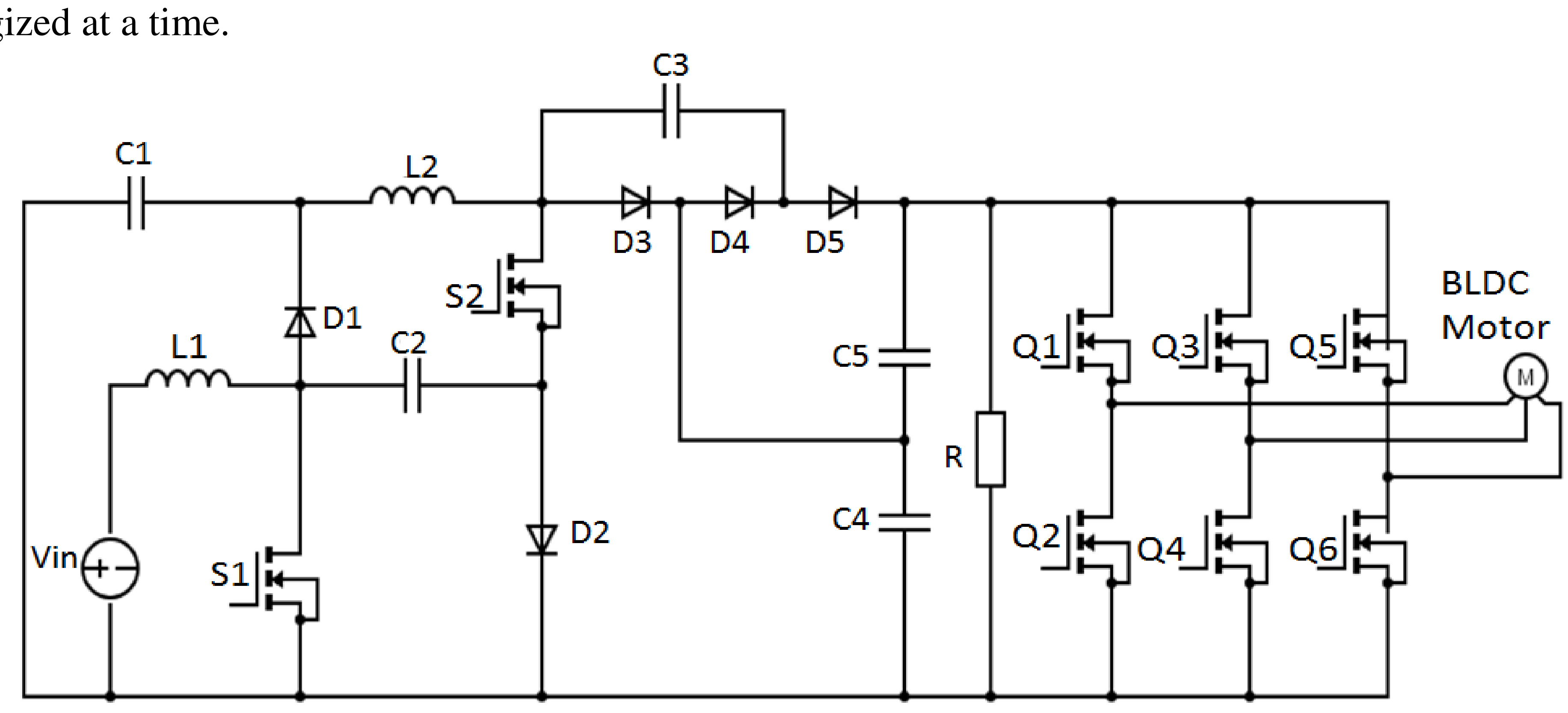

Fig.6. BLDC motor drive circuit scheme with high gain boost converter

Fig.6. shows the combined proposed circuit scheme for a BLDC motor driver. The input to the inverter(voltage source inverter) is given through a high gain boost DC-DC converter. The high gain converter will give an output voltage ten times that of the input voltage and it is given as input to the inverter. The out of inverter is a three phase AC and is given to the BLDC motor. The pulses to the inverter are given through the rotor position feedback through the hall effect sensors. The speed of the motor is controlled by controlling the duty ratio of high gain converter in a closed loop using PI controller.

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IV. SIMULATION

The simulation is done in MATLAB/Simulink as shown in Fig.7. Here for the simulation the duty ratio is taken as 0.42 for an input voltage of 4.8V and output voltage of 48V. The switching frequency is taken as 20 kHz for a 40W power.

TABLE II
SIMULATION PARAMETERS

Parameter	Values
Input voltage	4.8V
Output voltage	48V
Power	40W
L_1, L_2	0.12mH , 4.9mH
C_1, C_2, C_3, C_4, C_5	100 µF, 80 µF, 80 µF, 10 µF, 10 µF
BLDC motor	
Stator phase inductance	3mH
Stator phase resistance	2 Ω

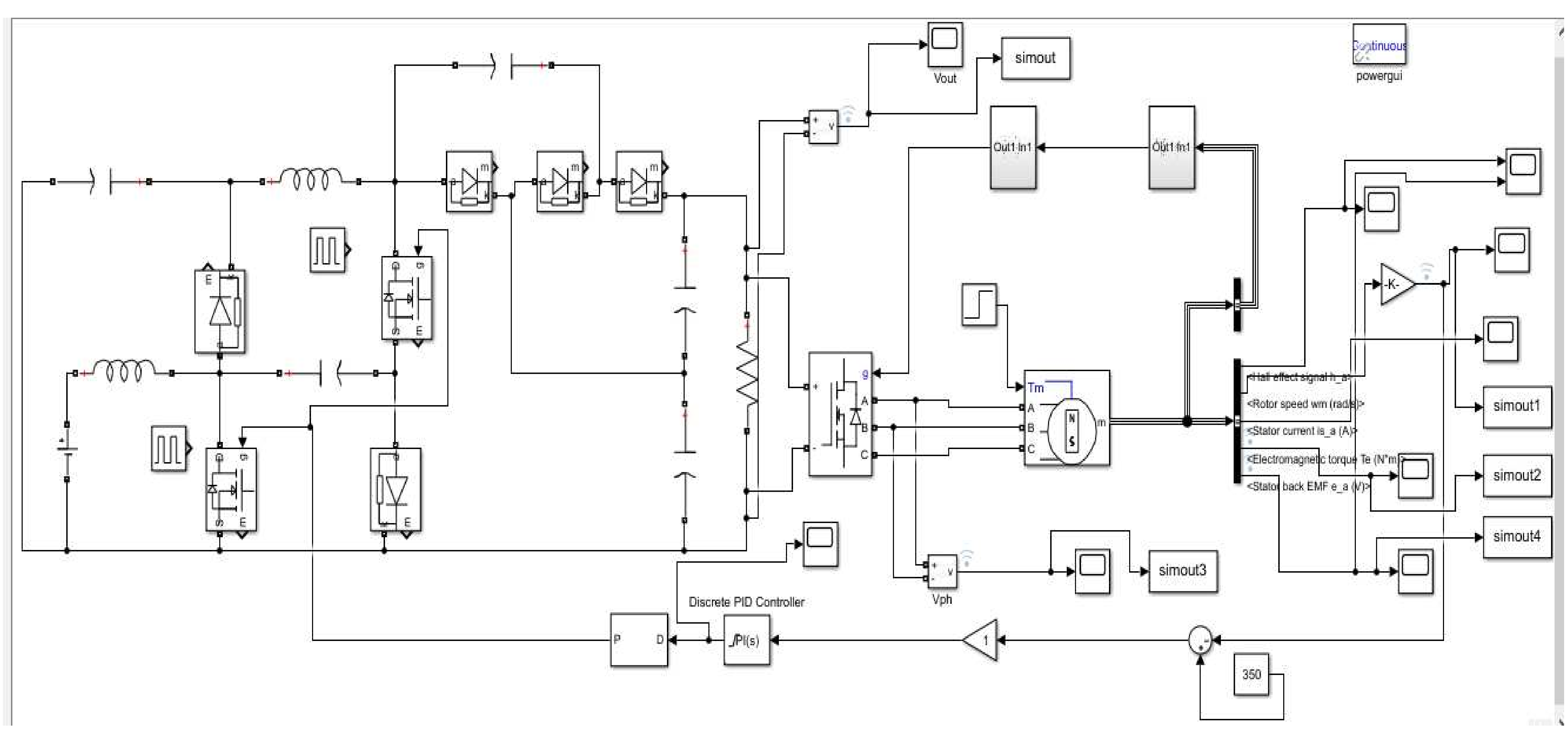

Fig.7. Simulation diagram

The Fig.7 shows the simulation diagram in closed in closed loop for the speed control of BLDC motor. Fig.8 and Fig.9 respectively shows the input and output voltage of the high gain converter.

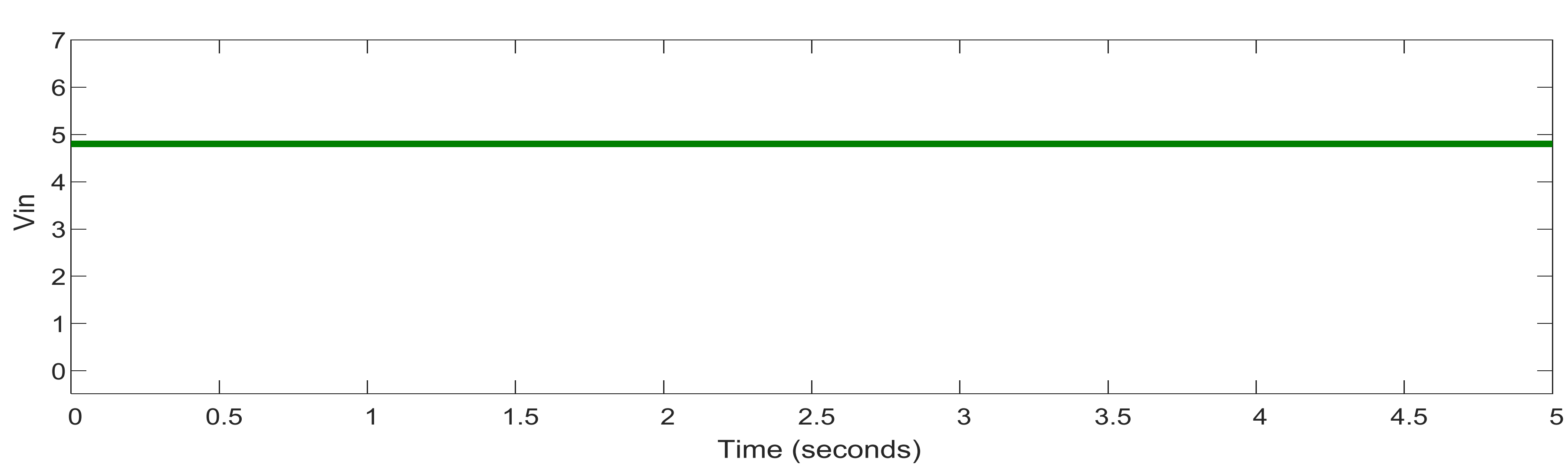

Fig.8. Input voltage

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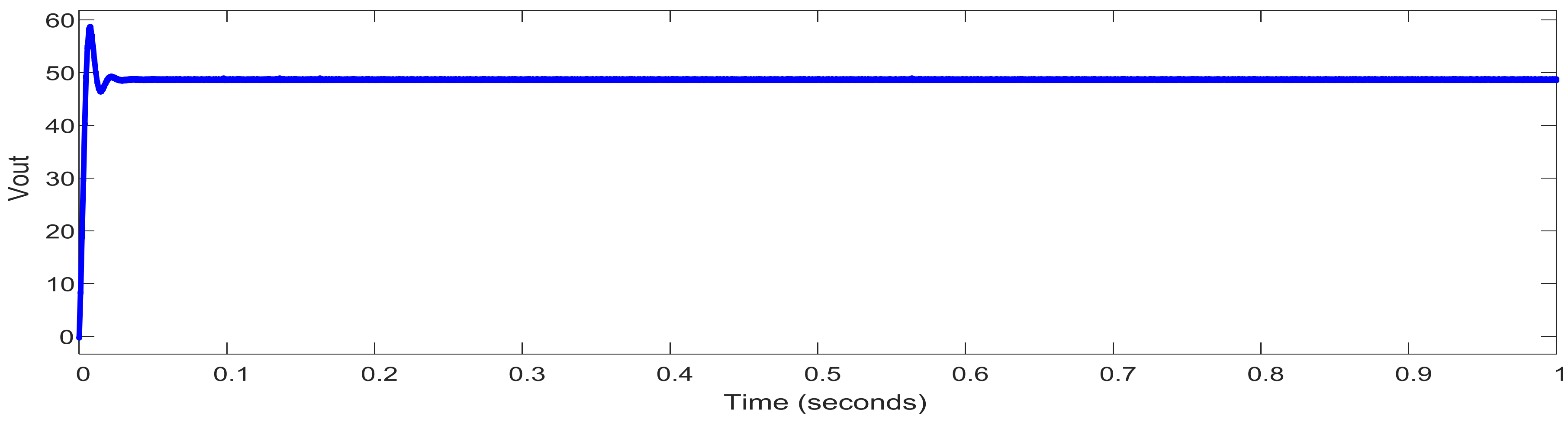

Fig.9. Output voltage

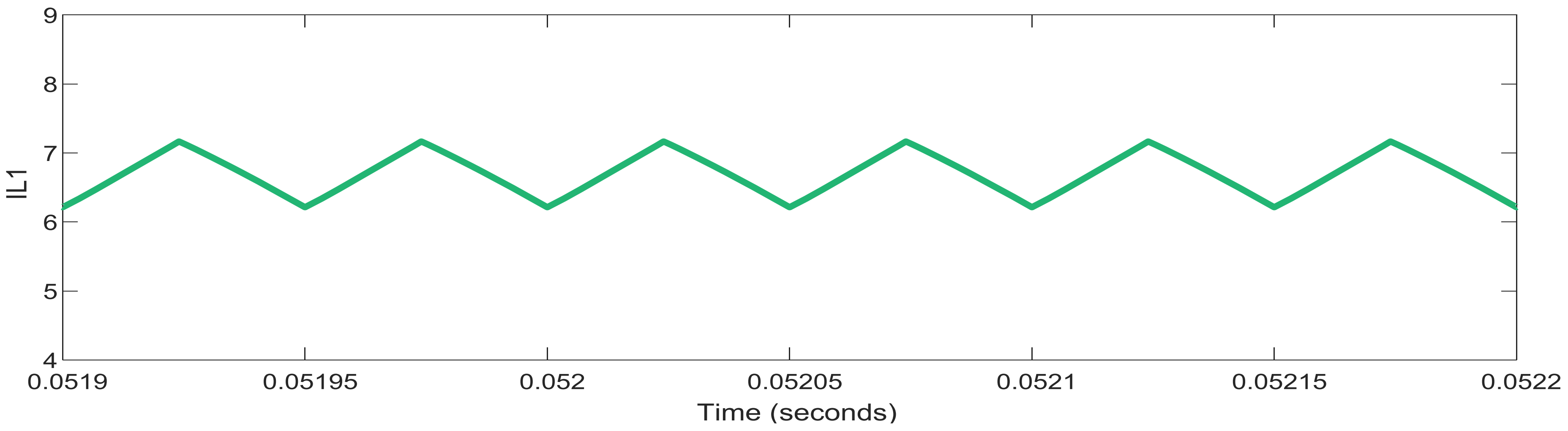

Fig.10. Current through inductor L_1

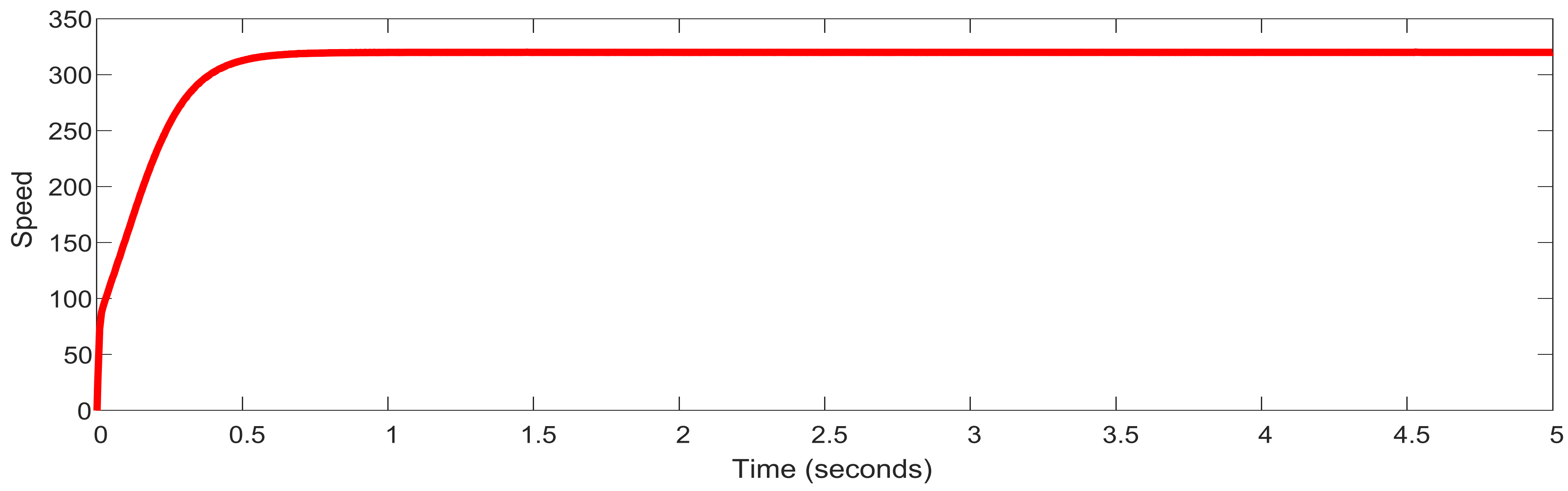

Fig.11. Speed of motor

Fig.10 shows the speed of the motor obtained as 320 rpm for an input voltage of 48V and Te = 0.2 Nm
TABLE III shows the power consumption of motor for ceiling fan application at different speeds

TABLE III
POWER CONSUMPTION AT DIFFERENT SPEEDS

Speed	Power consumption
320 rpm	35 W
250 rpm	24 W
150 rpm	14 W

V. CONCLUSION

A boost DC-DC converter with high gain of about 10 times the input voltage is proposed for BLDC motor drive applications with a reduced voltage stress across the power semiconductor devices. The converter converts a low input voltage 4.8V to 48V. The speed of the motor is controlled by changing the output voltage of the high gain boost DC-DC converter by changing the duty ratio in a closed loop using PI controller. Simulation is done using MATLAB/simulink for different speeds of the motor.

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Single Phase Multilevel Transformer less Inverter for Adjustable Speed AC Motor Drive

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Abstract:Transformer less inverters have shown considerable improvements with respect to transformer isolated inverters. In particular, transformer less inverters have smaller size and weight, lower cost and higher efficiency, which makes them the preferred solution in grid-connected photovoltaic (PV) applications. Since no transformer is present, then there is a galvanic connection between the power converter and the electrical grid. As a result, a leakage current may flow through the ground path and the power circuit. The leakage current flowing path involves the equivalent parasitic capacitances, which are the capacitances formed between the PV cells and the grounded frame of the PV panel. The values of capacitances are in the order of nano farad to microfarad, and depend on atmospheric and physical operation conditions, namely, moisture, dust, PV panel size, frame structure etc. The leakage current may affect the system efficiency and reliability and may cause electromagnetic interference (EMI) issues. Additionally, it represents a potential electric hazard to humans in contact with the PV array. Hence, the lack of galvanic isolation may represent a huge safety risk, if the leakage current is not properly handled. The common mode analysis or a detailed leakage current analysis of the presented topology is done.

Keywords:Transformer less inverters, multilevel inverters, pulse width modulation, common mode analysis

I. INTRODUCTION

The global power demand is increasing day by day and most of the developing countries as well as the under developed ones are relying almost completely on the conventional sources of power. Even the developing new infrastructures have brought the fossil fuel usage very high. The excessive use of fossil fuels have caused climatic impacts and it is high time we move to the renewable energy sources like solar and wind. The recent developments in the power electronic sector have enabled the extensive use of solar energy conversion system (SECS) and wind energy conversion system (WECS). The converters make use of power electronic switches like IGBTs and MOSFETs for conversion purpose. The multilevel inverters are becoming significant in these energy conversion systems. The energy storage requirement in the present scenario is met with the DC power only. This stored DC power is converted to AC for industrial applications. Presently used two level inverters have higher switching losses owing to high switching frequency at which it operates. The lower voltage stress across each switch and a lower total harmonic distortion (THD) contributes to better performance with multilevel inverters. The three basic topologies are diode clamped, capacitor clamped and cascaded H-bridge multilevel inverter. There are many other topologies described in the literature. The grid connected multilevel inverters are used for active power injection into the grid whenever the grid demands power. This kind of distributedgeneration are encouraged in many developed countries where the transition from the conventional energy sources have already begun. The reactive power supplied by the grid connected multilevel inverter helps in improving the power quality of the system. Hence, the unity power factor condition is achieved as all the reactive power required by the load is supplied through the multilevel inverters. Since the multilevel inverters have higher number of levels, its THD value will be much lesser compared to the two-level inverters. Thus, only a small ripple filter is required at the output. The transformer less inverters have several improvements with respect to transformer isolated inverters. Particularly, smaller size, weight, lower cost and higher efficiency which makes it preferable in grid tied applications.

A transformerless inverter having smaller size and weight lower cost and high efficiency, which make them preferred solution in grid connected renewable energy applications [1]. There is no transformer is present a galvanic connection is present between the converter and grid so a large leakage current may flow through the ground path. Parasitic capacitance present between renewable energy cell and grounded frame,that capacitance depended on atmospheric temperature and physical conditions [2]. The leakage current may affect the system efficiency. It will cause electromagnetic interference. Also, huge safety risk due to lack of galvanic isolation [3]. In multilevel inverter both magnitude and frequency of the leakage current generated in a renewable energy system mainly depends on inverter tropology and modulation technique [4]. A single-phase H-bridge converter with bipolar PWM and the neutral point clamped converter that present initially low leakage current [5]. One of the main goals in the design of transformerless grid connected converters is to reduce or eliminate the leakage current. The solutions reported so far can be classified in the design of modulation and control schemes [7], and the proposal of new transformer less grid-connected inverter topologies [8]- [9]. In [10], a modulation strategy for a new topology of a three-phase NPC converter is proposed. This topology consists of two additional switches, two diodes and split capacitors on the DC-side. In this topology, the diodes and the capacitive divider limit the blocking voltage of the switches. Multilevel topologies have demonstrated certain advantages to inject power towards the grid with respect to simpler topologies. For instance, it has been shown that a cascade multilevel inverter (CMI) does not need a voltage-boost converter stage for a proper operation, which improves the overall efficiency of the PV system. Moreover, as the AC output voltage is formed by multiple voltage levels, then the total harmonic distortion (THD) is considerably reduced, which reduces the size of the output filter. Multilevel topologies and the associated modulation schemes have also been presented to reduce leakage current. In [11], a modified H6 inverter topology without input split capacitor is proposed, which uses a hybrid modulation scheme. This topology can be considered as a T-type inverter, as it uses a bidirectional switch to create the five levels in the output voltage. The bidirectional switch is built out of four diodes and one switch, where the diodes may affect the efficiency. The modulation scheme is close to a level shifted technique, where an offset over the control signal is added. Moreover, the proposed solution does not deal with the leakage current issue.

II. METHODOLOGY

DC-DC converter topologiesare created to meet the demands of particular DC loads. Buck, boost and buck-boost are some of the DC-DC converters that can be used as switching regulators to regulate unregulated DC voltage by converting it to suitable utilisation voltage by increasing or decreasing the DC output voltage with the helpof a PWM switching technique which operates at a fixed frequency. When a converter is required, it needs power switching devices to turn on and off. Depending on the parameters and applications of the circuit design, power switching devices such as thyristors, BJTs, MOSFETs and IGBTs are used. Appropriate gate drive signals produced by a gate driver circuit must be considered when triggering power switching devices Pulse Width Modulation. PWM switching is used to regulate the voltage frequency and phase delay of the DC-DC converters.

A. Proposed approach

Fig.1 shows the circuit of single phase 5 level inverter. It is based on H bridge configuration and a t type configuration. It has two part; a converter part and inverter part. In converter side there is a flyback converter that will boost the input dc voltage to desired dc voltage. Then the five-level inverter in the second stage has functions of regulating dc bus voltage and converting dc power to ac power. It is lighter and more compact compared to other multilevel topologies. This topology has less switching power loss, reduced harmonic distortion and reduced EMI.

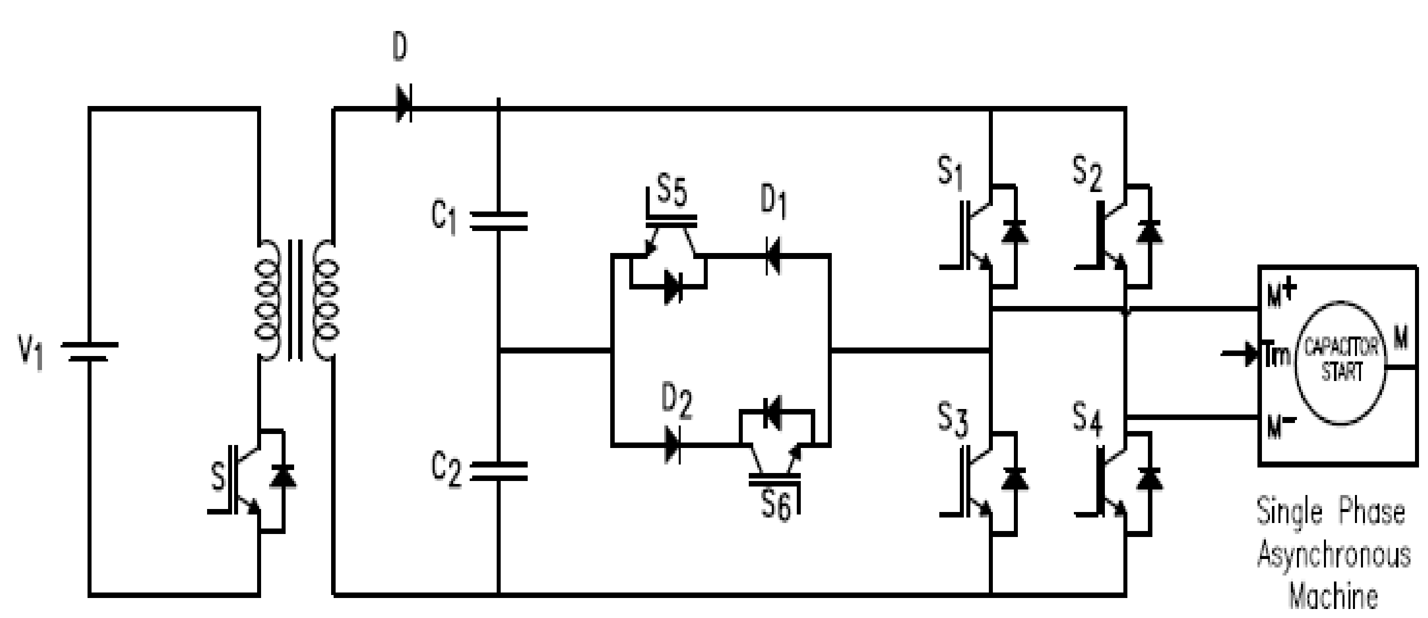

Fig. 1. Proposed DC-AC Converter System

B. Flyback converter

When the switch S is closed the primary of the transformer is directly connected to the input voltage source. The primary current and magnetic flux in the transformer increases, storing energy in the transformer. The voltage induced in the secondary winding is negative, so the diode is reverse-biased (i.e. blocked). The output capacitor supplies energyto the output load. When the switch S is opened, the primary current and magnetic flux drops. The secondary voltage is positive, forward-biasing the diode, allowing current to flow from the transformer. The energy from the transformer core recharges the capacitor and supplies the load.

C. Single phase five levelinverter

Single phase 5 level PWM inverter to reduce the harmonic components of output voltage and load current are used in the proposed system. PWM inverters has able to control output voltage and frequency simultaneously. It has simple structure and a smaller number of switches. In the inverter topology is an H-bridge based topology and could be used in transformer less inverter applications [12]. Here, one of the legs of the inverter is modified in such a way as to gain access to the midpoint of the split DC link. This is achieved by using a bidirectional switch and this leg is termed as a T-type leg. The other leg is kept unmodified. The modulation scheme used is a pulse width modulation scheme. The main feature of this modulation is that the two-level leg commutes at fundamental frequency. The circuit diagram is shown in Fig.1. This 5-level T shaped asymmetrical H-bridge inverter is based on an H-bridge configuration. The bidirectional switch is introduced to connect the midpoint of the DC link formed by S_1 and S_3. This allows a three-level generation from the T-type leg. The different modes of operation are explained in detail.

The five modes of operation are given below. In mode I operation, the inverter voltage obtained is, $V_{AB} = V_1$. During positive half cycle of the inverter operation, $V_{C1} = V_{C2} = \frac{V_1}{2}$ are generated across the capacitors. In this figure, switches S_1 and S_4 are on. This corresponds to normal operation of a cascaded H-bridge inverter. Output voltage is positive and maximum. Current enters through S_1 and returns through S_4 from the DC source.

In mode-II operation, the inverter output still in positive half cycle, S_1 is turned off whereas S_6 is turned on simultaneously. D_2 is forward biased here. Switch S_4 remains in on condition. The output voltage is half the DC link voltage and positive, that is $V_{AB} = V_{PV}/2$. The output current flows from lower capacitor C_2 through switches S_6, S_4 and diode D_2.

In mode-III, the zero or null state is produced in two different ways, simultaneously switching on S_1 and S_2 or S_3 and S_4, keeping other switches off in both the cases. Zero state can also be achieved by switching off all the switches.

In mode-IV, the negative half cycle of the inverter output voltage begins. The voltage level generated is $-V_1/2$. The switches acting during this mode are S_5 and S_2. The diode conducting is D_1. The other semiconductor devices do not conduct.

In mode-V, the voltage level generated is $-V_1$. The switches acting during this mode are S_3 and S_2. The diodes do not conduct in this mode. The other semiconductor switches do not conduct.

Fig.2 shows the sector distribution along one grid period. For better visualization, the plot on the left has been shown with lower switching frequency.

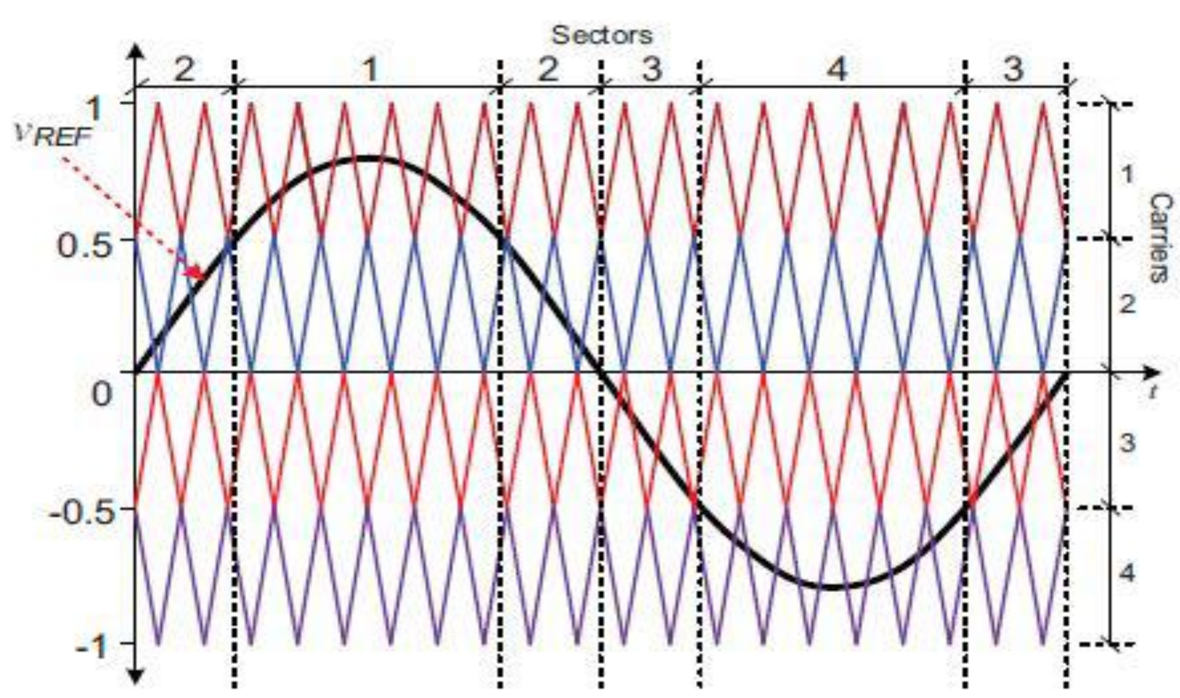

Fig.2.Definitions of sectors and carriers in PWM strategy

III.COMMON MODE ANALYSIS

The common mode model for the five level T-type asymmetric H-bridge inverter is shown in Figure 3. To analyse this model, it is convenient to define the common mode voltage (CMV) V_{CM} , the differential mode voltage V_{AB} and leakage current or common mode current i_{CM}.

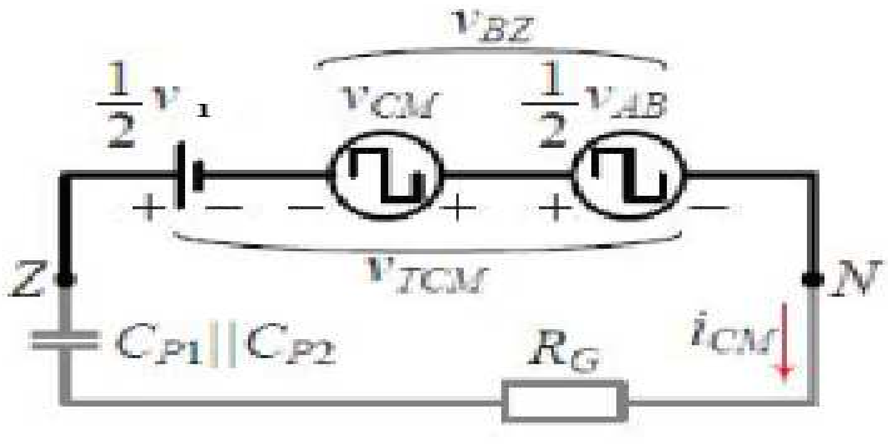

Fig.3. Common mode model for the proposed converter

$$V_{CM} = \frac{V_{AZ} + V_{BZ}}{2} \tag{1}$$

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$$V_{AB} = V_{AZ} - V_{BZ} \tag{2}$$

$$i_{CM} = i_1 - i_2 \tag{3}$$

where V_{AZ} and V_{BZ} are the inverter output voltages with respect to point Z. Here, Z is referred to as the common point. Table 1 shows the evaluated result of V_{AB} and V_{CM} for all possible outcomes of V_{AZ} and V_{BZ}, adhering to the above definitions. For clarity, the ground impedance ZG will be considered as RG, a simple resistor. By applying Kirchhoff's voltage law to the current trajectories of i_1 and i_2, we get the following equations,

$$V_{AZ} = sLi_1 + v_S + i_{CM}\left(R_G + \frac{1}{sC_p}\right) + \frac{v_1}{2} \tag{4}$$

$$V_{BZ} = i_{CM}\left(R_G + \frac{1}{sC_p}\right) + \frac{v_{PV}}{2} \tag{5}$$

In the practical implementation of the modulation scheme, dead times must be included between switching signals S_2 and S_4, and between signals S_1 and S_3, to avoid short-circuiting the source formed by $V_{C1} + V_{C2} = V_{PV}$. Dead times must be also included between signals S_1 and S_5 to avoid short circuiting C_1, and between signals S_3 and S_6 to avoid short circuiting C_2. However, theintroduction of such dead times may cause abnormal excursions to invalid voltages for a given Sector. The solution for this issue involves the use of some switching states redundancies as explained next. Recall that, in Sector 1, the valid output voltage levels are V_{PV} and $V_1/2$. However, if a dead time is introduced between S1 and S_5=S_6, then an abnormal jump to 0 V would arise. Therefore, it is recommended to treat S_5 and S_6 as different signals. That is, to keep the output voltage V_{AB} in $V_1/2$, it is suggested to introduce a dead time in between S_1 and S_5 only, while keeping signal S_6 ON during such a dead time. Notice that this is possible due to diode D_2.

TABLE I
COMMON MODE VOLTAGE CALCULATIONS

state	V_{AZ}	V_{BZ}	V_{AB}	V_{CM}
1	V_1	0	V_1	$\frac{V_1}{2}$
2	$\frac{V_1}{2}$	0	$\frac{V_1}{2}$	$\frac{V_1}{4}$
3	0 V_1	0 V_1	0 0	0 V_1
4	$\frac{V_1}{2}$	V_1	$-\frac{V_1}{2}$	$\frac{3V_1}{4}$
5	0	V_1	$-V_1$	$\frac{V_1}{2}$

A similar situation arises in Sector 4, where the valid outputvoltage levels are $-V_1$ and $\frac{-V_1}{2}$. In this case, it is suggested to introduce a dead time between S_3 and S_6 only, while S_5 can be maintained ON during the dead time. This keeps the output voltage V_{AB} in $\frac{V_1}{2}$ thus avoiding abnormal excursions to 0V . Recall that, in Sectors 2 and 3, the valid output voltage levels are $\frac{-V_{PV}}{2}$, 0 and $\frac{-V_1}{2}$. At the zero crossings, in Sectors 2 and 3, a dead time between S_2 and S_4 may cause abnormal excursions towards either V_{PV} or $-V_1$ depending on the current direction. These, however, are not valid output voltage levels for such sectors. To overcome thisissue, it is proposed to keep either switch S_1 ON for a positive load current or switch S_3 ON for a negative load current during such a dead time. The need to know the sign of the load current can be obviated if the current is due to a predominantly inductive load. In this case, it isenough to know the previous sector. That is, S_1 is kept ON if coming from Sector 2, while S_3 is kept ON if coming from Sector 3. It is also very convenient to include a common mode EMI filter to reduce even more the leakage current. These filters are usually included in every commercial inverter to comply with EMI standards.

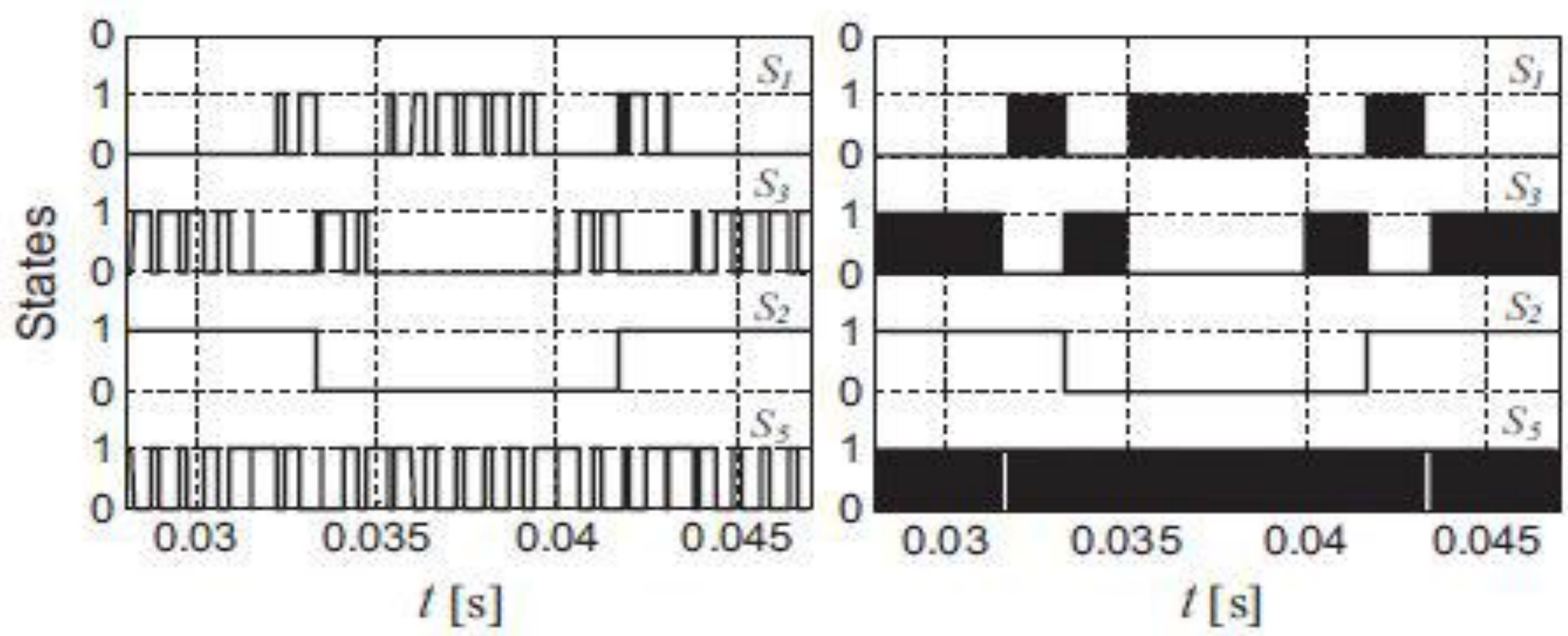

Fig.4. Switching pattern of S_1, S_3, S_2, and S_5 at low switching frequency and high switching frequency

IV. SIMULATION AND RESULTS

Simulations are conducted using MATLAB/Simulink to verify the system performance. Simulation results are obtained using designed equations and output was obtained as expected. TABLE II shows the simulation parameters of proposed system.

TABLE II
SIMULATION PARAMETERS

COMPONENTS	SPECIFICATIONS
Input voltage	36V
Output voltage	230 V
Rated power	200 W
Switching frequency	100 kHz
capacitors (C_1,C_2)	2 µF
Load resistor	100Ω

The proposed converter system was designed for a power of 200 W, input voltage 36 V, output voltage 230 V and switching frequency of 100 kHz. The duty cycle for the flyback converter operating is 0.4. The Fig. 5shows the simulation diagram of the five level inverter. Fig. 6 shows theswitching pulses to inverter by SPWM technique. Fig. 7 shows the input and output voltage waveforms and output current waveforms. The speed and torque of the single phase AC motor is shown in the Fig. 8. The FFT analysis shown in Fig 9.

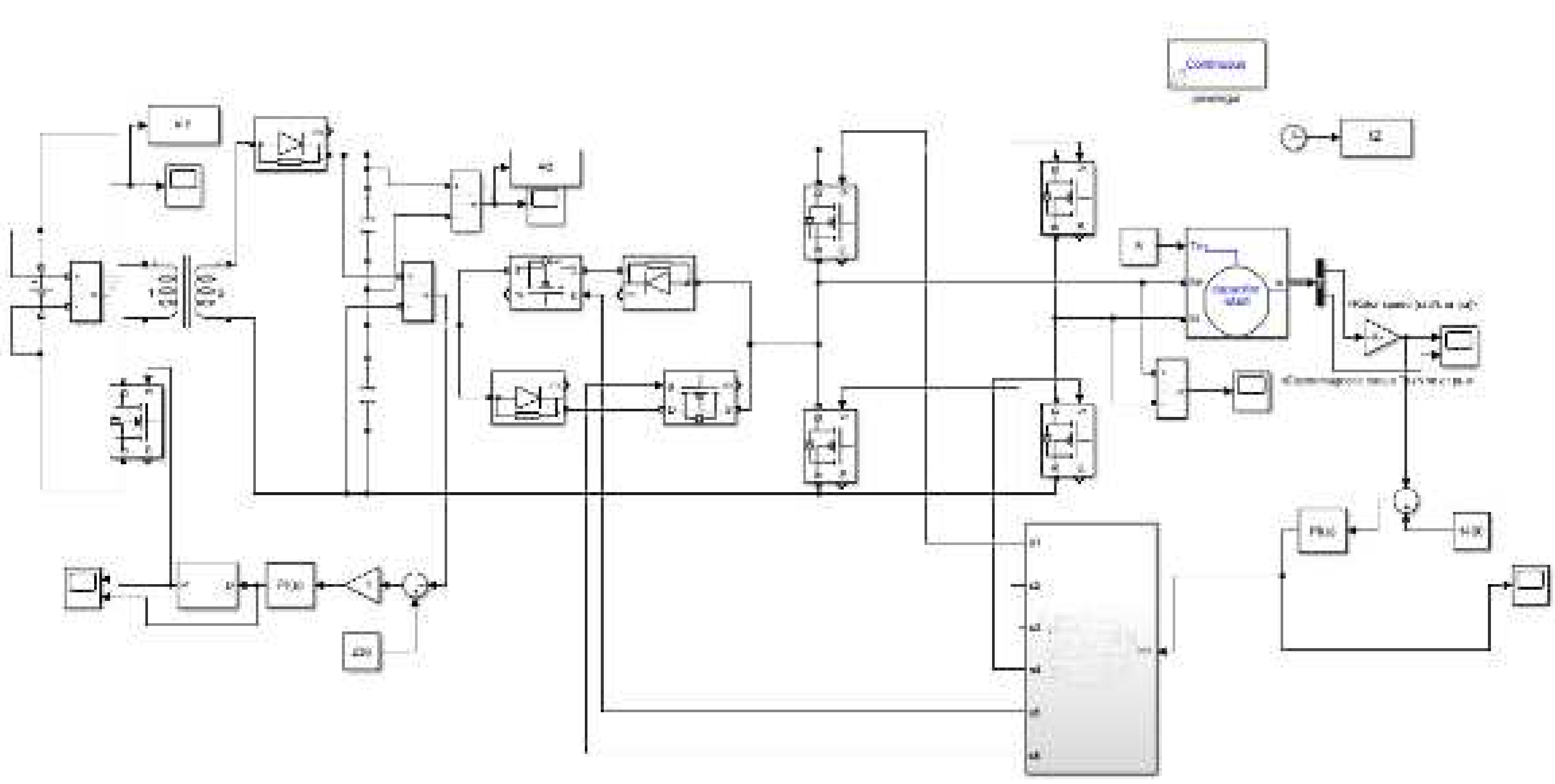

Fig. 5. Simulation diagram of proposed DC-AC converter system

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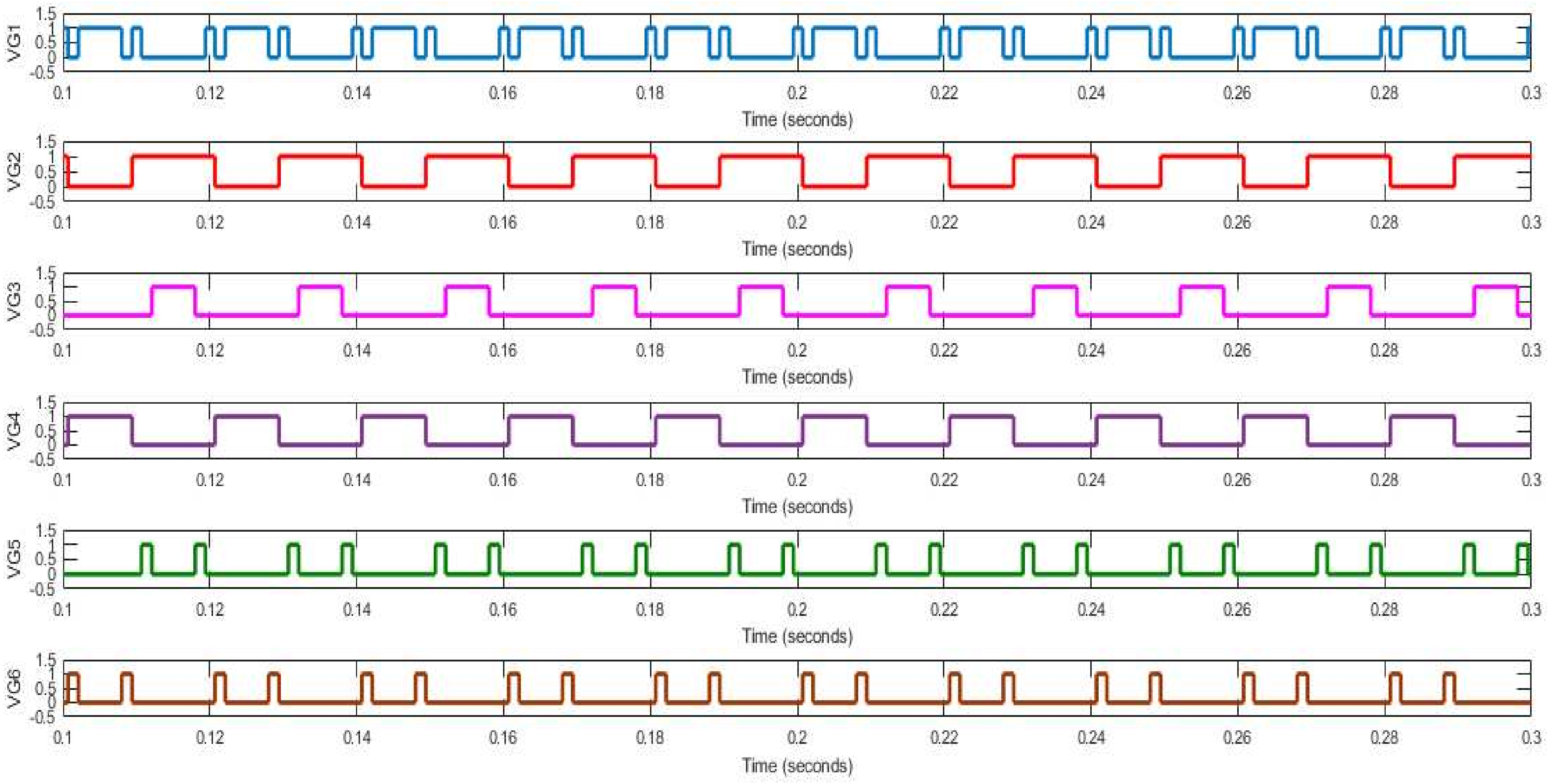

Fig. 6. SPWM pulses to inverter switches

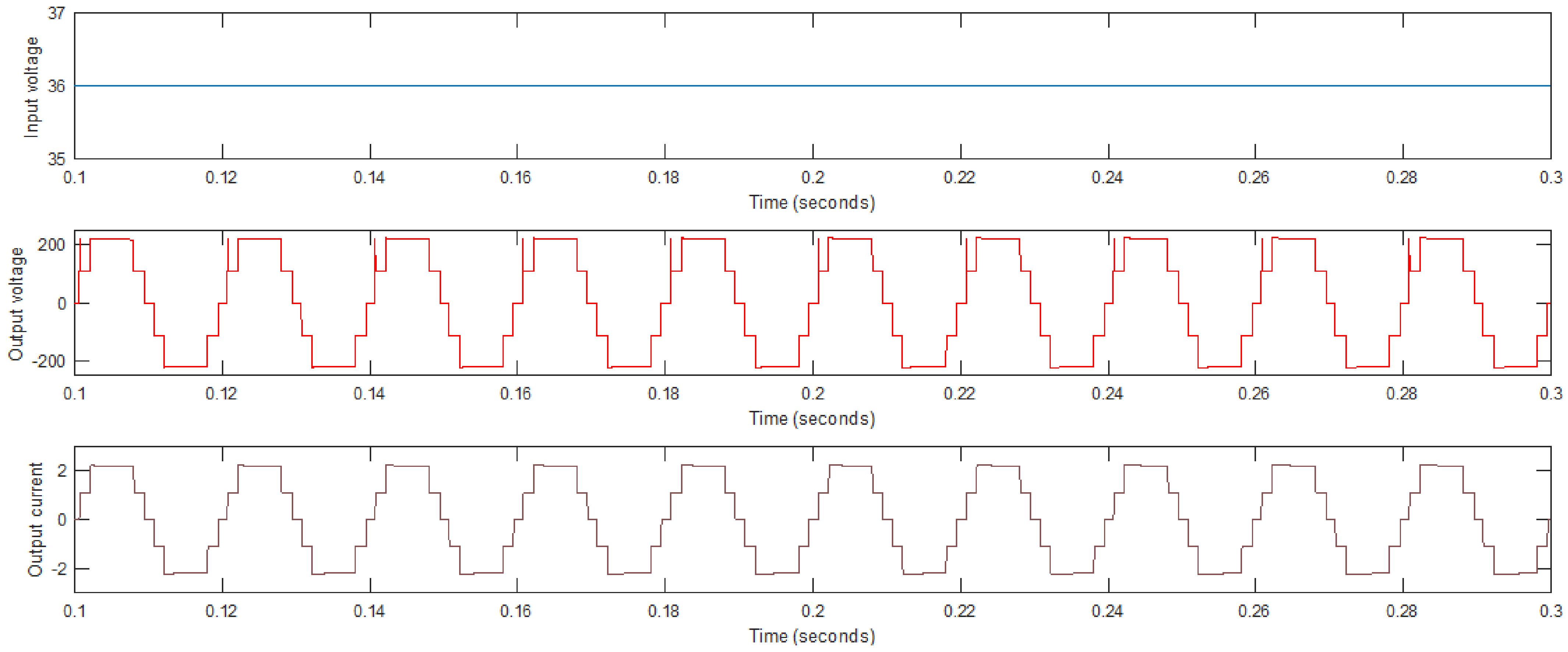

Fig. 7. Input voltage, output voltage, output current waveforms.

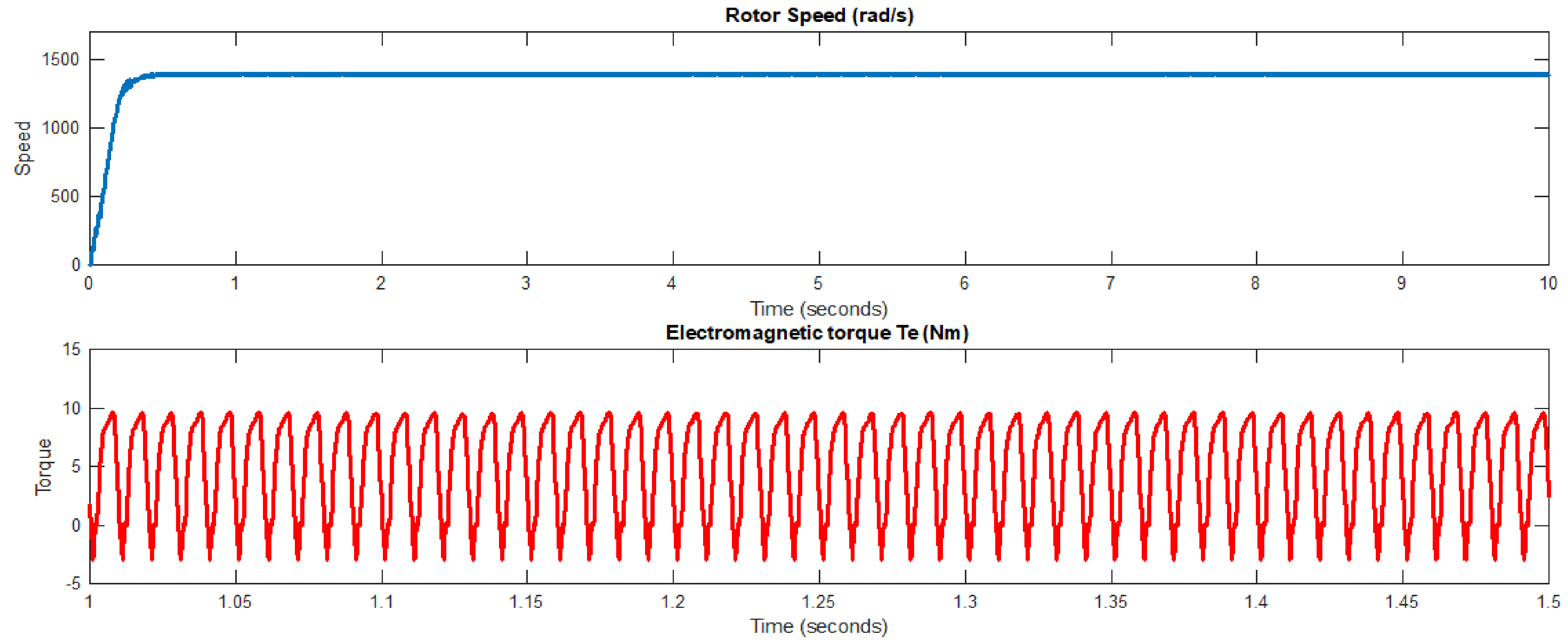

Fig. 8 speed and torque of the motor load

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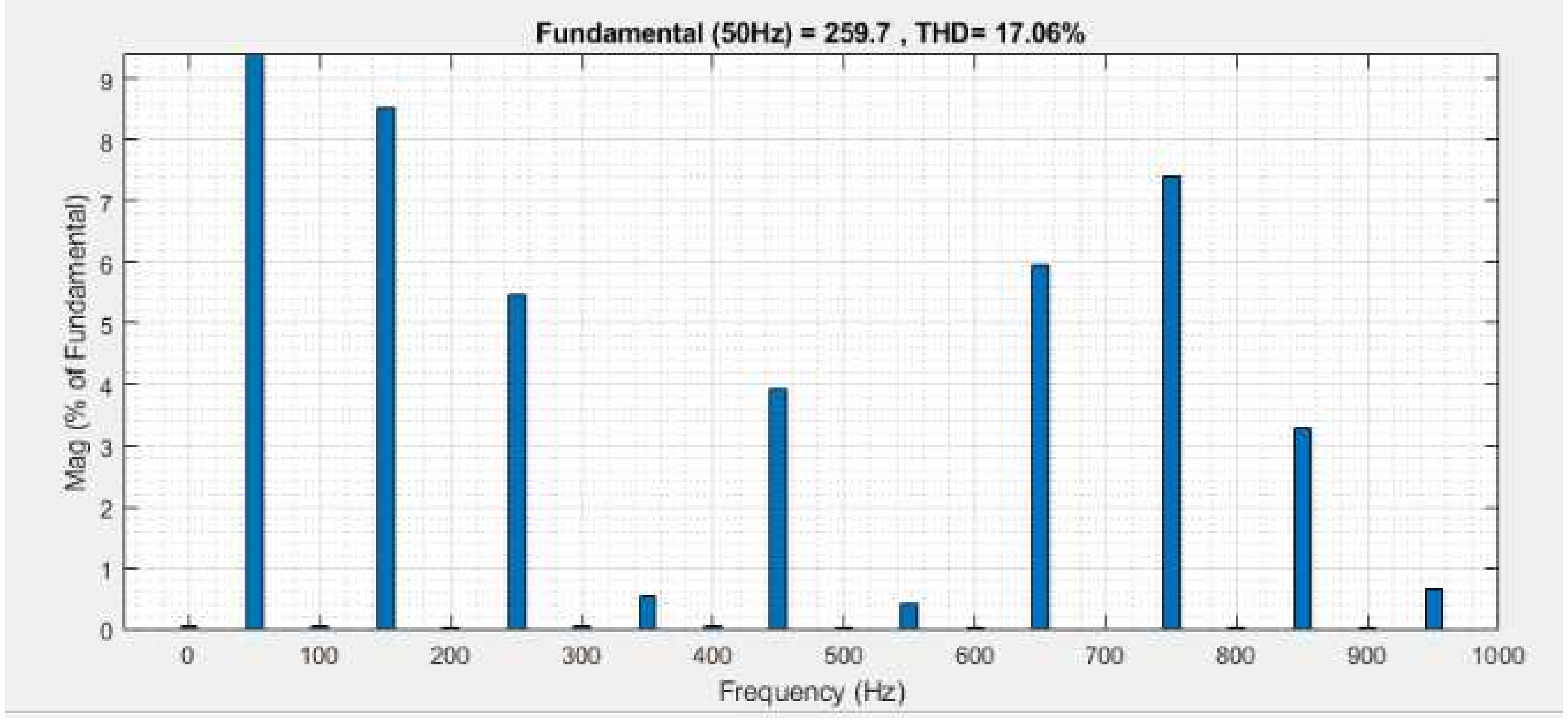

Fig. 9 Harmonic content of the output voltage

V. CONCLUSION

In this paper a multilevel transformerless topology and its modulation technique were proposed. The topology was based in the conventional H-bridge inverter with an auxiliary circuit. The latter consisted of a bidirectional switch formed by two IGBTs or MOSFETs and two diodes. The bidirectional switch was connected between the middle point of the first leg in the H-bridge and the middle point of the input split capacitor, i.e. a T-type leg. The other leg is kept unchanged. Therefore, the topology was referred as asymmetrical T-type. The proposed topology provided five output voltage levels, which turns out to be an important advantage regarding other commercial single-phase topologies. Besides, to control the power flowing from the DC source to the load, a PWM modulation strategy based on a sinusoidal multicarrier technique was proposed. Both inverter and PWM were aimed to overcome the leakage current issue in low power transformer less renewable energy systems applications. The proposed inverter and its modulation strategy were tested by numerical simulations and experimentally, the results showed that the common mode voltage allows an operation with an RMS value of the leakage current below the maximum value allowed by the German standard DIN VDE 0126-1-1. Moreover, the multilevel characteristic lowers the harmonic content, which permits the reduction of filters. According to the analysis and the numerical and experimental results, it was concluded that the proposed topology and the modulation technique were suitable for our applications.

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Modified High Gain Cuk Converter

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Abstract: There is increased demand on renewable energy systems due to over exploitation of fossil fuels and pollution caused by them. The output voltage is lower than that required which imposes need for a high voltage gain dc-dc converters. Cuk converters can step up or down the voltages according to requirements and is a combination of Buck and Boost converters. This project analyses a modified Cuk DC-DC converter that has higher voltage conversion ratio than the conventional Boost and Cuk converter. Furthermore, reduced ripple content sand component size make it a good solution for high voltage applications.

Keywords: Renewable energy, Cuk converter, Duty ratio, Switching frequency, SMPC

I. INTRODUCTION

The demand on energy is increasing day by day. This cannot be met with the supply from oil, coal or gasoline. This put forth the need for renewable energy resources. Fortunately, mankind has started to turn towards renewable energy. But the renewable energy resources raise the problem of high cost. The initial cost is a huge amount for a small area of solar array. Also the efficiency is below 20%, but they can supply energy over the years. The Switched Mode Power Converters are power electronic circuits that step up or step down the voltage to required levels[3]. This is doneby temporarily storing the input energy and then releasing it to the output at a different voltage. The storage may be in either magnetic field storage components like inductors, transformers or electric field storage components like capacitors. The use ofDC to DC converters comes into play at the point of low voltage output of renewable energy resources.This low efficiency can be increased by using DC to DC converter to obtain high voltages or higher power. So many researches are conducted on altering charger circuitry. The modification is done either by increasing gain of converter or the control strategy. The basic converter topologies are Buck, Boost, Buck-Boost and Cuk[2]. The boost converter steps up the voltage [6] whereas buck converter step up the voltage. There are many converter topologies with high gain. SEPIC converters are modified with use of switched inductor to achieve high gain[6]. It has got different configurations like XLL, LYL, etc. The quadratic boost converters are made soft switching using ZCS and ZVS property such that there are no additional conduction losses[5]. Higher efficiency can be attained for conventional coupled-inductor boost converter by employing diode clamping circuit[7]. Cuk converters are advantageous that both the input current and output current are considerably ripple free[1]. There is lower requirement of external filtering equipment in comparison with other converters. Always the research motive is to implement changes in charger circuitry or its control method. For the same purpose there is alarming need to somehow increase the converter output. A converter can give stepped up or stepped down outputs. The output depends on the gain or conversion ratio of converter. By altering converter circuit set up the gain can be increased to required level. The gain is a function of duty ratio. The converter performance can be controlled by controlling the switching of converter. The basic converter topologies are either cascaded or cascaded together to improve conversion ratio of converters.
This paperpresents a Cuk DC to DC converter modified by cascading a conventional boost converter with Cuk converter and provides a gain which is a multiple of gain of boost and Cuk converters. Thus the gain is improved to a great extent and shows combined properties both the converters. The main feature is that the whole converter is controlled by single switch. The converter can provide a gain of about 10 times at a duty cycle of 90%. Both step up and step down is possible depending on duty ratio.Besides, circuit structure has been analyzed and designed. Also, high gain converter has been analyzed. Calculation of components rating has been achieved. Besides, simulation of Cuk DC- DC converter has been achieved in MATLAB Simulink.

II. CONVERTER TOPOLOGY

The modified Cuk converter is a combination of the conventional boost converter and Cuk converter. The output of boost converter acts as input to the Cuk converter. The arrangement is such that it becomes a single controlled device DC-DC topology. By adjusting the duty ratio, it can be made possible to obtain a higher or lower level of voltage output. Since the design is done for renewable energy applications, voltage step up is required[1].The block diagram of the converter topology is shown in Fig. 1. The conversion ratios of conventional boost and Cuk converters are multiplied for gain of the noval converter.

For Boost converter,

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \tag{1}$$

For Cuk converter,

$$\frac{V_o}{V_{in}} = \frac{D}{1-D} \tag{2}$$

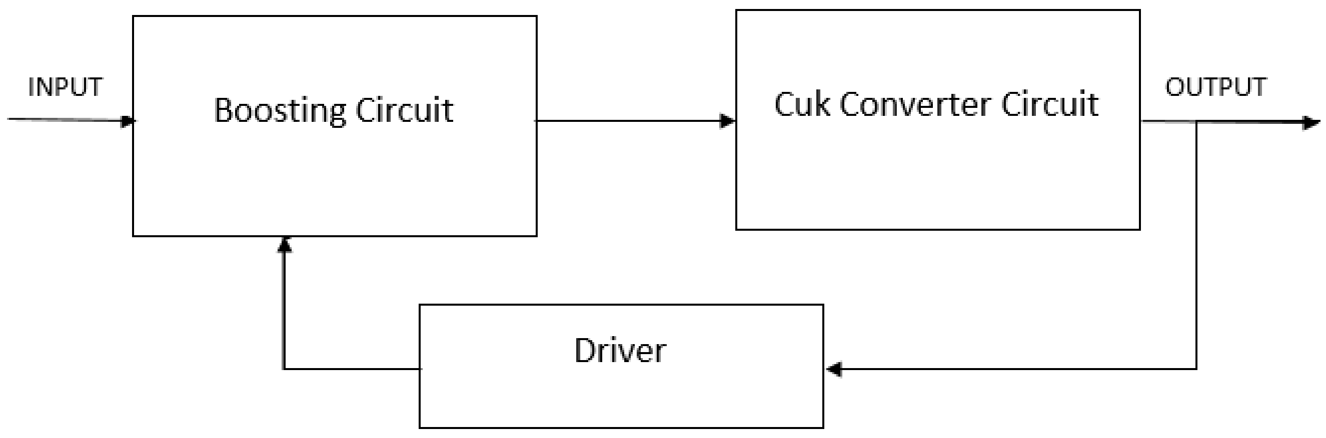

Fig. 1 Block Diagram

The Fig.2 shows the circuit setup of proposed converter topology. The circuit comprises of a conventional boost circuit followed by a Cuk converter. The boosting system consists of one inductor and one capacitor along with two diodes. There are 3 inductors, 3 capacitors, 3 diodes, the supply and a switch. A resistive load is given at the output of the modified system.

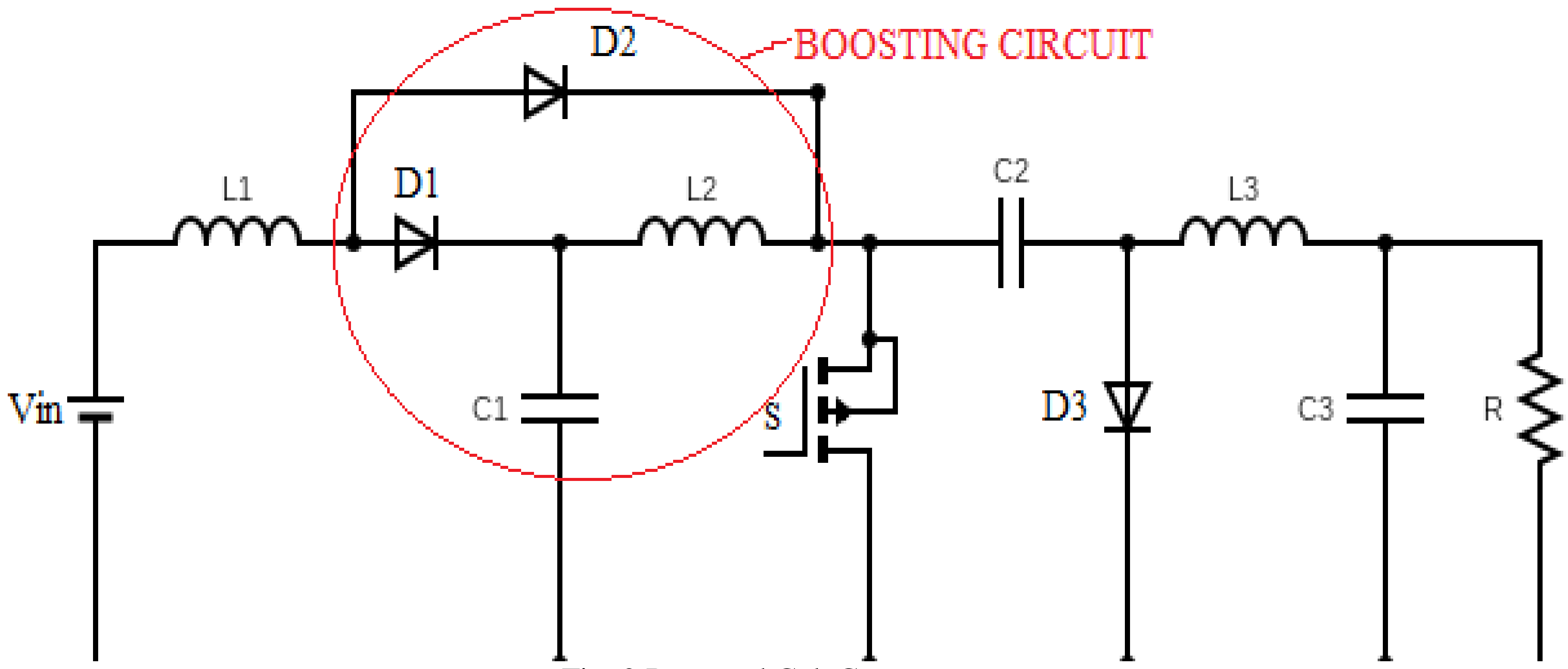

Fig. 2 Proposed Cuk Converter

Even though the circuit is a combination of conventional boost and Cuk converter, it is controlled by a single switch. Here S is the control device. D_1, D_2 and D_3 are diodes. The highlighted portion represents the boosting circuit. V_{in} is the input voltage to be altered. The output is obtained across the load resistor R. The features of proposed circuit is as follows:
1)The converter is having continuous current at both input and output side;
2)A high switching frequency is adopted to reduce switching losses;
3) Singly controlled device topology.
The working of the converter depends upon state of control device, the switch. A duty cycle also called power cycle is the fraction of one period in which a system remains active. It is usually expressed as a percentage or a ratio. D represents duty cycle and T_s is the total time period. T_s depend on switching frequency. The working is divided into two parts – Mode1 and Mode 2.

A. *Mode 1 (0 to DT$_s$)*

Between this duration, the controlled device is in conducting mode. Diode D_2 is in forward bias condition due to input supply V_{in}. Diode D_1 and D_3 are inreverse biased condition due to the action of capacitors C_1 and C_3 respectively. The inductors L_1, L_2 and L_3gets charged for input supply, capacitors C_1 and C_2 respectively. The current flowing through the inductor starts rising and slope of capacitor voltage is decreasing as it is discharging. Capacitor C_3 is discharged into the load. In Mode-I, two power devices are ON; diode D_2 and controlled device S. The current flowing through diode D_1 is zero and negative voltage appear across diode D_3 due to OFF condition.

B. *Mode 2 (DTs to T$_s$)*

Between this duration, the controlled device is in non-conducting mode. The inductor L_1 is discharges into capacitor C_1 along with input supply V_{in} through diode D_1.The inductor L_1 and L_2 are demagnetized along with input supply Vin into capacitor C_2 through diode D_1 and D_3. The inductor L_3 is demagnetized into capacitor C_3 through diode D_3. In mode-II, three inductor L_1, L_2 and L_3 are demagnetized or current flowing through three inductors is decreasing. The three capacitor C1, C2 and C3 are charged from three inductor L_1, L_2, L_3 and input supply V_{in}. The current flowing through Capacitor C_1, C_2 and C_3 is increasing. In mode-II, diode D_2 and controlled device S is not conducting. The current flowing through diode D_1 is same as current flowing through inductor L_1.

The mathematical analysis is done by applying volt-sec balance on the ON and OFF state equations of the converter, the voltage conversion ratio is obtained.

$$\frac{V_{in}}{L}.DTs + \frac{V_{in}-V_{C1}}{L}.(1-D)Ts = 0 \tag{3}$$

The voltage conversion ratio is thus given by,

$$\frac{V_0}{V_{in}} = \frac{D}{(1-D)^2} \tag{4}$$

Design principles dealing with converter component selection are as follows. Inductor (L) is determined using the inductor current and voltage across inductor

$$i_L = \int_0^t v_L dt + i_L(0) \tag{5}$$

$$\Delta i_L = i_L(DTs) - i_L(0) \tag{6}$$

Desirable current ripple is assumed and magnetizing inductance is calculated as

$$L_m = \frac{DV_C}{\Delta i_L f_{sw}} \tag{7}$$

Capacitor (C) can be determined as

$$V_c(t) = V_c + \frac{1}{C}\int_0^t V_c dt \tag{8}$$

$$C = \frac{DI_{Lm}}{\Delta V_C f_{sw}} \tag{9}$$

$$\Delta V_C = 20\%\ of\ V_c$$

Load resistor, $R = \frac{V_0}{I_o}$ (10)

III.SIMULATION

The simulation for the circuit was developed using MATLAB/Simulink software.On selecting the power, switching frequency, input and output power as given in table the circuit parameters are calculated. The duty ratio is taken as 75% and other parameters are tabulated as in Table 1. These values are used in the simulation study.Both open loop and closed loop simulations are done. The closed loop is done for a referent voltage of 85 V. For the circuit to function in boost mode the duty ratio must be greater than 0.39. The closed is achieved by simple PI controller. The closed loop simulation circuit is given in Fig. 3.
Fig. 4 shows the simulation output. There are slight variation in exact values due to the difference in parameter values as practical values of components are considered. The inverted output is almost equal to 85 V.

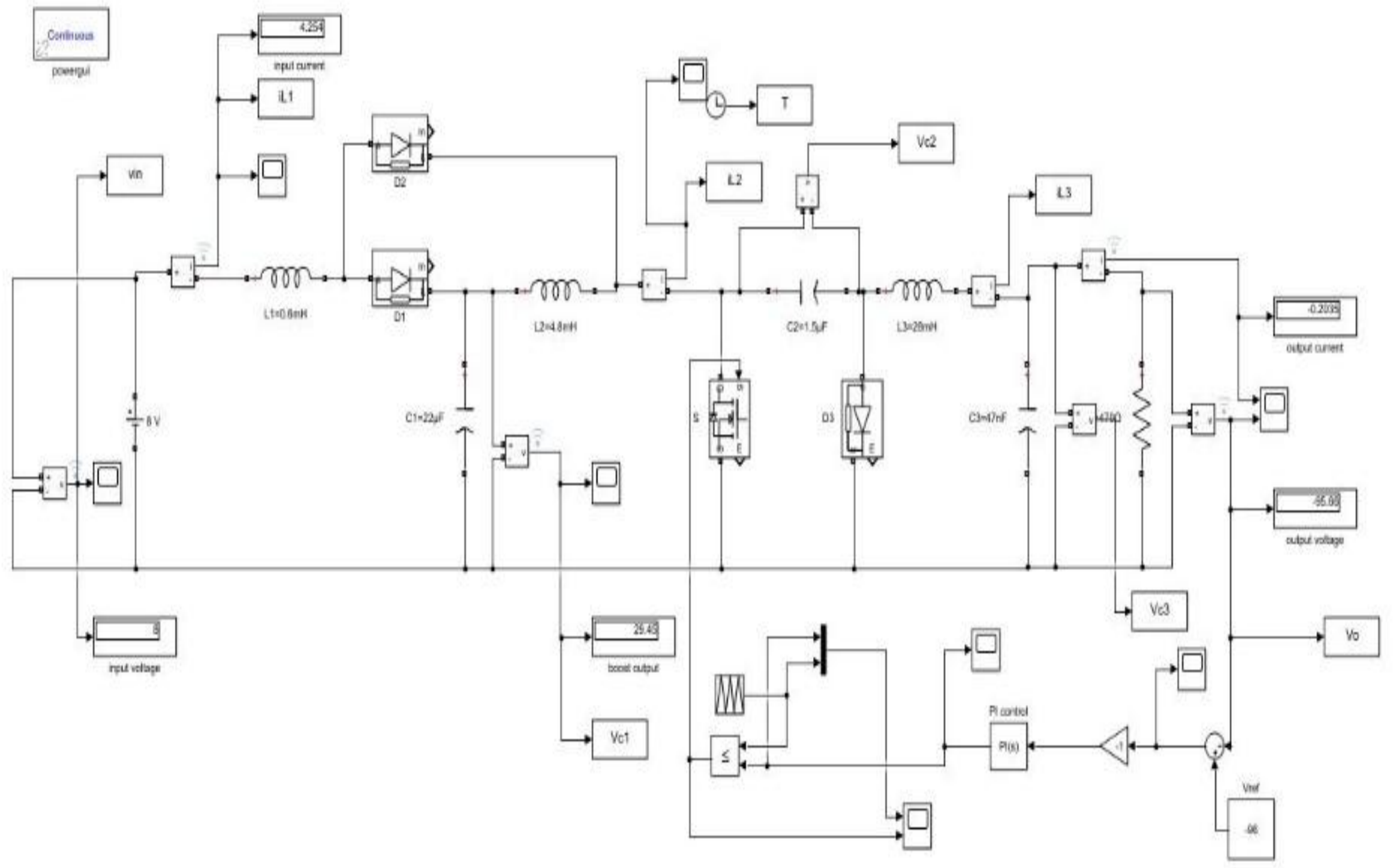

Fig. 3 Closed Loop Simulation Circuit

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TABLE I
SIMULATION PARAMETERS

Sl.No	SIMULATION PARAMETERS OF CONVERTER	
	PARAMETER	VALUE
1	Power	16W
2	Input Voltage	8V
3	Output Voltage	-96V
4	Duty ratio	0.75
5	Switching frequency	50kHz
6	Inductor (L_1)	0.6mH
7	Inductor (L_2)	4.8mH
8	Inductor (L_3)	28mH
9	Capacitor (C_1)	22µF
10	Capacitor (C_2)	1.5µF
11	Capacitor (C_3)	0.047µF

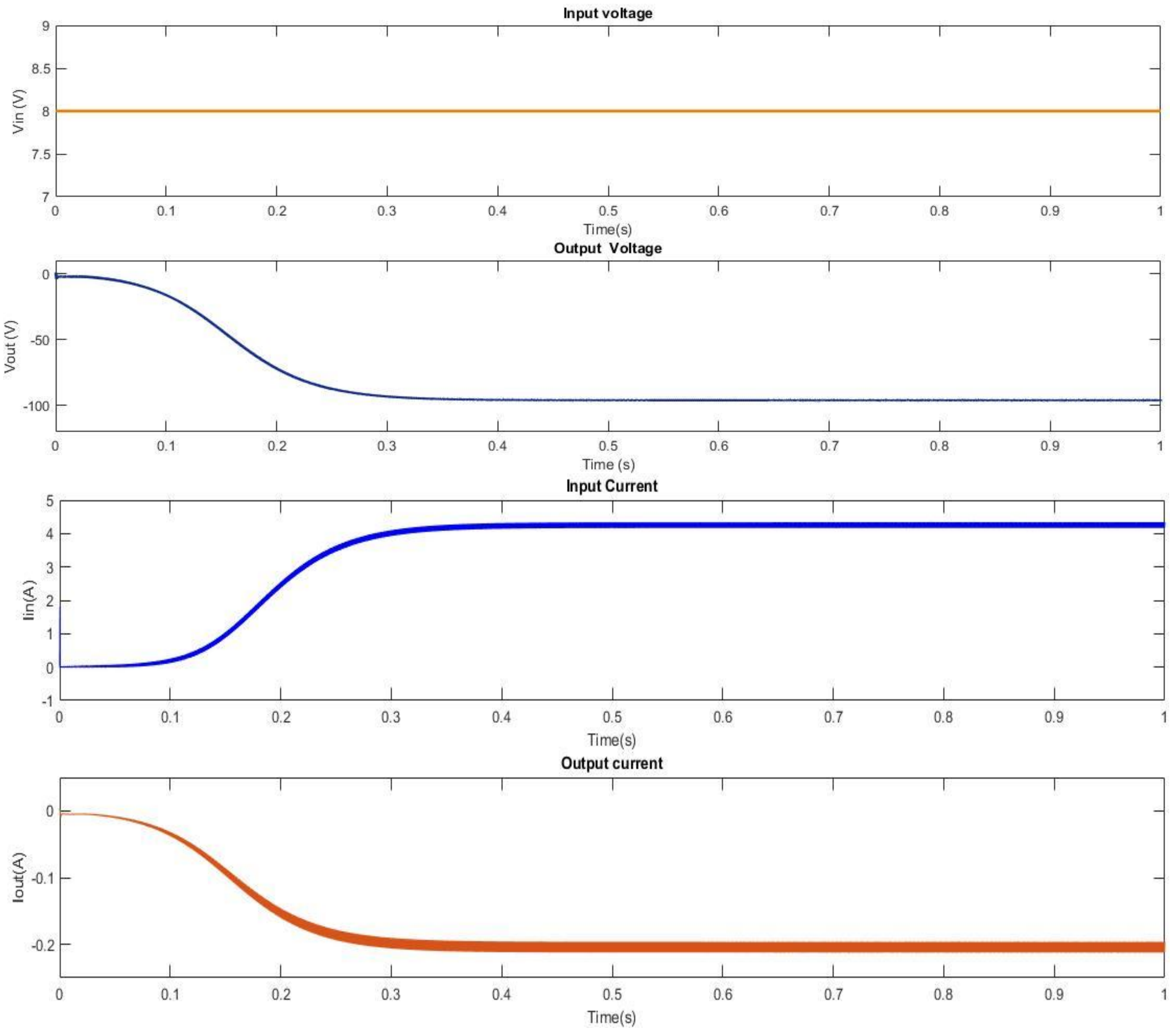

Fig. 4 Input and output voltage and current waveforms in closed loop

IV. ANALYSIS

The conventional converters boost and Cuk are simulated in MATLAB for same power input and duty cycle. From the results obtained it is clear that the proposed converter is advantageous. The work could give a high gain by combining the other two converters and the whole converter is controlled by single switch. The ripple content is much lesser along with less voltage stress. This reduces the switching losses. The observation is tabulated as in Table II.

TABLE II
COMPARISON BETWEEN CONVERTERS

CHARACTERISTICS	BOOST CONVERTER	CUK CONVERTER	MODIFIED CUK CONVERTER
Output (V)	28.7	-23.01	-92
Gain	$\frac{V_o}{V_{in}} = \frac{1}{1-D}$	$\frac{V_o}{V_{in}} = \frac{D}{1-D}$	$\frac{V_0}{V_{in}} = \frac{D}{(1-D)^2}$
Ripple (%)	ΔV = 12 ΔI = 5	ΔV = 16 ΔI = 3.1	ΔV = 10.2 ΔI = 1.3
Voltage stress (V)	29.22	20.6	11
Switching losses	More	Moderate	Less

V. CONCLUSION

A high gain Cuk DC-DC converter with is proposed for photovoltaic applications which is modified by cascading a conventional boost converter with Cuk converter. Here the modified converter provides a gain which is a multiple of gain of boost and Cuk converters. Thus the gain is improved to a great extent. It shows combined properties of Cuk and Boost converters. A conventional boost circuit is added prior to the Cuk converter whose output stands as Cuk input. The gain is very high compared to the conventional boost and Cuk converters. The design and analysis along with MATLAB simulation shows that there is improved voltage conversion ratio at higher frequencies. This higher switching frequency reduces the component size .The output voltage ripple is also decreased. It works as a viable solution for high voltage applications. Moreover it is a single controlled device. It is designed to convert 8V input voltage to 96 V output voltage and 16W output power. The proposed converter can act in both boost and buck mode. It is a best option for low output voltage of RE resources.

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A Dickson Multiplier Based High Gain DC-AC Converter for Renewable Energy Applications

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Abstract: A Dickson charge pump voltage multiplier cell (VMC) based DC-AC converter is presented in this paper. The converter configuration consists of a DC-DC two stage interleaved boost converter on its input side and 180^{o} revolved set up of two Dickson voltage doubler cells on the output side. Equal sharing of current in the input stage and ripple annulment at VMC stages allows the system to easily meld with various renewable energy sources like solar. Converter topology designed at 200W provides 400V output voltage for an input as low as 20V and integrated with a single phase H-bridge inverter to acquire 230V RMS AC voltage at the output for diverse applications. Simulation analysis of the proposed system is verified using MATLAB/SIMULINK.

Keywords:Renewable, Solar, High gain, Dickson charge pump, Voltage multiplier cells

I. INTRODUCTION

Eternally increasing demand for energy and expending fossil fuels has led to the efficient use of various renewable energy sources (RES). A liveable future prefers RES as an intact solution for world-wide power generation with low exhalation of greenhouse gases. Currently, huge focus is given to extract the energy from sun and photovoltaics can utterly solve the power crisis to an extend if fitly utilised. Photovoltaic panels (PV) are used to translate available solar energy into electricity [1]. DC output power of a solar cell varies with irradiation, temperature and to harness maximum power, different maximum power point tracking (MPPT) techniques are used[2][3]. Integration of high gain DC-DC power electronic converters increased the performance of the system and can link solar panels, fuel cells etc. to 380V/400V DCdistribution system. A typical solar panel output a voltage of low value 30 to 40V. Step up converters act as power enhancing stage to produce 400V DC output voltage and interconnectwith grid or AC loads [4] as demonstrated in Fig. 1.

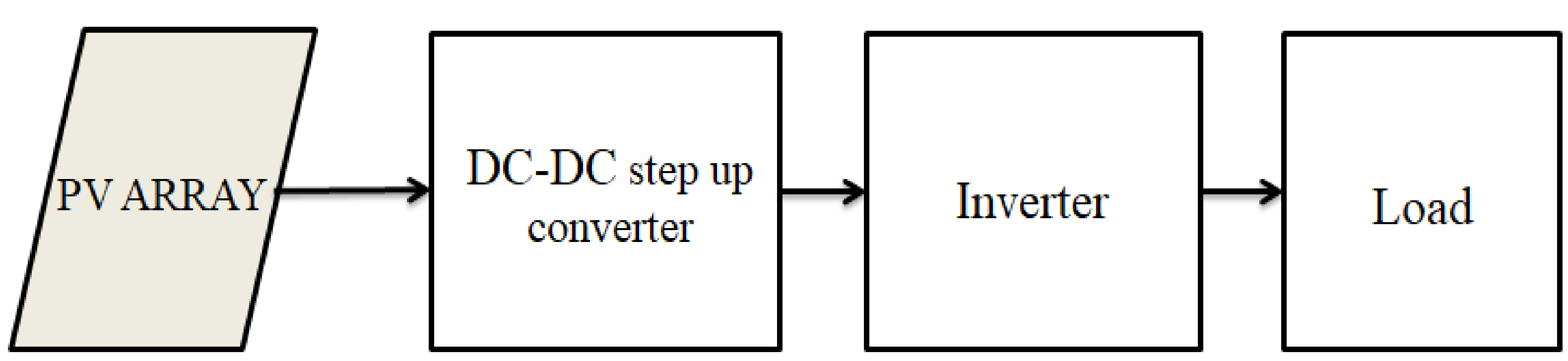

Fig. 1. Block diagram of photovoltaic system

Design and experimental analysis of non isolated converters [5] based on boost topology produces high voltage gain ratio, but due to operation at high duty cycles, converter suffers high voltage stress to intensify the voltage to 400V DC. Derived topologies of this converter [6][7] experiences reverse recovery issues and extra effort to ensure stability. Isolated circuits used as an interface in low voltage RES, [8] with active clamp flyback configuration has low power density, high cost and low efficiency to produce high gain. Practical design considerations of the forward converter circuit can boost the 20V input to 400V and achieves high gain by increasing the turns ratio, leading to leakage inductance problems. SL – SC (switched inductor – switched capacitor) based high voltage boost converters [10] prefer coupling inductors to produce required voltage gain and avoid problem of leakage inductance. Presence of high input current and floating ground disables the converter configuration from high power applications. Interleaving technique in converters produce equal sharing of input current with reduced magnetic storage requirement. A soft switching method based interleaved boost circuit [11] is a high gain power electronic converter widely used in distribution generation systems (DGS). Due to processing of power multiple times, converter suffers efficiency problems in generating 400V voltage and requires high cost of generation.

Use of voltage multiplier cells with power converters has increased the boosting capability with high DC output voltage. This diode-capacitor network are widely used in power converters used an interface in distribution buses with reduction in ripple content. In requirement of high voltage and high current, transformer less high gain converter [12] with ripple cancellation, boost 20V input to voltage required for micro grids. Voltage stress is high with low efficiency.

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Interleaved high step – up converter with built – in transformer voltage multiplier cells (TVMC) for high conversion systems [13] has reduced switch voltage stress and TVMC improve the conversion efficiency. Complexity in design and leakage inductance issues are associated with these voltage doubler cells.

Dickson-based VM (voltage multiplier) cell converter systems [14] are widely developed these days providing large voltage multiplication. It can wholly or partially eliminate the use of transformers by charging and discharging of internal voltage multiplying capacitors. Several converter topologies based on Dickson CP (charge pump) gives high boosting to the circuit for producing required voltage.This paper analyses a DC – AC high gain converter [15] built on Dickson VMC with reduced voltage stress for renewable energy applications. Converter is highly apt for producing 400V output from 20V input and generates230V AC by integrating with inverter. Uninterrupted sharing of input current makes the converter suitable for solar applications. Paper is organised as follows:- Section II deals with the detailed analysis of converter configuration and section III investigates the design of components with necessary equations. Section IV contains simulation results. Section V gives the conclusion of the paper.

II. ANALYSIS OF CONVERTER TOPOLOGY

Voltage multipliers are comprised of capacitors and diodes connected in different configurations. This passive element network in each stage makes it viable to generate high output voltage from a low value input voltage. Dickson charge pump VMC in Fig. 2(a). is a voltage doubler circuit with a multiplication factor of two and requires a feed of two clock pulses which are in antiphase. Converter with parallel connection of two boost converters and VMC network is capable of rising voltages from 20 V to 400 V along with the inverter. Initially the voltage from DC source is converted to high voltage DC and again it is inverted to 230V AC such that it could be used in various AC applications as well. Fig. 2(b). shows the detailed diagram of proposed Dickson multiplier based converter.

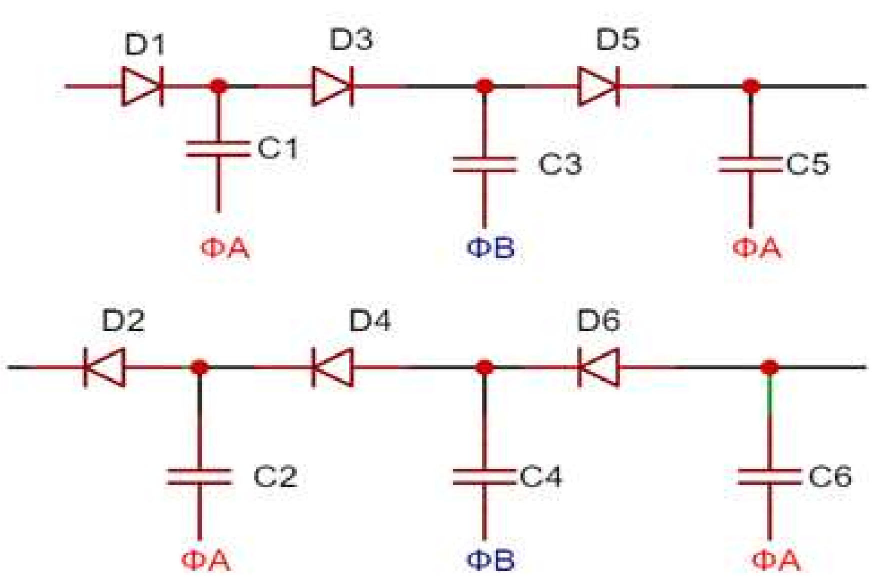

Fig. 2(a). Dickson multiplier

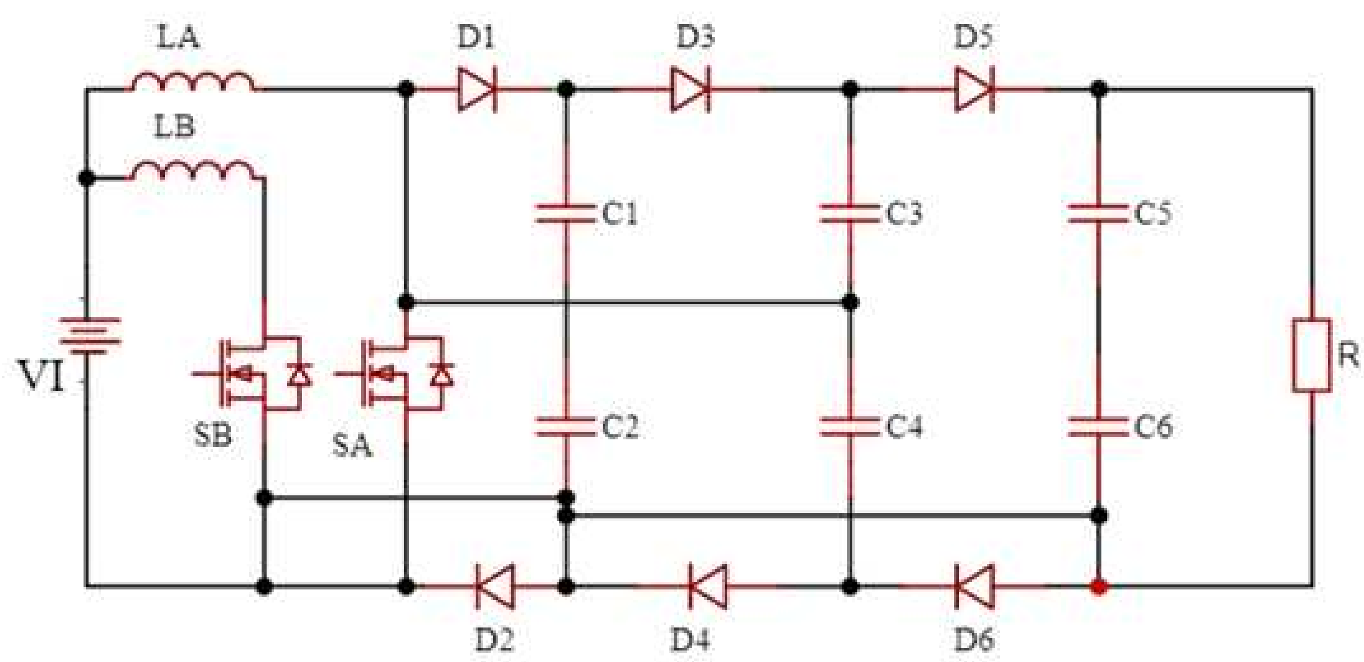

Fig. 2(b). Equivalent circuit

Input current is equally divided through the two phases of interleaved boost stage. Due to interleaving in input side, converter has minimum ripple and continuous input current. This makes the current measurement flexible, thereby converter can be used for maximum power point tracking (MPPT) applications. S_A and S_B are the two switches of the interleaved stage with inductors L_A and L_B. The output of interleaved boost converter is 200V for 20V input and this is given to the 180^o flipped Dickson VMC part of the system. The output of the second stage is 400V. Voltage boosting diode capacitor configuration is constructed by employing two Dickson VMC and flipping one cell by 180^o. Thereby, phase Φ_A of the upper capacitor is connected to phase Φ_A of the lower capacitor and similar arrangement for phase Φ_B. Each stage contains a voltage multiplier cell with capacitors C_1, C_2, C_3, C_4, C_5, C_6 and diodes D_1, D_2, D_3, D_4, D_5, D_6.This converter topology inspired from Bifold Dickson VMC structure [15] produces filtered output voltage with high gain and reduced voltage stress by capacitors and diodes in each stage. For the normal operation of the converter, a duty ratio of less than 50% is not chosen when both switches are ON and one of the switches must be ON at every point of time. 180^o out of phase gate signals are given to the switches leading to three modes of operation.

State 1:- In first mode, both switches are active with input source transferring energy to the two phase inductors, L_A and L_B. Diodes in the VMC stages are not operating and OFF. Capacitors C_5 and C_6 produces the required voltage across the load.

State 2:- S_A is ON and S_B is OFF in this mode of operation. Input source charges the inductor L_A and L_B releases its energy to the voltage multiplier cell stage. Diodes D_2, D_3, D_6 are ON while diodes D_1, D_4, D_5 are reverse biased. Capacitors C_2, C_3 and C_6, are charged by L_B and input voltage. After state 2, converter operates in state 1 again and the changeover to mode 3.

State 3:- Third mode is the opposite of mode two and S_A is OFF and S_B is still ON in this operation. L_B is charged by the input source in this mode and energy in L_A is released to the Dickson multiplier stage. Diodes D_2, D_3, D_6 are reverse biased and D_1, D_4, D_5 are forward biased and ON. Capacitors C_1, C_4 and C_5, are charged by L_A and source voltage.

III. DESIGN OF CONVERTER

The input power is transferred to the output stage by charging and discharging the voltage multiplier circuit capacitors. Using volt-second balance to the inductors, the capacitor voltages in each stage can be generalized by the following equation.

$$V_{CnA} = V_{CnB} = \frac{nV_I}{1-D} \tag{1}$$

where, n is the number of VMC stages and A and B are the two phases, D is the symmetric duty cycle of two switches. The converter can also work with asymmetrical duty ratios and also with two separate power sources.

We can write output equation for the converter as,

$$V_{out} = V_{CnA} + V_{CnB} = \frac{2nV_I}{1-D} \tag{2}$$

Output voltage is the sum of voltages across the last level capacitors and hence the voltage gain of the converter topology is expressed as,

$$\frac{V_{out}}{V_I} = \frac{2n}{1-D} \tag{3}$$

For an input voltage of 20V, output voltage can be calculated from the above equation as,

$$V_{out} = \frac{2*3*20}{1-0.7} = 400V$$

The converter topology with 20V input source like a solar panel at 70% duty ratio will produce an output voltage of 400V. High voltage gain is produced with low stress across passive semiconductor devices. The required inductor value can be calculated by,

$$L_A = L_B = L = \frac{V_I*D}{\triangle I_L * f_{sw}} = 100\mu H \tag{4}$$

The RMS currents of inductors L_A and L_B in the two phases are equal and designed based on the assumed value of inductor current ripple. Two inductors of same inductance value are designed as inductor L_A in one phase dischargesthe stored energy to the same number of capacitors as L_B. For 200W output power, both inductors carry a current of 5.5A and as the inductor currents are interleaved, ripples can be easily filtered out with smaller value of capacitors.

The capacitors are designed based on maximum voltage and current specifications. Along with input stage, both capacitors in each VMC stage should possess same value to achieve equal current sharing. Considering the allowed voltage ripple, output capacitor is selected based on the following equation.

$$C = \frac{I_{ORMS}\,(1-D)T_{sw}}{\triangle V_{C1}} = 10\mu F \tag{5}$$

Voltage stress across the diodes and capacitors are minimum and depend on the number of stages. Voltage stress decreases when numbers of stages are increased. Switch voltage stress is also slightest.

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IV. SIMULATION RESULTS AND DISCUSSIONS

MATLAB/SIMULINK software with variable continuous solver ode23 is used to develop the prototype model and verify the results. Duty ratio is fixed as 0.7 with switching frequency 100kHz. The converter was designed for a gain factor of 20. Simulation parameters are stated in Table I.

TABLE I
SIMULATION PARAMETERS

Parameters	Values
Input voltage	20V
Output voltage	400V
Switching frequency	100kHz
Duty ratio	0.7
Inductors	100µH
Capacitors	10µF
Load resistance	800Ω

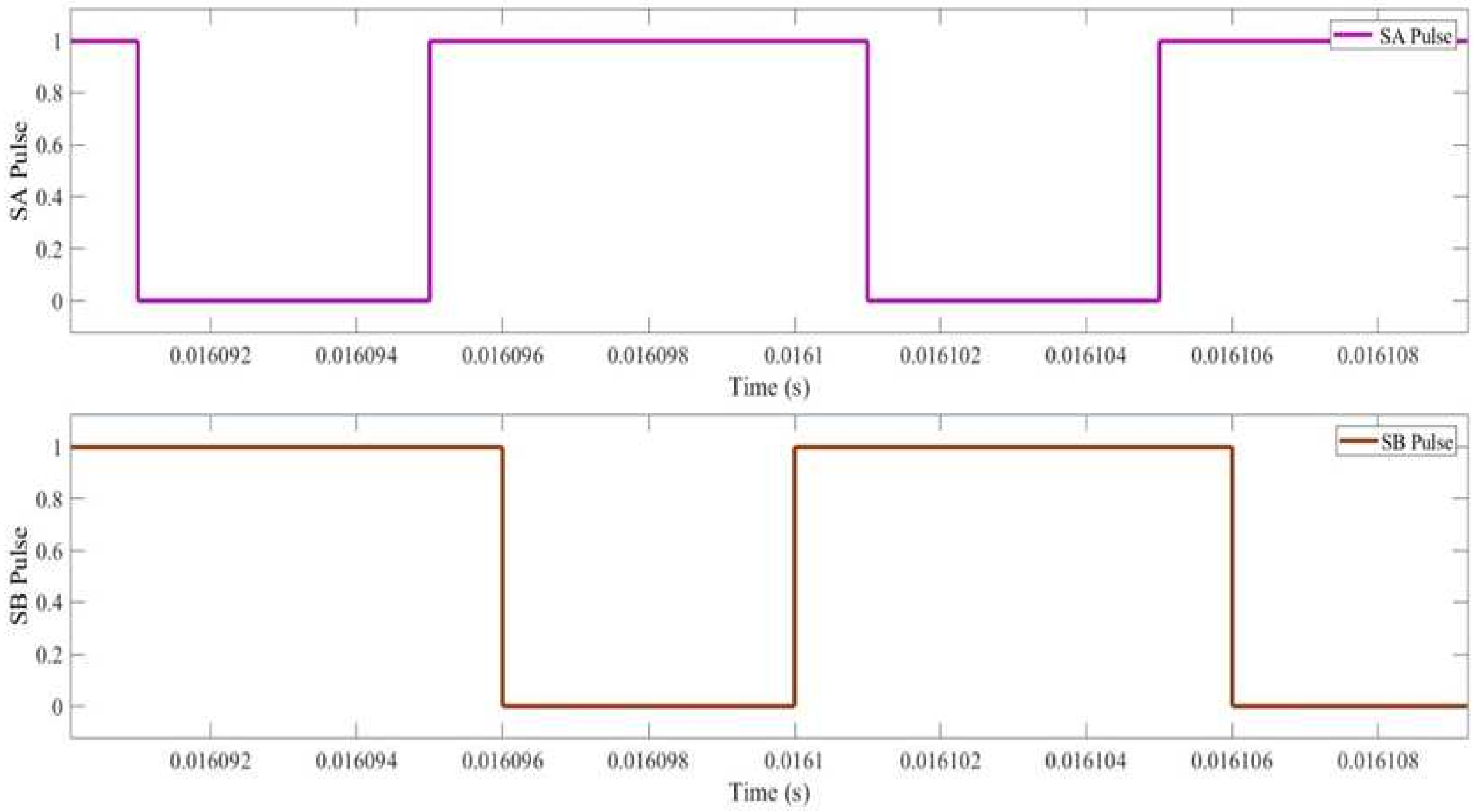

Fig. 3. Gate pulses given to the switches

Fig. 3. illustrates the switching pulse given to the converter with 180^0phase shift. The 20V input voltage waveform is shown in Fig. 4. Solar panel with 20V V_{PV} can be used as input source. A DC voltage source is used in the input side and produces output voltage of 400V shown in Fig. 5.Open loop simulation results are depicted below.

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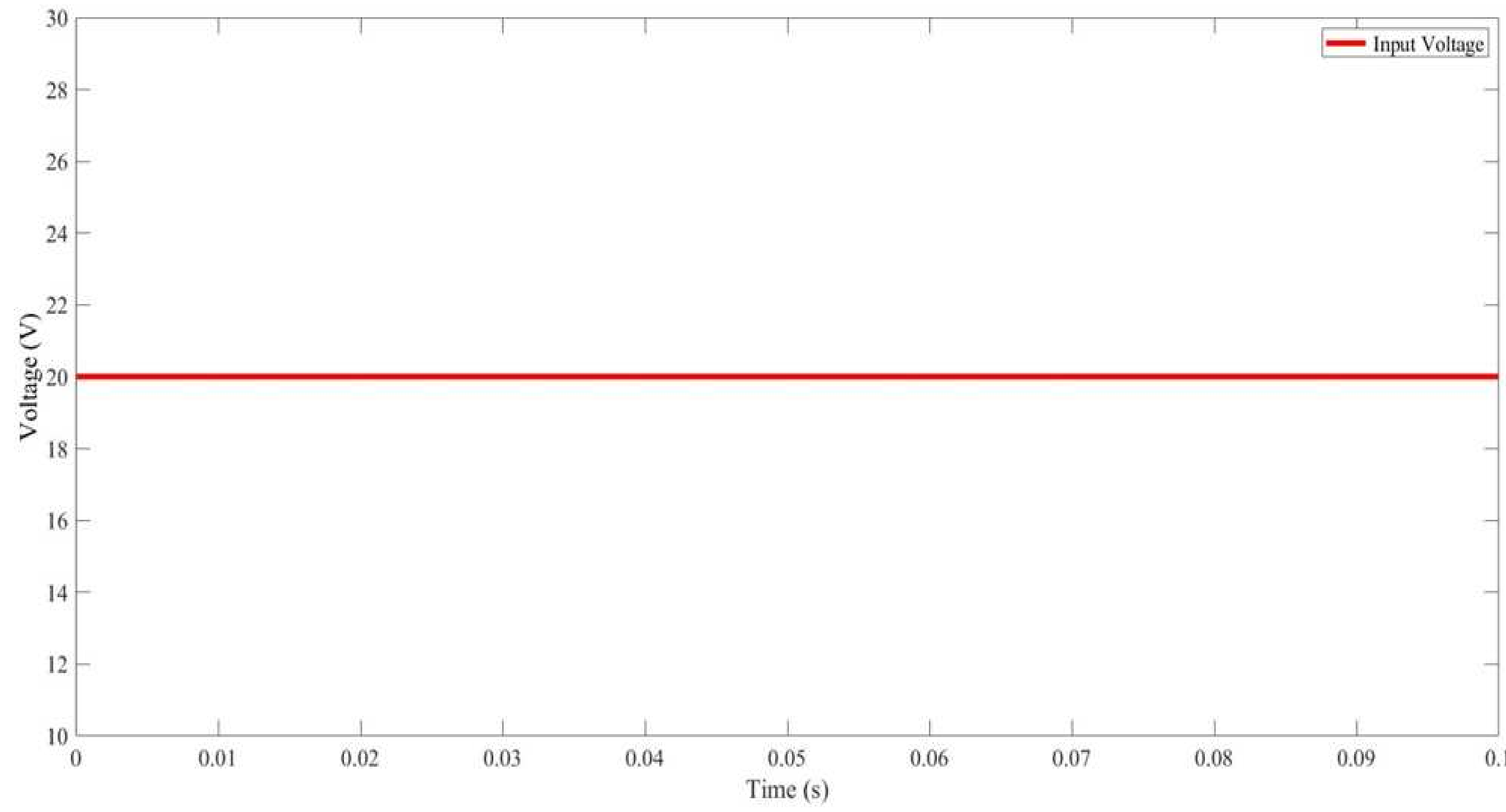

Fig. 4. Input voltage

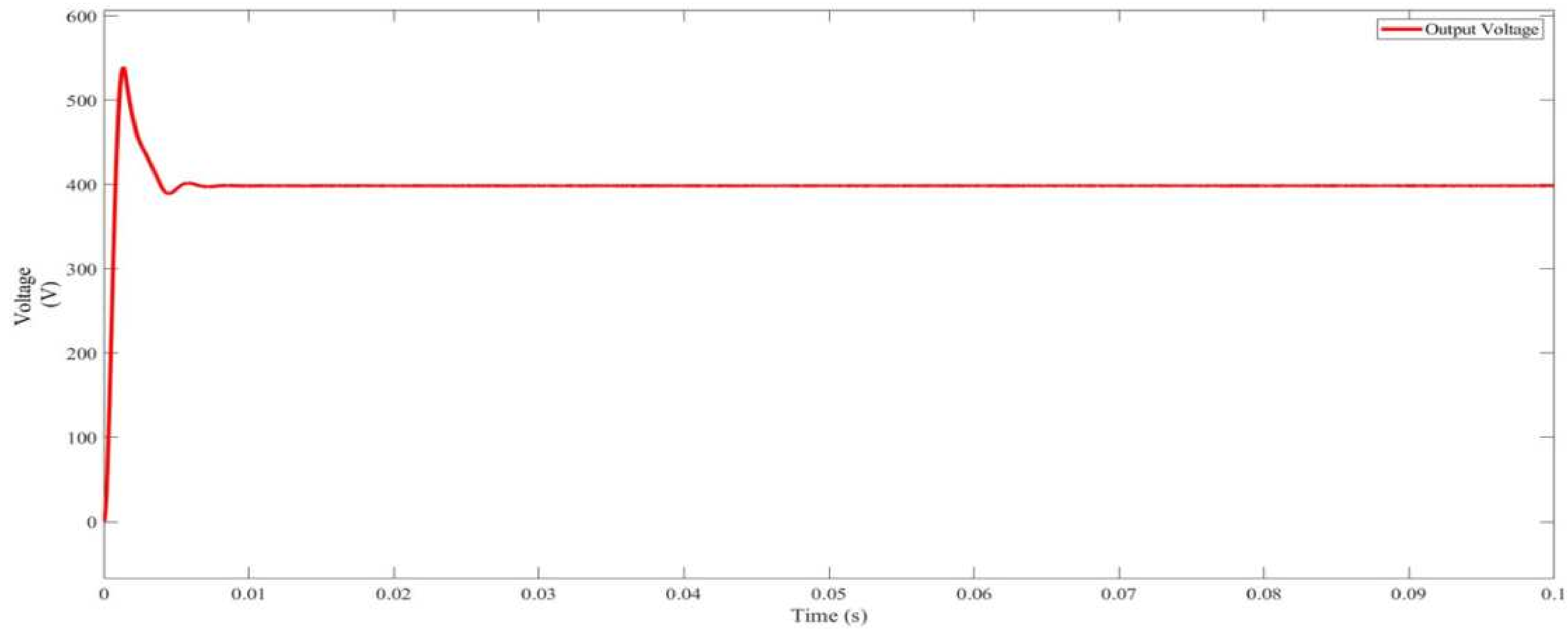

Fig. 5. Output voltage

Fig. 6. exhibits the schematic of the system configuration integrated with single phase H-bridge voltage source inverter consisting of two MOSFET switches per leg [19]. AC voltage of desired 230V magnitude and 50Hz frequency is obtained by correct sequence of closing and opening of switching devices after filtering. Switches S_1 and S_4 turn ON at the same time and then S_2 and S_3 in succession i.e. diagonally.Converter topology along with inverter circuit makes the system more efficient for different applications. When DC output is required, only converter portion is used and connected to the load and in case of AC voltage, inverter is connected. A converter based on voltage multiplier cells integrated to an inverter reduces total harmonic distortion (THD) and improves the power factor.

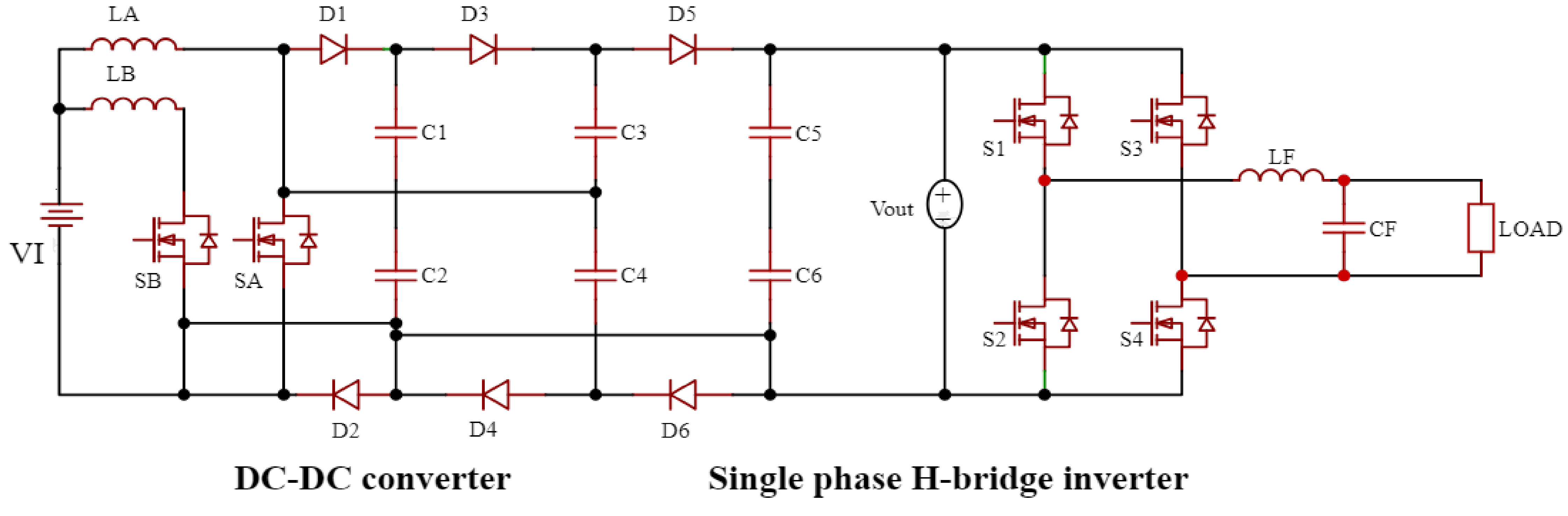

Fig. 6. Proposed DC-AC converter topology

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PWM generation block is given in Fig. 7.and MATLAB output waveform is obtained for the above circuit displayed in Fig. 8. PWM signals for the switches of single phase inverter are generated by comparing a sine wave and repeating sequence set as triangular wave. Input voltage of 20V DC is given to the system and 230V AC is obtained using the inverter after filtering that is connected along with the high gain converter.

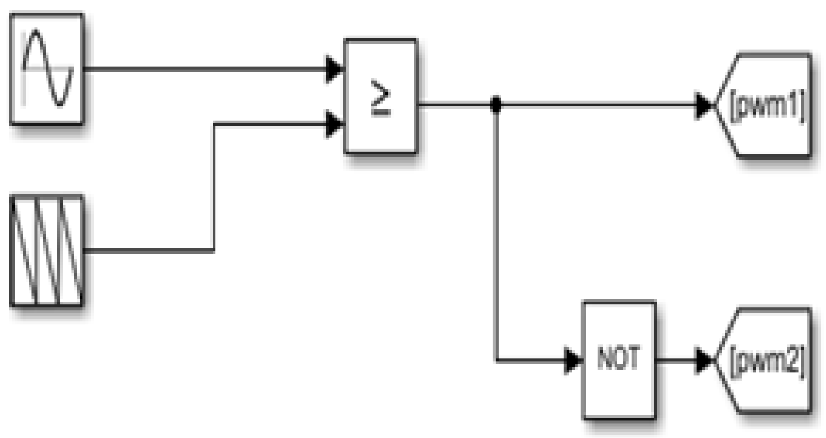

Fig .7. PWM generation block SIMULINK

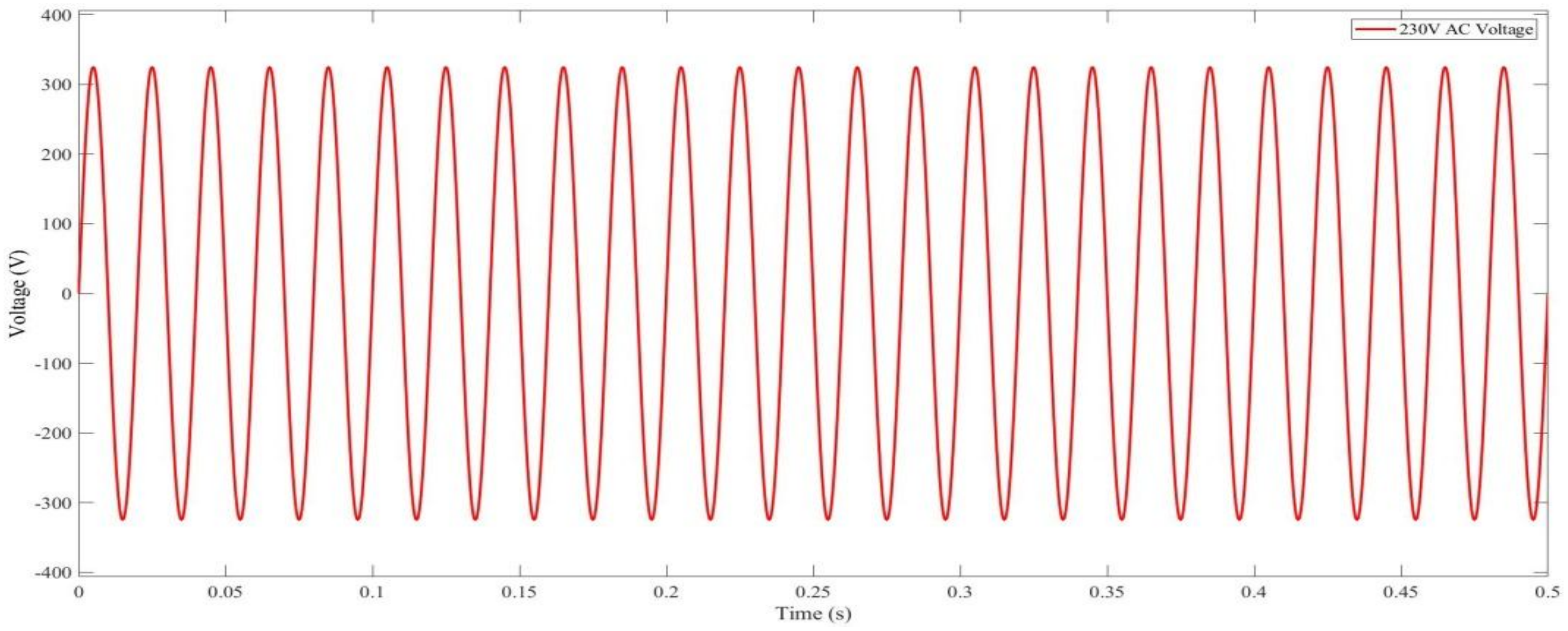

Fig. 8. 230V AC voltage

V. CONCLUSION

A high voltage – gain converter topology using Dickson CP voltage multiplier cell with reduced voltage stress and uniform current circulation between inductors is presented in this paper. Proposed DC-AC converter is based on two-phase interleaved boost stage and 180^oupturned Dickson VMC network. Smaller rating of capacitors used by the converters improves charging and discharging with better efficiency and low cost. Converter studied in this manuscript can be beneficially used for photovoltaic applications with linking solar panels to the 400V DC distribution systems in micro grid system, UPS (uninterruptable power supplies) etc. with a gain factor of 20. Single or dual independent PV panels can be used with suitable MPPT algorithm. Converter along with inverter producing 230V AC output voltage can be used for residential and industrial applications with reduced harmonics.

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Switched Capacitor Based Z-Source Converter for Renewable Energy Based Power Generation

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Abstract: This paper proposes a switched capacitor based z-source converter with continuous input current and common ground. The step up dc-dc converters utilize the advantages of both z-source network and switched capacitor. In comparison to the conventional z-source converter, it has high voltage gain, high efficiency and low voltage stress across the switches .High voltage gain and continuous input current have made this converter suitable for renewable energy based applications and fuel cell applications. The converter operates in duty cycle range between 0 and 0.5. Hence, extreme duty cycle problems can be eliminated.The proposed converter is analysed and is compared with other non-isolated boost converters.Also the converter isdesigned and is simulated using MATLAB/SIMULINK software to verify the validity of the converter.

Keywords: Renewable energy, Z-source, Switched capacitor, DC-DC, High gain

I. INTRODUCTION

The global energy consumption is increasing gradually. Fossil fuels, which are the major source of energy production will be over soon due to its increased usage in order to meet the huge energy demand. Also the atmospheric pollution will be at its peak and will be adversely affecting the living beings and the entire environment. The mankind has already started giving attention to energy crisis and environmental pollution. As a result of this, renewable energies are being adopted by many countries all over the world for energy production [1]. Renewable energy sources such as fuel cells and solar panels are employed to generate electrical energy. But these sources normally provides low output voltage and have less efficiency [2]. So most of the renewable energy sources need boost converters to step up the voltage from low voltage to high voltage [3]. Beyond this purpose, the dc-dc converters have wide application areas.

High turn ratio transformers are used in isolated dc-dc converters to achieve high voltage gain [4]. But the large leakage inductance of transformer results in poor efficiency. Therefore in order to achieve high efficiency non-isolated high gain converters are preferred [5]. Conventional boost converter has good gain, but its efficiency decreases on practical implementation. Also it suffers from diode reverse recovery problem [6]. Other non-isolated converters utilise the advantage of coupled inductor, switched inductor and switched capacitor which improves overall efficiency and gain of the converters [7][8]. Cascaded boost converter can attain high voltage gain, but it becomes unstable and inefficient while achieving large gain [9]

Z-source and quasi Z-source converters have been developed and implemented in nineties [10]. Its voltage gain can be increased further by combination with other techniques. But they are not suitable for high voltage applications. Hence they were combined with the techniques like coupled inductor, switched inductor and switched capacitors. The switched inductor based configuration have high cost and it is complex and bulky too [11]. Then they were combined with switched capacitor structure. The switched capacitor is able to achieve flexible voltage regulation on combination with the DC-DC converters [12]. A cascaded switched capacitor combined with Z-source has improved voltage gain [13]. But it is having a complex structure.The switched capacitor network is combined with quasi Z-source configuration to obtain improved voltage gain and efficiency [14]. It has common ground and reduced voltage stress across components and is suitable for renewable energy basedapplications.The switched capacitor based z-source converter with common ground between source and load side possess high voltage gain [15]. But it has discontinuous input current which limits its applications.

This paper proposes a newdc-dc converter formed by the combination of z-source network and switched capacitor having continuous input current. The converter has advantages like increased voltage gain, reduced voltage stress across components and good efficiency when compared with other non-isolated converter topologies.

This paper is arranged with 6 sections as follows. Section II deals with operating principle of the converter along with its configuration. In section III, steady state analysis and design of the converter is presented. In section IV, proposed converter is compared with other converters. Simulation results are given in section V and conclusion in section VI.

II. PROPOSED CONVERTER CONFIGURATION

The proposed converter consist of the reformed conventional z-source converter and additional components. To achieve the improvement in the boosting operation of the conventional z-source converter, this paper presents a new structure which is shown

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in fig.1 with common ground and continuous input current.It comprises of two switches, four diodes, three inductors and five capacitors. Both switches are turned on and off simultaneously. The new structure is analysed and compared with similar converters.

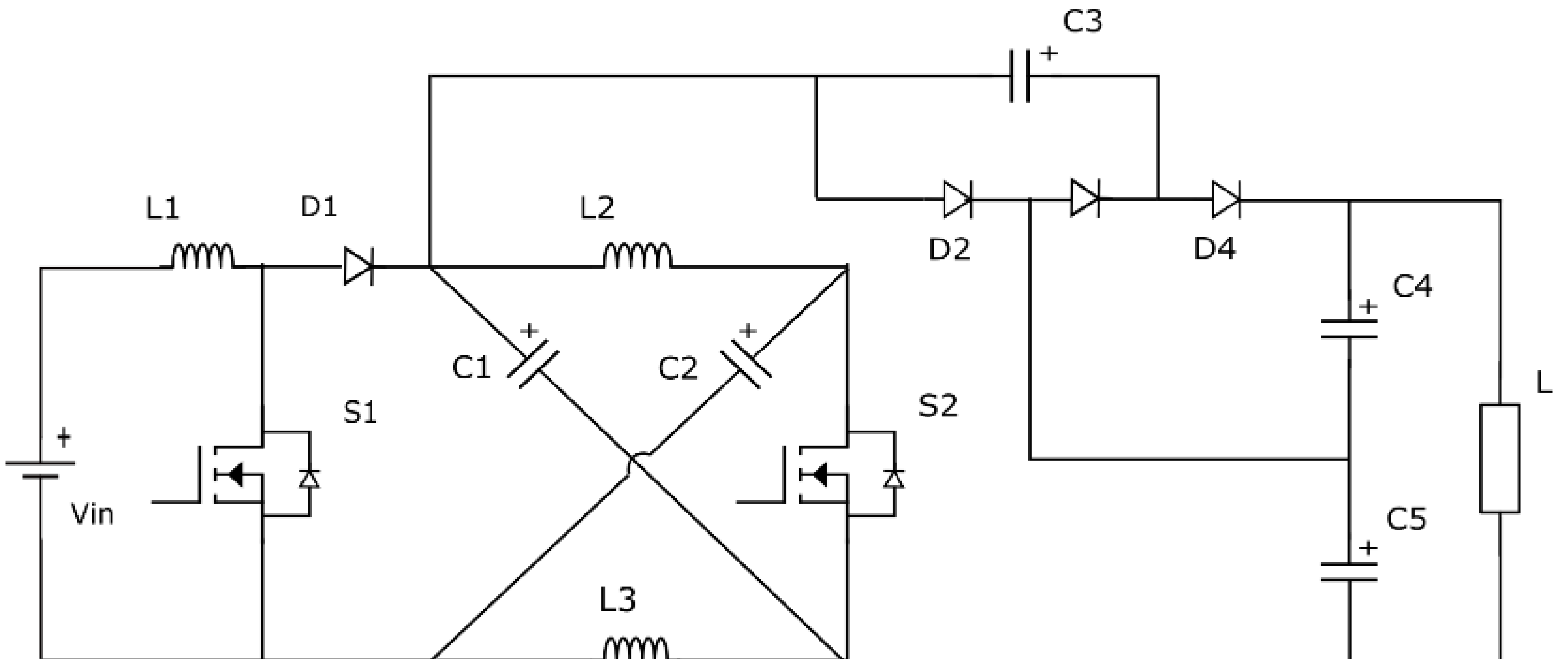

Fig.1 Proposed switched capacitor based z-source converter

The proposed converter has common ground and the capacitor parallel with the load is divided into two capacitors which are common with the switched capacitor. The common capacitor helps to reduce the number of components.
The other positive point of the proposed converter is the method of using switched capacitor to increase the voltage gain effectively. The voltage gain of the proposed converter is given by equation (1). The other switched capacitor based z-source converter configurations shown in fig.2 and fig.3 are investigated which are not effectual as the proposed converter topology. The converter 1 shown in fig.2 is not having common ground and its voltage gain is given by equation (2). The 2nd configuration shown in fig.3 has common ground. The voltage gain of converter 2 is given by equation (3).

$$G = \frac{V_O}{V_{in}} = \frac{3-2D}{(1-2D)(1-D)} \quad (1)$$

$$G = \frac{V_O}{V_{in}} = \frac{2}{1-2D} \quad (2)$$

$$G = \frac{V_O}{V_{in}} = \frac{3-2D}{1-2D} \quad (3)$$

From the voltage gain equations(1), (2) and (3) it is clear that the proposed converter has voltage gain higher than the converters shown in fig.2 and fig.3. It has voltage gain greater than or equal to 3.The converters 1 and 2 are having discontinuous input current which limits its applications. The proposed converter has continuous input current which is one of the advantage over the other two converters.

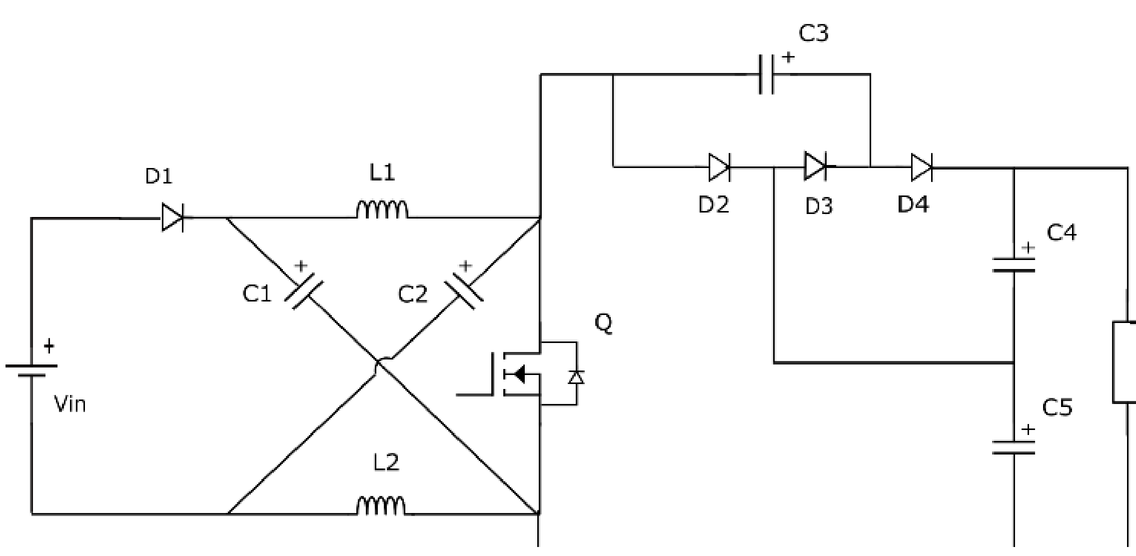

Fig. 2 converter 1 configuration

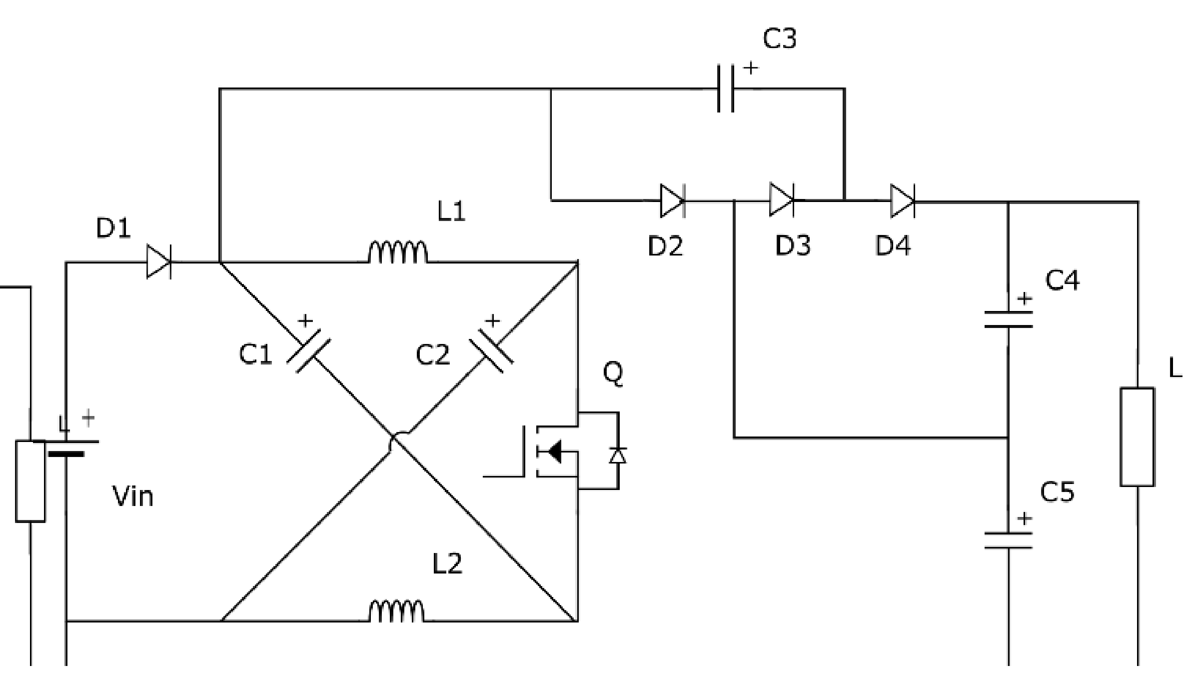

Fig.3 converter 2 configuration

The proposed converter operates in $0 \leq D \leq 0.5$. The states of converter operation and the time duration of each state is defined by the duty cycle D. The inductors and capacitors will be charging or discharging and diodes will get turned on or off depending on each state of the converter. Thus, the duty cycle is an essential parameter in the analysis of the converter.

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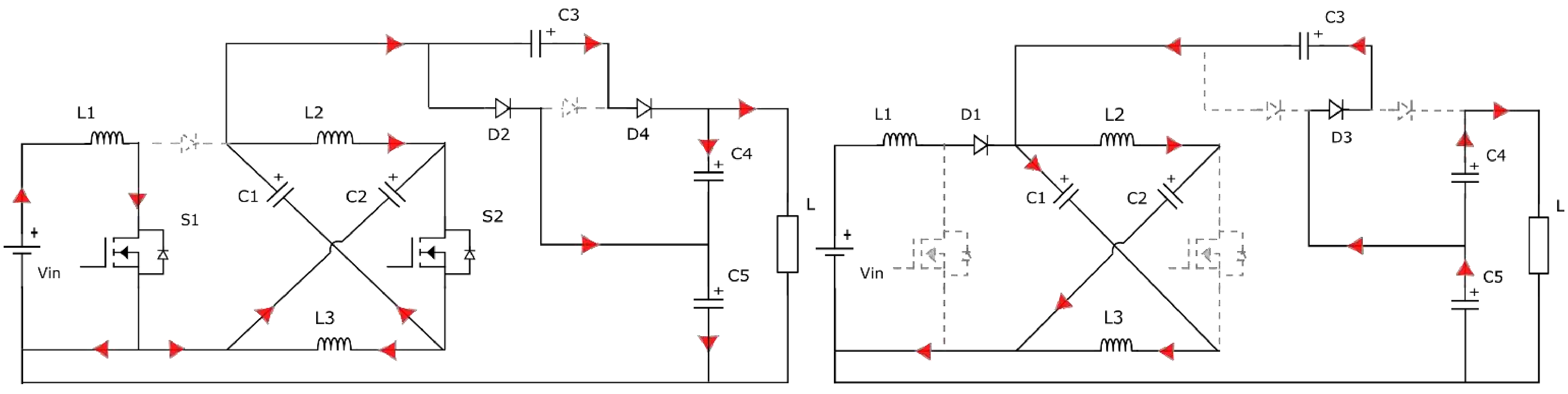
III. OPERATION PRINCIPLE OF THE PROPOSED CONVERTER

The converter has two modes of operation. It will be working in mode 1 when the switches are turned on and works in mode 2 when switches are turned off. The components of the converter are assumed to be ideal and the equivalent circuit for the operating stages are shown in fig.4. For analyzing the working principle of the converter, it is assumed to be working in continuous conduction mode (CCM).

Mode 1: In this mode, PWM signals are given to both switches. The switches are turned on, then the diodes D_1, D_3 are off and the other two diodes D_4, D_5 are on. The inductors are magnetized linearly. Capacitors C_1, C_2, C_3 discharge and C_4 , C_5 get charged. The capacitor C_3 transfers energy to the load. The equivalent circuit of the mode 1 operation is shown in fig.4(a)

Mode 2: In the second mode of operation, both the switches are turned off. The diodes D_1 and D_3 conduct and other two diodes are reverse biased in this mode. Capacitors C_1 and C_2 get charged by the inductors L_2 and L_3. Capacitor C_3 is charged by the capacitor C_5 and C_4 transfer energy to load. Mode 2 operation is shown in fig.4(b).



(a) Mode 1 (b) Mode 2

Fig.4 Equivalent circuit of the proposed converter in mode1 and mode 2

Operation equations of the converter can be obtained by steady state analysis. Certain assumptions are made for the simplicity of the analysis of the converter.

1) The voltage across the capacitors are assumed to be constant due to infinitely large capacitance.
2) The current through the inductors are assumed to be constant due to infinitely large inductance
3) The forward voltage drops, on-state resistance of all power semiconductor devices and parasitic parameters are ignored.

Voltage second balance equation of the inductors leads to finding the voltage gain of the converter. The balance equation consider the average voltage across the inductor in one duty cycle to be zero.

By applying Kirchhoff's Voltage Low (KVL) in equivalent circuit of mode 1(fig.4(a)), the equations can be derived as follows.

$$V_{L_2} = V_{L_3} = V_{C_1} = V_{C_2} \tag{4}$$
$$V_L = V_C \tag{5}$$
$$V_{L_1} = V_{in} \tag{6}$$
$$V_{C_3} = V_{C_4} \tag{7}$$
$$V_{C_1} + V_{C_2} = V_{C_5}, \quad V_{C_5} = 2V_C \tag{8}$$
$$V_O = V_{C_3} + V_{C_5} = V_{C_4} + V_{C_5} \tag{9}$$

Following equations are obtained by applying KVL in figure 4(b).

$$V_{L_1} = V_{in} + V_{C_3} - V_{C_5} \tag{10}$$

$$V_L = V_{in} - V_C - V_{L_1} \tag{11}$$

Applying voltage second balance principle on inductors,

$$(V_L \times DT) + (V_L \times (1 - D)T) = 0 \tag{12}$$

$$\left(V_{L_1} \times DT\right) + \left(V_{L_1} \times (1 - D)T\right) = 0 \tag{13}$$

We get ,

$$V_C = \frac{V_{in}}{1-2D} \tag{14}$$

substituting (10) in equation (7) and (8), and by solving, we get

$$V_{C_3} = V_{C_4} = \frac{V_{in}}{(1-2D)(1-D)} \tag{15}$$

$$V_{C_5} = \frac{2\,V_{in}}{1-2D} \tag{16}$$

$$G = \frac{V_O}{V_{in}} = \frac{3-2D}{(1-2D)(1-D)} \tag{17}$$

Voltage gain of the converter is given by the equation (17). It conveys that the converter possess high voltage gain and is higher or equal to 3. The proposed converter operate in $0 \leq D \leq 0.5$.

A. Voltage stress on the components

All the components of the converter will be suffering from reverse voltage. Voltage stress across each component should be considered and reduced during the design and implementation of the converter. The voltage stress across capacitors, switches and diodes are investigated in this part.

Voltage stress across capacitors are given by the following equations. Voltage stress across C_1 and C_2 are equal and is obtained by substituting (16) in (13) and is given by equation (18).

$$V_{C_1} = V_{C_2} = V_C = \frac{1-D}{3-2D} V_O \tag{18}$$

We get voltage stress across C_3 and C_4 by substituting (16) into (14), and the voltage stress across C_5 is equal to $2V_c$, then the voltage stress will be twice (18)

$$V_{C_3} = V_{C_4} = \frac{1}{3-2D} V_O \tag{19}$$

$$V_{C_5} = 2V_C = \frac{2(1-D)}{3-2D} V_O \tag{20}$$

In order to choose the components, voltage stress across the diodes and switches has to be calculated. The voltage stress across the switches are given by (21) and (22).

$$V_{S_1} = \frac{1-2D}{3-2D} V_O \tag{21}$$

$$V_{S_2} = \frac{1}{3-2D} V_O \tag{22}$$

The voltage stress across diodes are defined as follows,

$$V_{D_2} = V_{D_3} = V_{D_4} = \frac{1-2D}{3-2D} V_O \tag{23}$$

$$V_{D_1} = \frac{2(1-D)}{3-2D} V_O \tag{24}$$

B.DesignOf Inductors And Capacitors

For the design of inductors of the converter, it is assumed that the maximum required current ripple of the inductors is Δi_L. The currents flowing through the inductors L_2 and L_3 are same. The inductance can be calculated using following equations when the inductors are in charging state.

$$L = v_L \frac{dt}{di_L} \tag{25}$$

$$L_1 = v_{L_1} \frac{dt}{di_{L_1}} \tag{26}$$

Where, $di_{L_1} = \Delta I_{L_1}$, $di_L = \Delta I_L$, $dt = D \times T = D/f$ (f is the switching frequency) and $v_L = V_c$, $v_{L_1} = V_{in}$. The inductance of inductors can be derived from equation (25) and (26) and obtained as follows.

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$$L_1 = \frac{D}{(1-2D)\Delta I_L f_s} V_{in} \tag{27}$$

$$L_2 = L_3 = L = \frac{D}{(1-2D)\Delta I_L f_s} V_{in} \tag{28}$$

The maximum required voltage ripple of the capacitors is assumed to be Δv_c for the design of capacitors. Then the capacitance of the five capacitors in the converter canbe calculated using equation (29) when the capacitors are in charging or discharging states.

$$C = i_c \frac{dt}{dv_c} \tag{29}$$

Where $dt = D \times T = D/f($ f is the switching frequency), i_C is the current flowing through the capacitor and $dv_C = \Delta V_C$. The capacitance of the capacitors are derived as follows.

$$C_1 = C_2 = \frac{I_O D}{\Delta V_C f_s} \tag{30}$$

$$C_3 = \frac{I_O}{\Delta V_{C3} f_s} \tag{31}$$

$$C_4 = \frac{I_O(1-D)}{\Delta V_{C4} f_s} \tag{32}$$

$$C_5 = \frac{I_O(2-D)}{\Delta V_{C5} f_s} \tag{33}$$

IV. COMPARISON WITH OTHER CONVERTERS

The comparison between proposed converter and other converters including conventional converters, converter in [12] and converter in [13] is shown in table 1. The voltage gain, amount of components, voltage stress across switches, nature of input current are considered as parameters for the comparison.

TABLE I
COMPARISON BETWEEN PROPOSED CONVERTER AND OTHER NON-ISOLATED CONVERTERS

Converter	**Boost converter**	**Conventional z-source converter**	**Switched capacitor based quasi z-source converter in [14]**	**Converter 1 configuration**	**Switched capacitor based z-source converter in [15]**	**Proposed converter**
Voltage gain	$\frac{1}{1-D}$	$\frac{1}{1-2D}$	$\frac{2}{1-2D}$	$\frac{2}{1-2d}$	$\frac{3-2D}{1-2D}$	$\frac{3-2D}{(1-2D)(1-D)}$
Amount of inductors	1	2	2	2	2	3
Amount of capacitors	1	2	5	5	5	5
Number of diodes	1	2	5	4	4	4
Maximum voltage stress across switch	V_O	V_O	$\frac{V_O}{2}$	$\frac{V_O}{2}$	$\frac{V_O}{3-2D}$	$\frac{V_O}{3-2D}$
Common ground	yes	no	Yes	no	Yes	Yes
Input current	Continuous	Discontinuous	Continuous	Discontinuous	Discontinuous	Continuous

Considering the voltage gain for comparison, proposed converter has higher voltage gain. It boost the input voltage with the highest voltage gain during whole duty cycle and the voltage gain is greater than or equal to 3. The proposed one can achieve maximum voltage gain in lowest duty cycle range without extreme duty cycle.

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The voltage stress across power switch for the proposed converter depends on the duty cycle. The voltage stress across switches in the conventional converters and converter in [12] is higher than that of the proposed converter. The voltage stress imposed by the proposed converter ranges between $V_0/3$ to $V_0/2.1$ which is less when compared with others.

For the conventional z-source and switched capacitor based z-source configuration (converter 1) has non-common ground. The potential difference between source and load side may appear as PWM voltage due to this non-common ground. The proposed converter is free from this problem as it has common ground between input and output sides. Continuous input current is another advantage of the proposed converter which makes the converter suitable for using with renewable energy sources. The conventional z-source converter and the switched capacitor based z-source converter configurations in [13] have discontinuous input current.

In comparison of the proposed converter with other converters, it is seen that the proposed converter has advantages such as high voltage gain with low duty cycles, low voltage stress across switches, continuous input current and common ground between source and load sides.

V. SIMULATION RESULTS

The converter is simulated using MATLAB/SIMULINK software. Simulation results are obtained using the designed equations and the output is obtained as expected. The table Ishows the simulation parameters for the proposed switched capacitor based z-source converter configuration.

TABLE II SIMULATION PARAMETERS FOR THE PROPOSED CONVERTER

Components	Specifications
Power	500 W
Input voltage, boost	48 V
Output voltage, boost	400 V
Inductor, L_1	600µH
Inductor, L_2, L_3	2.26 mH
Capacitors, C_1, C_2	220µF
Capacitors, C_3, C_4,C_5	470µF
Switching frequency	25000 Hz

The converter is designed for a power of 500 W, input voltage of 48 V and output voltage of 400 V. The duty cycle in which the converter operating is 0.3. The switching frequency is chosen as 25KHz. The converter is simulated with the specified parameters and output is obtained. For 48 V input an output of 396 V is obtained. The input and output voltage waveforms are shown in Fig.5

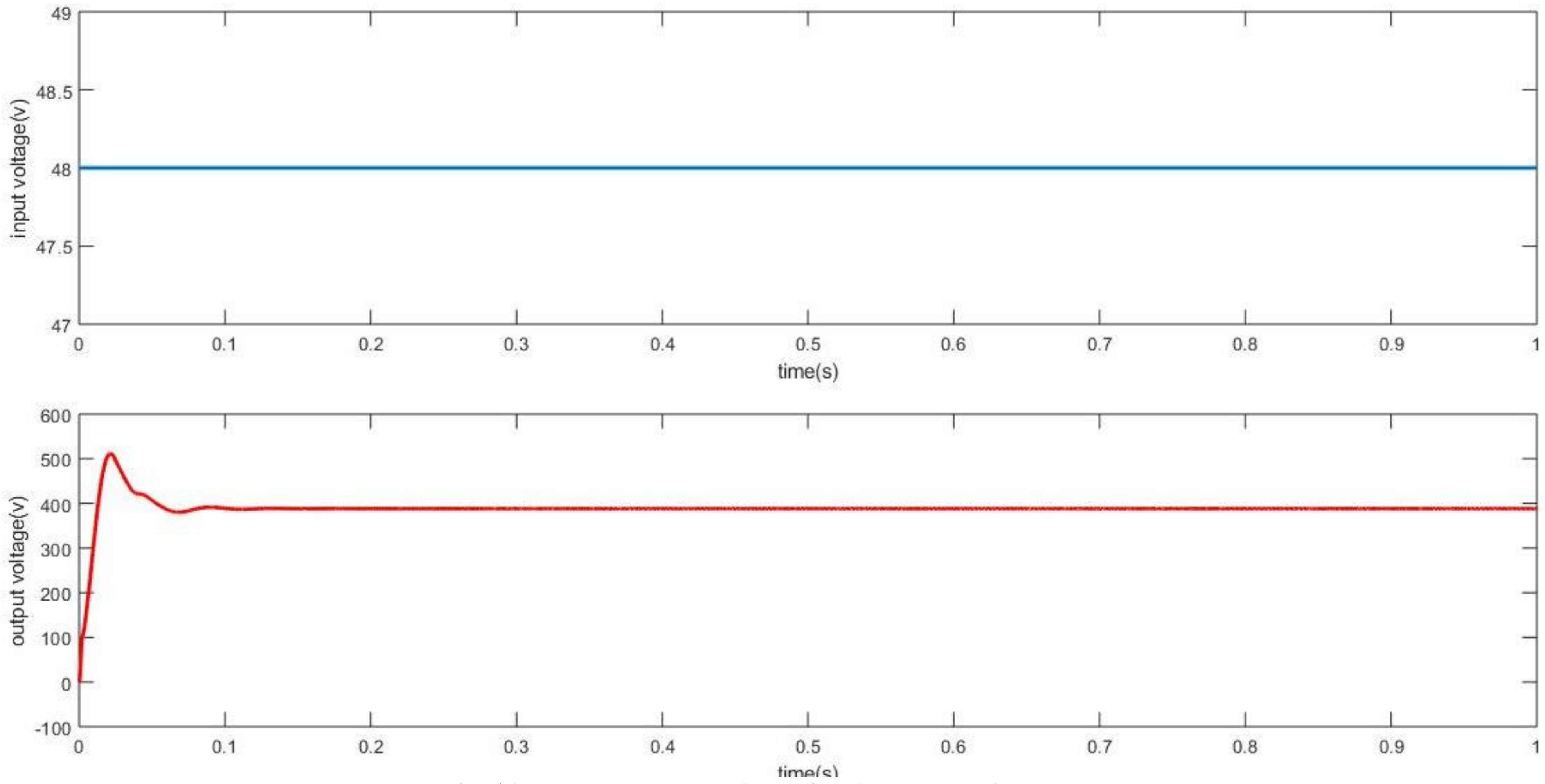

Fig.5 input and output voltage for the proposed converter

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VI. CONCLUSION

A switched capacitor based z-source converter with common ground and continuous input current isproposed in this paper. The proposed converter is formed by the combination of reformed conventional z-source converter and switched capacitor. Hence it own the advantages of conventional z-source converter and switched capacitor. Converter operates for a duty cycle ranging between 0 and 0.5. So extreme duty cycle problems can be eliminated. Non-inverter output and high efficiency are the advantages of the proposed converter.Also, the continuous input current has made the converter suitable for renewable energy based applications.

The proposed converter is analyzed and compared with other non-isolated step-up converters. In comparison to other converters, it has higher voltage gain and operates in boosting mode with higher maximum voltage gain. The converter imposes low voltage stress on components when compared with conventional converters during the entire duty cycle. The proposed converter has common ground and continuous input current which the conventional z-source converter doesn't have. In comparison with other converters the privilege of the proposed converter has been justified. Also the converter is designed for a power of 500 W and is simulated using MATLAB/SIMULINK software.

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Power Electronic Rectifier Circuit Modelling Using Machine Learning in Python

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Abstract: This paper tries to model a power electronic circuit - the single-phase controlled rectifier using machine learning techniques in the python programming language. Different machine learning algorithms are evaluated. An LSTM based neural network model was found to be most suitable for the purpose.

Keywords: power electronics, artificial intelligence, machine learning, python, design, drives, optimization

I. Introduction

The modelling of a circuit is a necessary component during the design stage to provide insights into the behaviour either on its own or in a large system. An accurate model is essential, which can include almost all aspects of the circuit at least implicitly. This has lead to the research into statistical modelling methods over the pure mathematical model. With the rise of modern data science techniques like machine learning, such models can be obtained far easier than before. This is a concept called 'digital twin' outlined in [4] and [7]. A case study using a boost converter is demonstrated in [1]. This paper focuses on building a digital twin for a single-phase controlled rectifier.

II. Single Phase Controlled Rectifier

Single-phase fully controlled rectifiers are obtained by replacing diodes in an uncontrolled rectifier with thyristors. The thyristors provide control over the output voltage of the circuit using its firing angle delay. The full converter is widely used for small dc motor drives. Depending on the load they can operate in discontinuous and continuous conduction modes. Here we are considering continuous conduction mode only. The single-phase full controlled converter was chosen because the mathematical model is more complex when compared to an uncontrolled rectifier, but is still simple enough to modelled using machine learning with few parameters. A single-phase fully controlled rectifier circuit diagram is shown in Fig. 1.

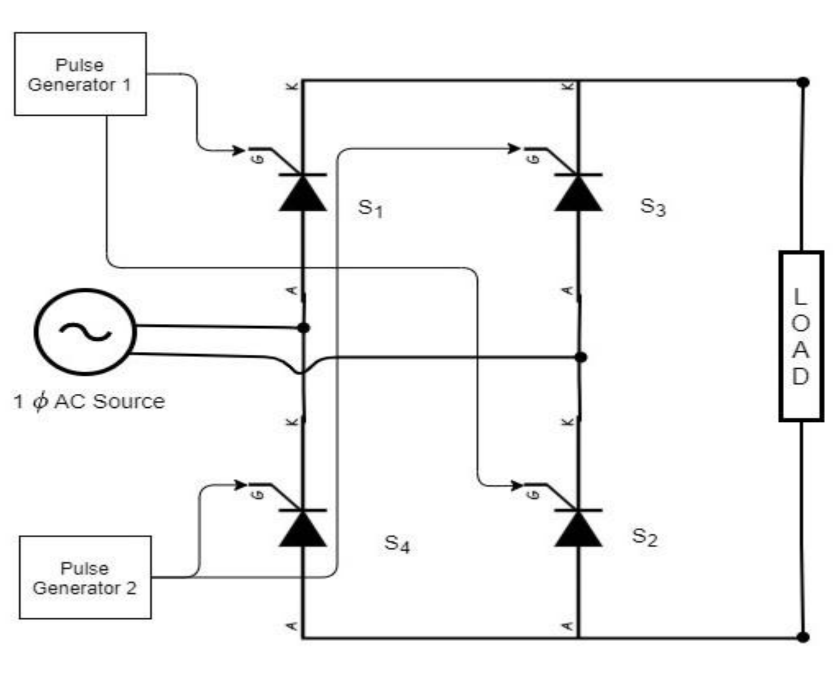

Fig. 1 Single-phase Fully Controlled Rectifier Circuit Diagram

III. Machine Learning

Machine learning (ML) is the study of computer algorithms that improve automatically through experience and by the use of data [3]. It is a subset of artificial intelligence (AI) technology. Over the past few years, the popularity of such algorithms and techniques gained a lot of momentum due to the advent of the "data age". These techniques provide a relationship function as a solution, given a set of input and outputs. The data-driven modelling using machine learning has been actively researched in the power electronics industry for the past few years. The data from [2] shows that the interest and implementations using these techniques are increasing year on year. The applications are broadly classified into design, control and maintenance. The proposed model here comes under the design category.

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IV. PYTHON

Python is an interpreted, high-level and general-purpose programming language. Its language constructs and object-oriented approach aim to help programmers write clear, logical code for small and large-scale projects. Python is dynamically typed and garbage-collected. It supports multiple programming paradigms, including structured (particularly, procedural), object-oriented and functional programming [5]. Python is one of the popular choices for machine learning due to its above given and various other features. Most of the existing models are based on simulation software such as MATLAB-Simulink. This software is good for the purpose, but is bulky and closed source or proprietary in nature limiting their application in real-world usage. Python is open-sourced and is lightweight. There is a large community of developers from across the industries that are utilising and improving python. This helps in faster troubleshooting, better third-party support etc. Being a general-purpose language, it is easier to utilise or transform our results into different situations, for example, the resultant model can be used in a virtual lab set up via the internet. It is also easier to interface python-based models into IoT applications as many of them use python as their core language. Python's ability to run in any hardware further helps in the deployment of the solution.

V. PROPOSED MODEL DEVELOPMENT

Here we are using the supervised machine learning technique. In this technique, a good part of the given dataset (80%) is used for training while the rest of the data is used for testing/validation.

A. Data collection and processing

Since this is a proof-of-concept based work, the data is generated from the Simulink model of the converter. The simulation diagram is shown in Fig. 2

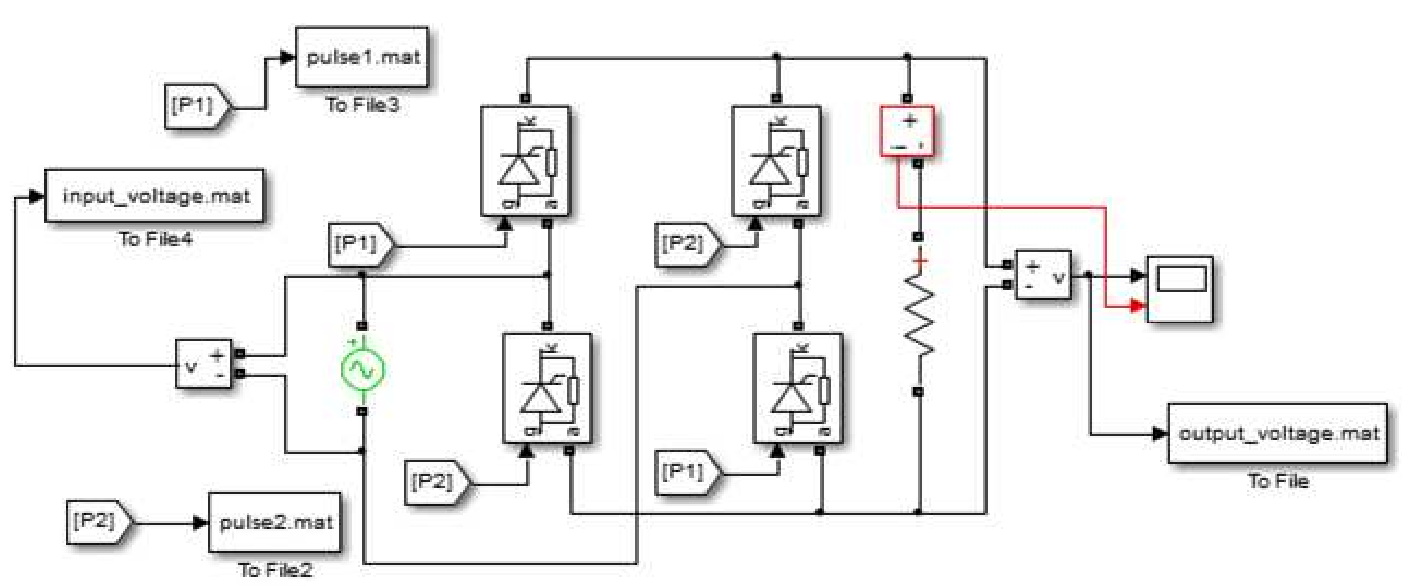

Fig. 2 Simulation Diagram of Single phase-controlled rectifier

The values set in the blocks are Input Voltage = 100 V, Frequency = 50 Hz, Load Resistance = 10 Ω Pulse Amplitude = 5 V. The power switching device used here is the 'Detailed Thyristor' from the Simulink library. The output of the simulation is shown in Fig. 3. The output shown is generated for a firing angle of 30^{o}. A similar result is expected after simulation with the ML model.

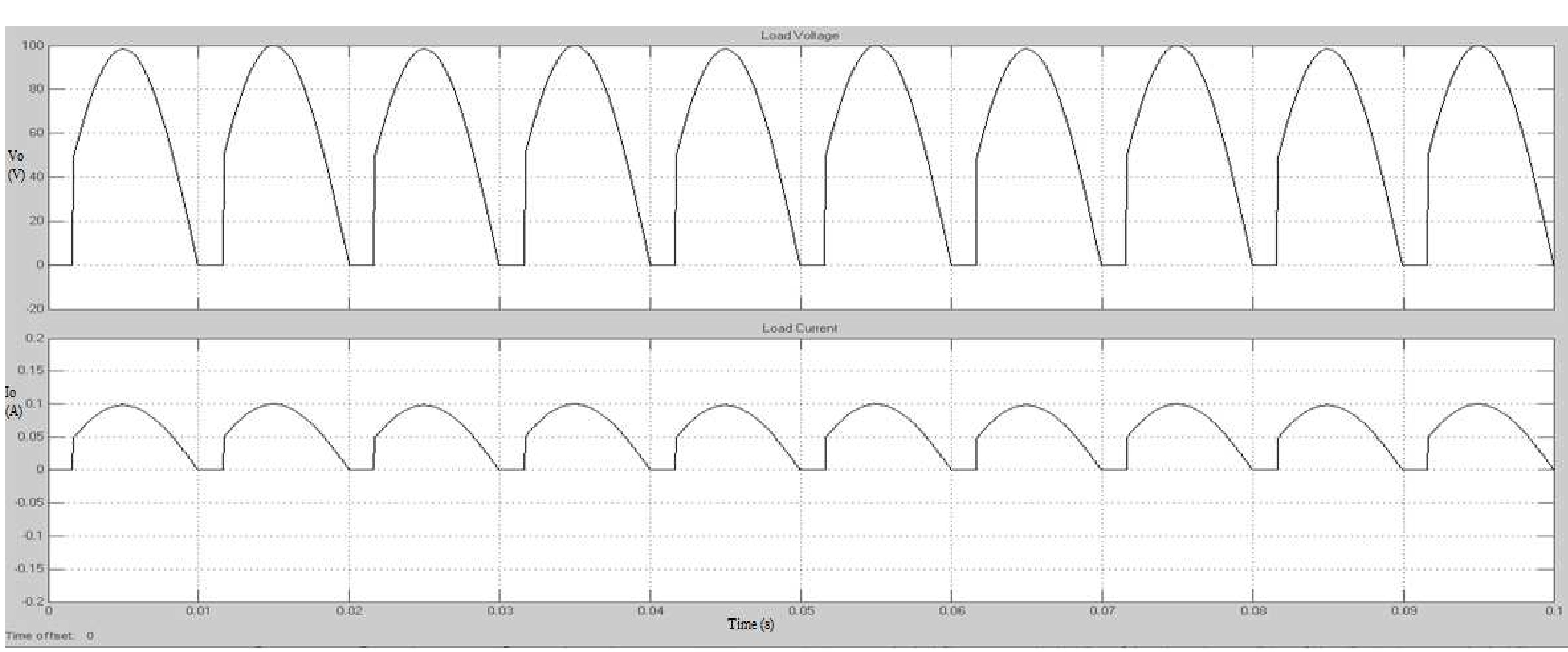

Fig. 3 Simulation Results

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The simulation data is saved to .m files and then converted to .csv files for processing in python. Simulation is run for 2 seconds and around 10,000 data points were obtained. This process is repeated for different values of firing angle of the thyristors, α from 0^o to 180^o. The data is then processed with the help of Pandas library. It is then cleaned to remove any missing entries and is scaled to fit in a range of (0, 1) to improve training performance as well as to reduce errors.

B. Model Training and Testing

Initially different algorithms were considered for training, but they either had poor performance while training or showed poor performance on testing with a different firing angle. A summary of the same is shown in TABLE 1.

TABLE 1
ACCURACY COMPARISON OF DIFFERENT ALGORITHMS

Algorithm	Training Accuracy	Testing Accuracy
Linear regression	0.20%	-
Support vector machines	85%	<40%
Multi Layer Perceptron	95%	<60%

Since the model being build utilises an ac signal, the output is time-dependent, i.e., the current value of output voltage is dependent on the previous values of output voltage. Hence the machine learning model must be able to predict a time series problem. For this, a Recurrent Neural Network (RNN) based Artificial Neural Network (ANN) is a good choice. But a normal RNN can only take value from one previous step. To overcome this, a specialised RNN named Long Short Term Memory (LSTM) network is used. This model is also useful for previous values more than just the one step behind i.e., RNN supports mainly

$$y(t) \text{ depends on } y(t-1)$$

while LSTM supports

$$y(t) \text{ depends on } y(t-1) \text{ or } y(t-2) \text{ or } y(t-3) \ldots$$

where $y(t)$ is the current output of the model and $y(t-1)$, $y(t-2)$, etc., are the previous output values. Here the input voltage and pulses for the thyristors are taken as input features for the model and output voltage as the predictor variable i.e., the output. The model is built using the Keras and tensor flow libraries. The LSTM model uses a tanh activation function, the loss function taken is Mean Absolute Error (Mae) and Adam optimizer. It contains an LTSM layer and a hidden layer for weight regularization. General structure of LSTM network is shown in Fig. 4.

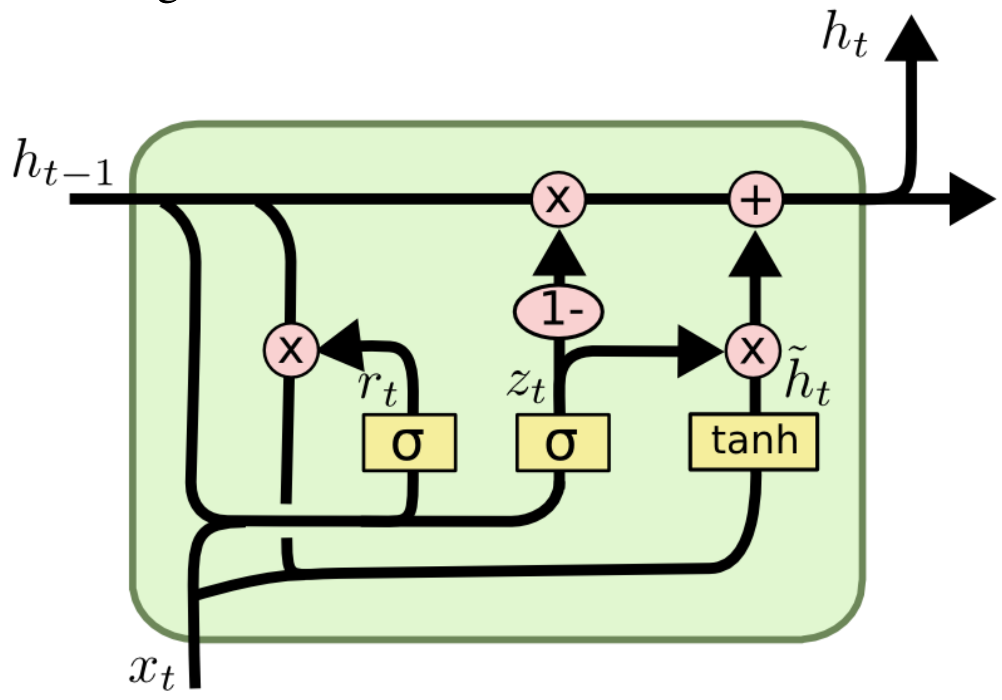

Fig. 4 General structure of an LSTM network

The training and testing loss is calculated each time over the 100 epochs as shown in Fig. 5. Here the testing loss approaches close to the training loss showing a relatively good fit and generalisation. A low validation loss of around 0.6-1% was observed during the model training. The dataset was split into 80% training and 20% testing.

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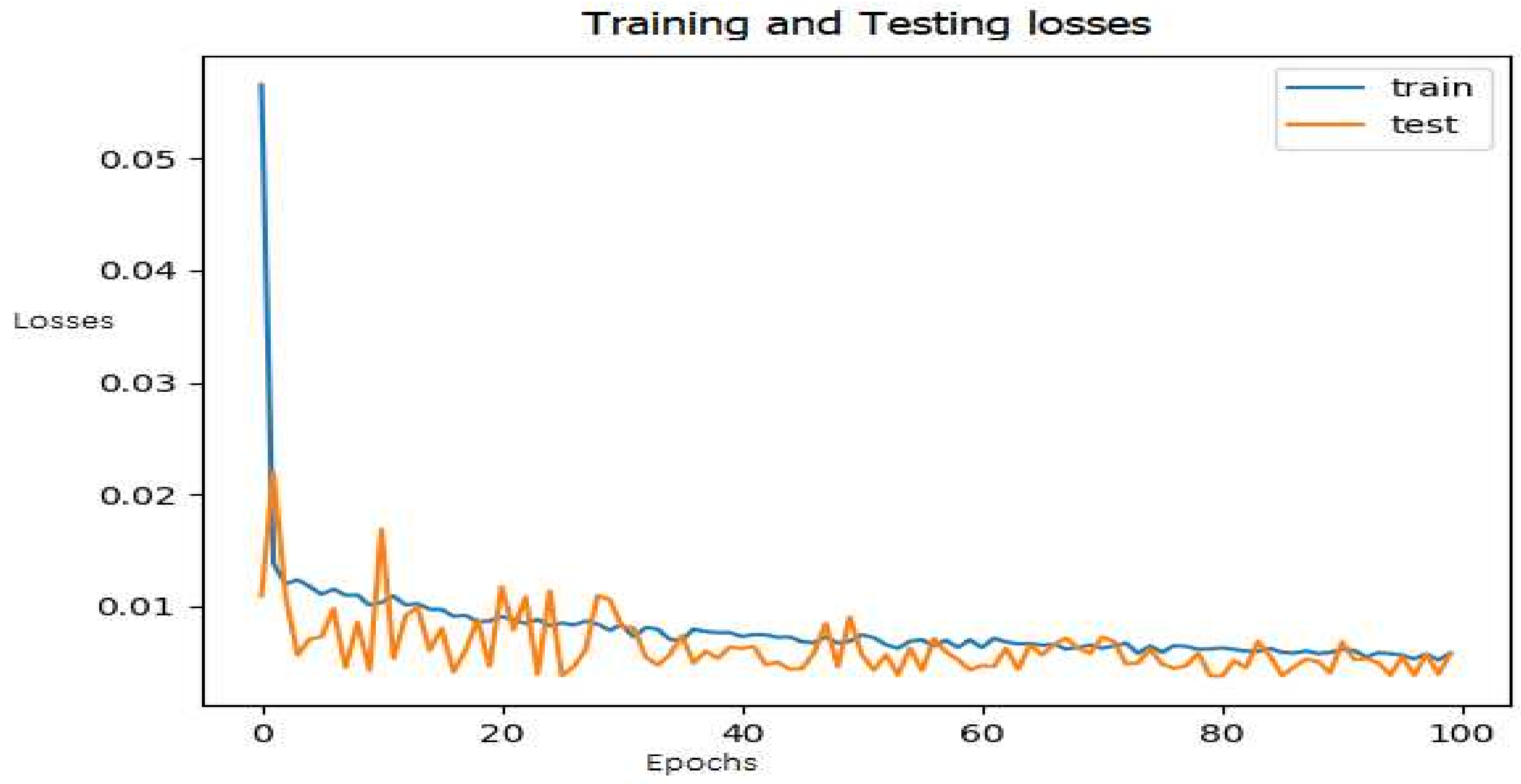

Fig. 5 Training and Testing loss vs. Epochs

The predicted value and actual value used for testing are shown in Fig. 6, which shows that the training was successful.

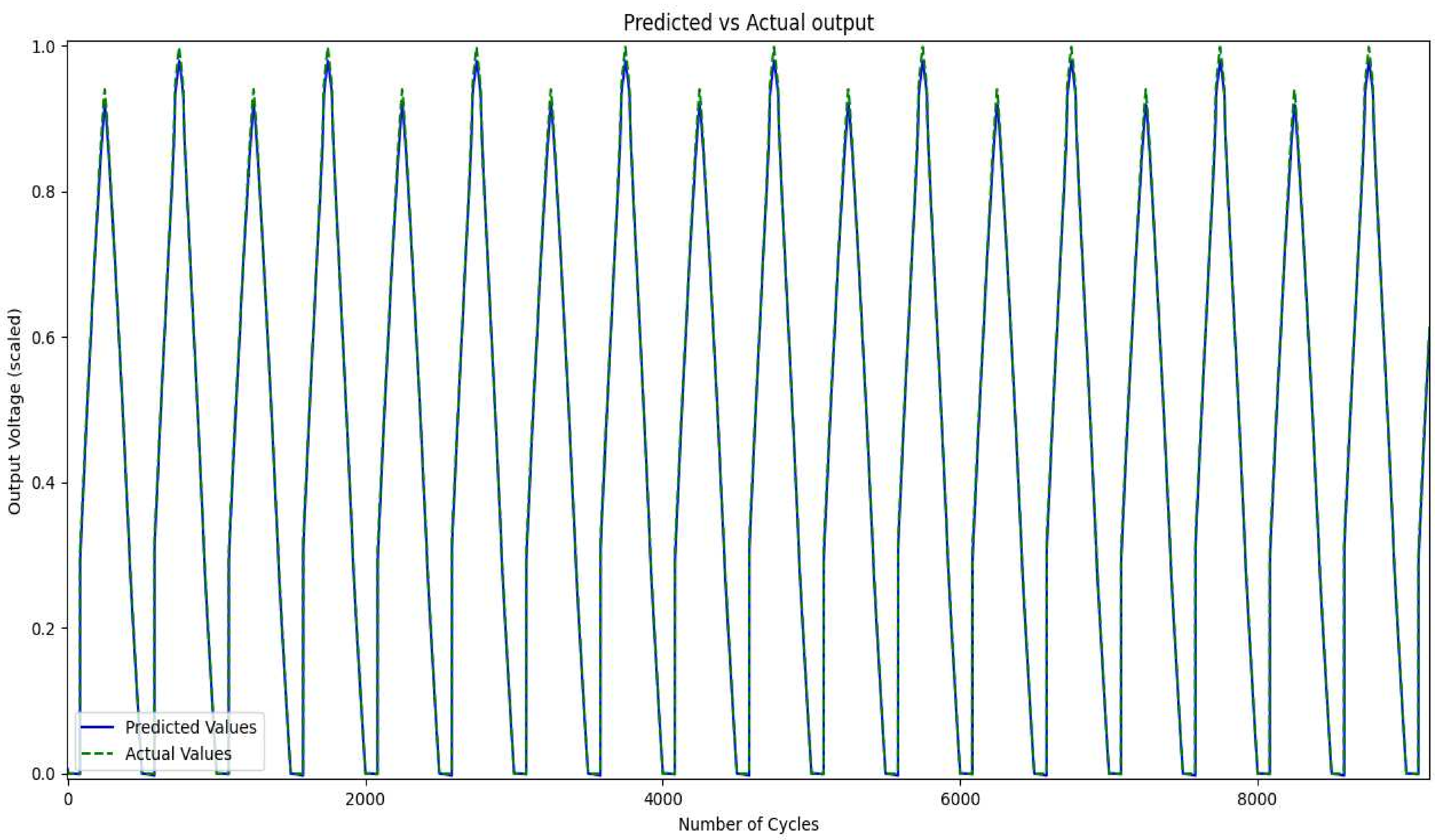

Fig. 6 Predicted output vs. Actual output

VI. CONCLUSION

This paper introduced a new modelling technique for AC-DC converters using Long Short Term Memory based ANN in Python. The developmental steps of the model, which includes data collection and processing, training, and testing/validation were discussed for a single phase fully controlled converter. It was clear that the machine learning-based models can provide very close results to the simulation. This method can become the stepping stone for broader AI applications in power electronics. With enough data and research, this method can be extended to more complex converters or inverters making them more of a universal tool for modelling.

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Review of Uninterruptible Power Supply System and Their Control Techniques

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Abstract: Uninterruptible Power Supplies (UPS) are the emergency backup device that supplies critical loads with clean and uninterruptible power in all grid conditions. Generally speaking, the UPS system offers regulated output with low total harmonics distortion (THD) and high input power factor, sinusoidal output voltage regardless of the voltage fluctuations in the grid. This paper offers a detailed review of UPS topologies, configurations and various control techniques used in the UPS. The sliding mode control (SMC) is recognized as the robust control with high stability, and the proportional-resonant (PR) control shapes the required output waveform according to the reference sinusoidal signal, a multi loop control method is introduced for this UPS inverter, where the inner loop uses the SMC and outer voltage loop uses the PR control.

Keywords: Uninterruptible Power Supplies (UPS), total harmonics distortion (THD), Sliding mode control (SMC), Proportional-resonant (PR)

I. INTRODUCTION

The Uninterruptible Power Supply (UPS) offers safe, conditioned, clean and uninterruptible energy for such sensitive and responsive loads such as computers, data centres, networking networks, airlines and medicine funds healthcare services, etc. It is desired to have output of regulated sinusoidal waveform with low total harmonic distortion (THD) irrespective of the changes in the grid voltage and changes in connected loads [1]. High reliability, high efficiency, low cost, low weight, and small size, etc. are other desirable qualities of the UPS system. There are several types of power issues with electric utility systems that involve line problems such as: supply failures, sags, brownouts, swells, spikes, under-voltages, bursts, frequency variations, noise, and harmonics.

The methods which, UPS can provide protection against power outages of some duration can be divided into three categories: [2,3] electromagnetic power conditioning equipment, static UPS systems, and rotary UPS systems. Electromagnetic power conditioners, typically Ferro resonant transformers and motor-generator sets (MG) are characterized by extremely high reliability, but even MG's are unable to provide more than a few seconds protection against utility failures, There rotary UPS systems extend the outage duration of an MG, by adding a DC motor and batteries to turn the shaft of the MG during the outage. Where static UPS systems, synthesize conditioned power electronically from either the rectified utility or a battery [4, 5].

There are many UPS systems is available in the market based on their ratings. Generally the smaller 300VA UPSs are used to back up to single computer, but the bigger unit of UPS can supply backup to an building with requirements of megawatts. Considering the importance of renewable energy resources [44-46], UPS systems with photovoltaic power as a source has also been introduced [6] in order to utilize the solar energy for long time by storing and converting them for sensitive loads and allUPS must fulfil the following specifications for standardized output.[7,8],

- Constant steady state RMS voltage with variation of only 2% in load current, battery voltage, or temperature.
- Transient peak voltage of deviation 10% is allowed during loading and unloading of UPS.
- It is not possible to allow the voltage drop by more than 5% of the rated voltage, for more than 2 AC cycles.
- Total Harmonic distortion (THD) of only 4% is allowed for all the load conditions.

II. CLASSIFICATION OF UPS

A variety of design approaches are used to implement UPS systems, each with distinct performance characteristics. The most common design approaches are as follows static, rotary, and hybrid static/rotary systems. [9]

A. *Static UPS systems*

This type of UPS are the most commonly used UPS systems. Their applications includes low power personal computers and telecommunication systems, to medium power medical systems, and to high power utility systems [10].Its main advantages are high efficiency, high reliability, and low THD, and major problems of this type of UPS systems are poor performance with nonlinear and unbalanced loads and cost is high for achieving very high reliability. Static UPS systems are further classified

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into three, they are, On-line, off-line, and line-interactive UPS systems.

1. On-line UPS systems

It consists of a rectifier, inverter, and a static switch as shown in the Fig. 1. During normal mode of operation, the rectifier charges the batteries and maintains constant DC link voltage. While the inverter converts the DC link voltage into required AC to feed the load. During power failure, the Magnetic Contactor (MC) disconnects the AC line, but the inverter keeps supplying power to the load from the battery bank without any interruption. Thus the inverter keeps on operation in both the modes. The advantages of this type of UPSs are very wide tolerance to the input voltage variation and precise output voltage regulation and there is not much transfer time during the transition from normal to back up modes. Regulation or changing the output frequency is also possible through this [11]. The disadvantages of this UPS systems are low power factor, high THD at the input, and low efficiency. The input current is destroyed by the rectifier unless an extra Power Factor Correction (PFC) circuit is added; but, this adds to the cost of the UPS system [12].

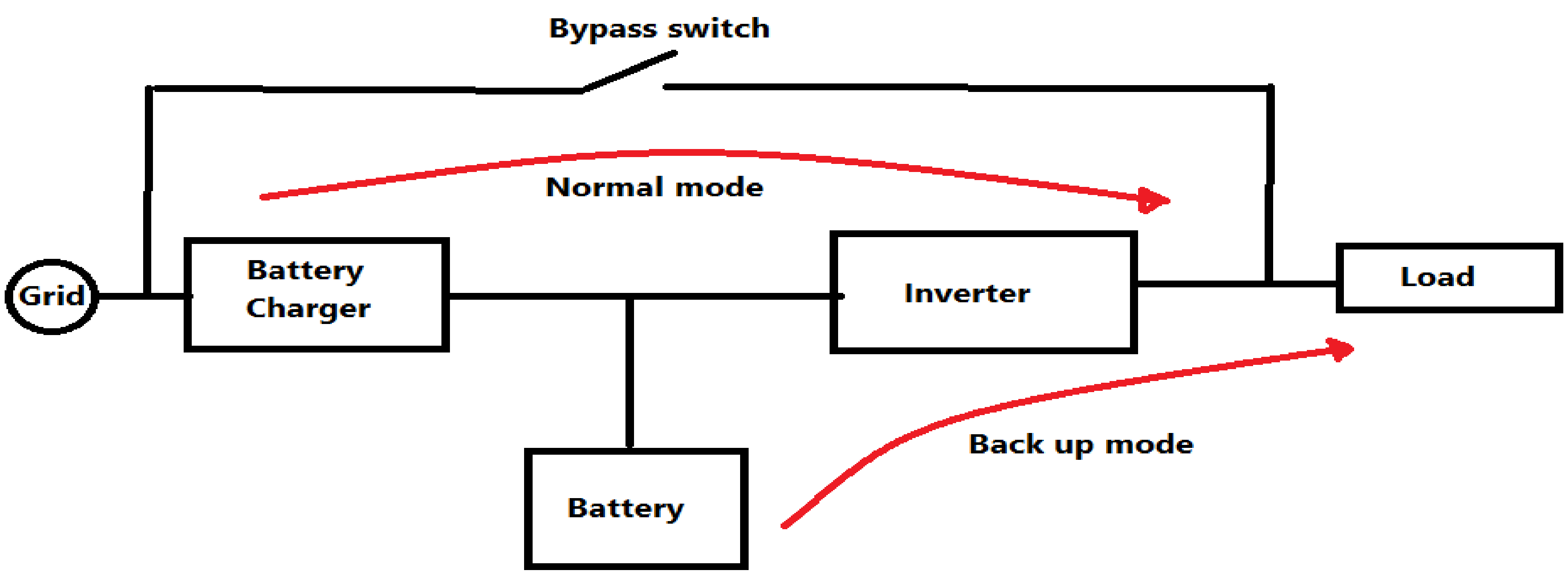

Fig. 1. Block Diagram of Online UPS system

2. Off-line UPS systems

The offline UPS consists of a battery charger, a static switch, and an inverter as shown in Fig. 2. Sometimes a filter and surge suppressor are used at the output of the UPS in order to avoid noise and disturbance before supplying the output of the UPS [13]. In normal mode of operation, battery charger will charge the battery, The battery charger charges the battery set, which is rated at a much lower power rating than the battery chargerin an on-line UPS since it is not required to meet the power demand of the load. This, in turn, allows the off-line UPS systems to be cheaper than on-line UPS systems and at the same time the load is being fed by thepower from main AC line. Here inverter is on the standby mode. When there is a power failure, the static switch connects the load to the inverter and the power is fed by the battery through the is generally less than 10ms, which does not affect the common loads.

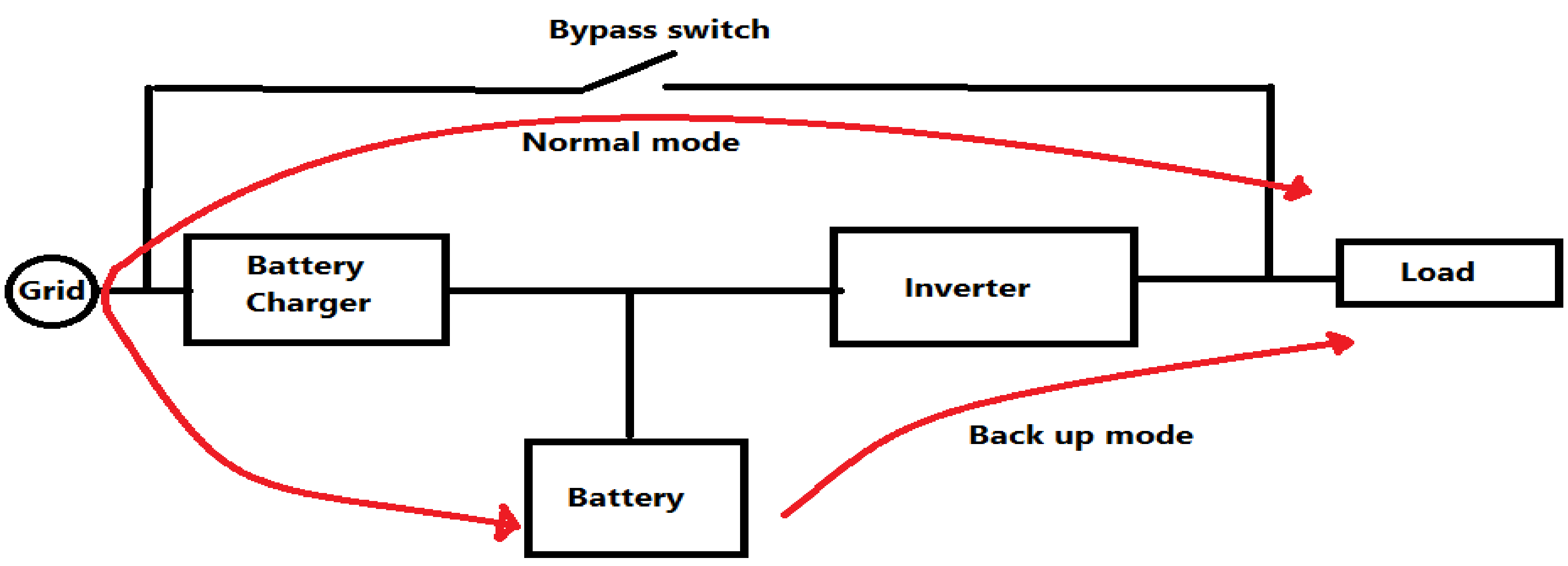

Fig. 2. Block Diagram of Offline UPS System

The advantages of the offline UPS are low cost, simple design, and smaller size of the system. But the lack of real isolation from the load and the lack of voltage regulation are the main drawbacks of the offline UPS system. Also the performance of this system during non-linear load is also very poor. Offline UPS are suitable for smaller loads with rating of about 600 VA.

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3. Line interactive UPS systems

Line Interactive UPS consists of a static switch, bidirectional converter/inverter, and a battery bank as shown in Fig. 3.The bidirectional converter/inverter connects the battery bank to the load. Additionally an output filter can be added at the output of the bidirectional converter or at the input side of the load [14]. This type of UPS can operate as on-line UPS or as an off-line UPS. During normal mode of operation, the main ACline supplies the power to the load and the bidirectional converter/inverter charges the battery. During thegrid failure, the static switch disconnects the load from the main supply and the bidirectional converter/inverter supplies the power to the load.

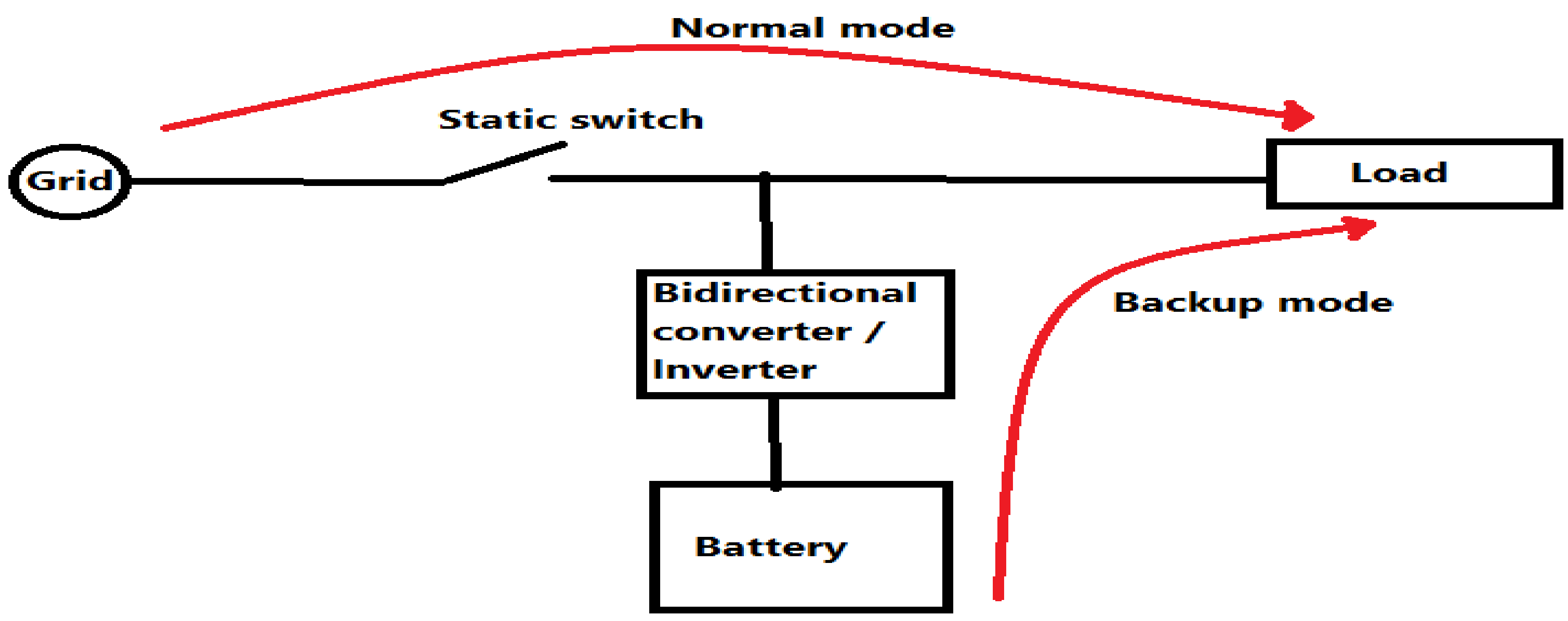

Fig. 3. Block Diagram of Line Interactive UPS system

The advantages of the line-interactive UPS systems are simple design, high reliability, high efficiency and lower cost compared to on-line UPS systems. They also have good harmonic suppression for the input current. Major disadvantages are there is no effective isolation between load and line, so by using a transformer will solve the problem, but it will further increase cost, size and weight of the UPS. Different commercially available UPS systems and their features are shown in the Table I [47-49].

TABLE I
TYPES OF COMMERCIALLY AVAILABLE UPSS AND THEIR FEATURES

UPS System	Range of kVA	Voltage conditioning	Cost per VA	Efficiency	Inverter always operating
Standby	0 – 0.5	Low	Low	Very high	No
Line interactive	0.5 - 5	Dependent on design	Medium	Very high	Dependent on design
Standby online hybrid	0.5 - 5	High	High	Low	Partially
Double conversion online	5 - 5000	High	Medium	Low	Yes
Delta conversion online	5 - 5000	High	Medium	High	Yes

B. Rotary UPS systems

Rotary UPS consists of an AC motor, a DC machine, an AC generator, and a battery bank and machines are connected via mechanical coupling as shown in Fig. 4. During normal operation, the supply AC powers the AC motor, which drives the DC machine, the DC machine drives the AC generator, which supplies the load [16]. During the stored energy mode of operation, the battery bank supplies the DC machine, which, in turn, drives the AC generator and the AC generator supplies the load. These systems are more reliable than static UPS systems, but constant maintenance and bigger sizes are the limitation of this type of UPS.

C. Hybrid Static/Rotary UPS systems

This UPS system combine the main features of both static and rotary UPS systems. This UPS consists of AC generator, a battery bank, and a static switch as shown in Fig. 5. They have low output impedance, high reliability, excellent frequency stability, and low maintenance requirements [17,18]. These types of UPS are used mainly in high power applications.

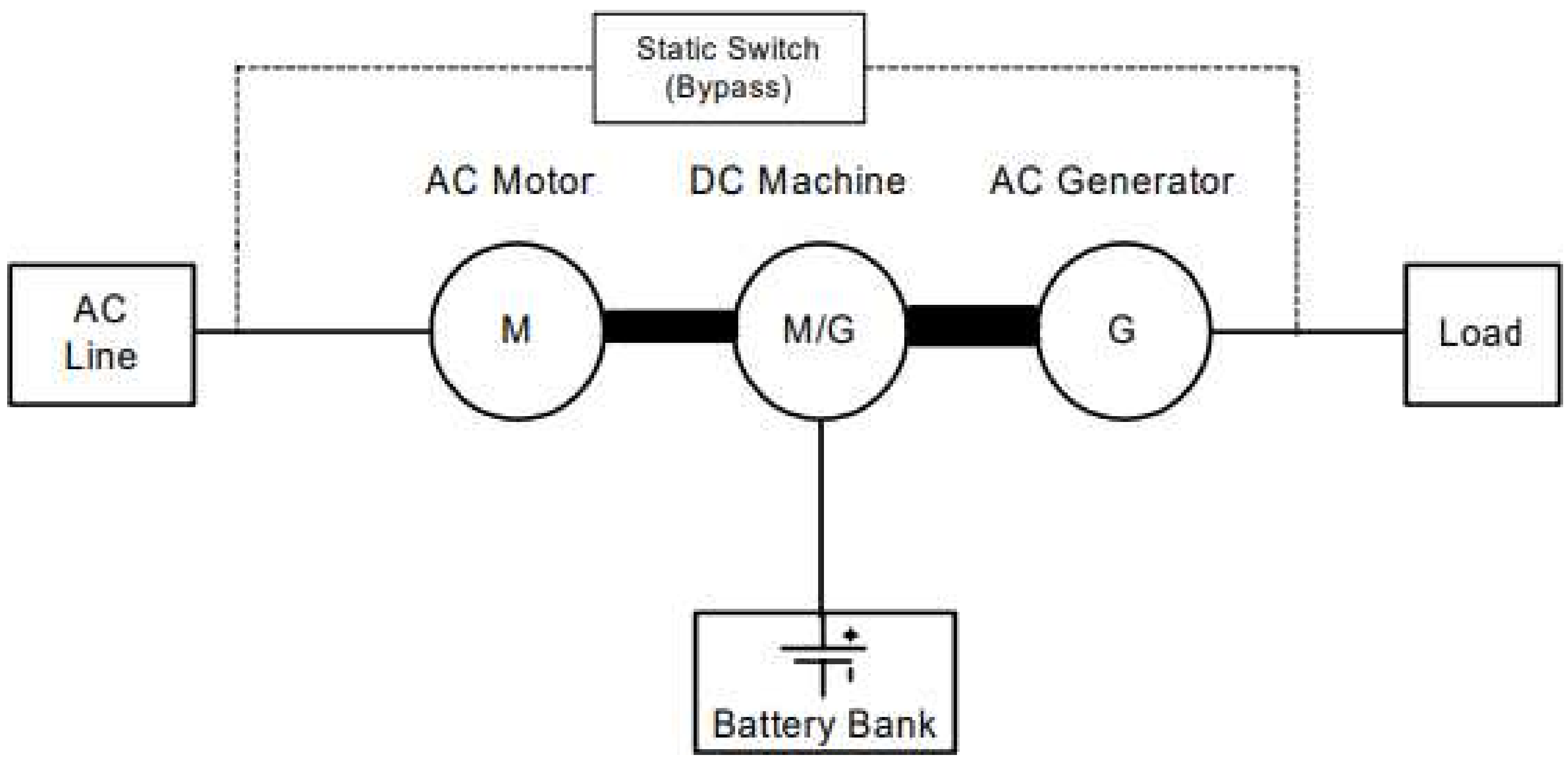

Fig. 4. Block diagram of a typical rotary UPS

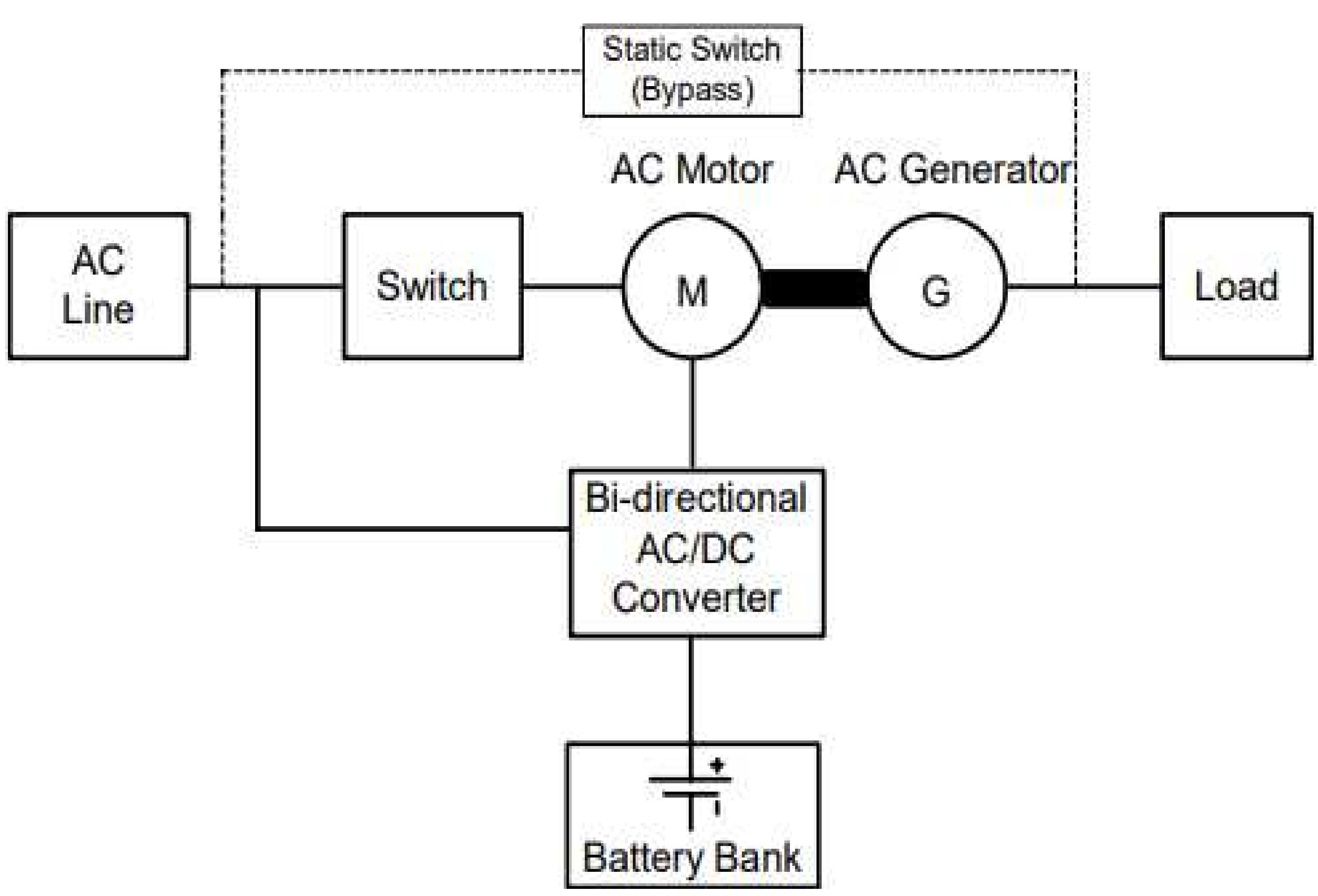

Fig. 5. Block diagram of a typical hybrid static/rotary UPS

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III. Control Techniques

Controlling technique is the most important part of the all UPS system. As the control technique changes, the parameters like THD of the output voltage, dynamic response to the transients and spikes, power factor correction, voltage and current regulation etc also changes for the UPS system. Currently there are many control methods to provide regulated output in all circumstances. The control techniques are mainly classified into two, they are single loop control and multi loop control[19].

A. *Single Loop Control*

In this control scheme, output voltage feedback loop is used to produce regulated output. The feedback signal is compared with the reference signal and the error is fed to any suitable controller which compensate the error produced and makes the output more regulated. Since it is simple to design and inexpensive it is preferred, but it's performance is poor on loading conditions [20].

B. *Multi-loop control*

This control techniques are commonly used for UPSs due to better performance compared to single loop control [21]. In most of the existing UPS systems, control scheme is based on sensing the current in the filter capacitor (L-C filter for removing higher order harmonics) and using it in an inner feedback loop and outer feedback loop incorporated to ensure that the load voltage is sinusoidal and well regulated [22]. As in Fig. 6 the plant is controlled by using two controllers Gc1 and Gc2 in outer and inner feedback loop respectively.

Generally current regulators employed as minor current loops are: sinusoidal PWM regulator, hysteresis regulators, and predictive regulators. In sinusoidal PWM, the output voltage feedback is compared with a sine referencesignal and the error voltage is compensated by a controller to produce the current reference. The current through the inductor or the capacitor (L-C filter) is sensed and compared with the reference signal. After compensated by another controller, the resultant signal is compared with a triangular waveform to generate SPWM signal for switching control. The SPWM current control has constant switching frequency and also provides fast dynamic responses [23,24].

By using multi loop control techniques, insensitivity to parameter variations, capability to produce nearly perfect sinusoidal load voltage at any load power factor with excellent load voltage regulation are obtained. Different high performance controllers have been proposed by employing multi-loop control scheme. Such as dead beat control [25], Model Predictive control [26], Iterative learning control [27] etc.

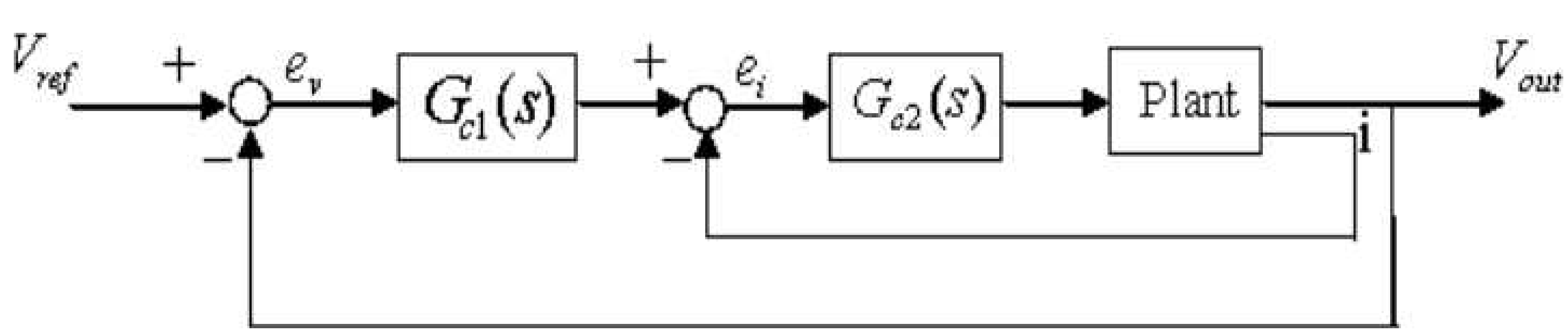

Fig. 6. Block diagram of a typical multi-loop controller

1. Predictive Control

This control technique uses system model to predict the future parameters of the controller according to the defined criteria. The concepts of this technique are easy to understand and can handle the system with many non-linearity's. The predictive control can be classified in Deadbeat control and Model Predictive control.The detail of each controller is as follows.

i. Deadbeat Control

In this control scheme, reference voltage is calculated at each sampling period using system model, and applied to follow the reference value in the next sampling instant. It offers fastest transient response, so it is one of the most used UPS control strategy [28]. But major disadvantages of this schemes are, control is very complex and is highly sensitive to parameter variations, and loading uncertainties. Unpredicted sources of disturbance, such as dead-times, dc-link voltage fluctuations etc also reduces performance of the UPS. Fig. 7. shows a deadbeat control scheme for UPS system.

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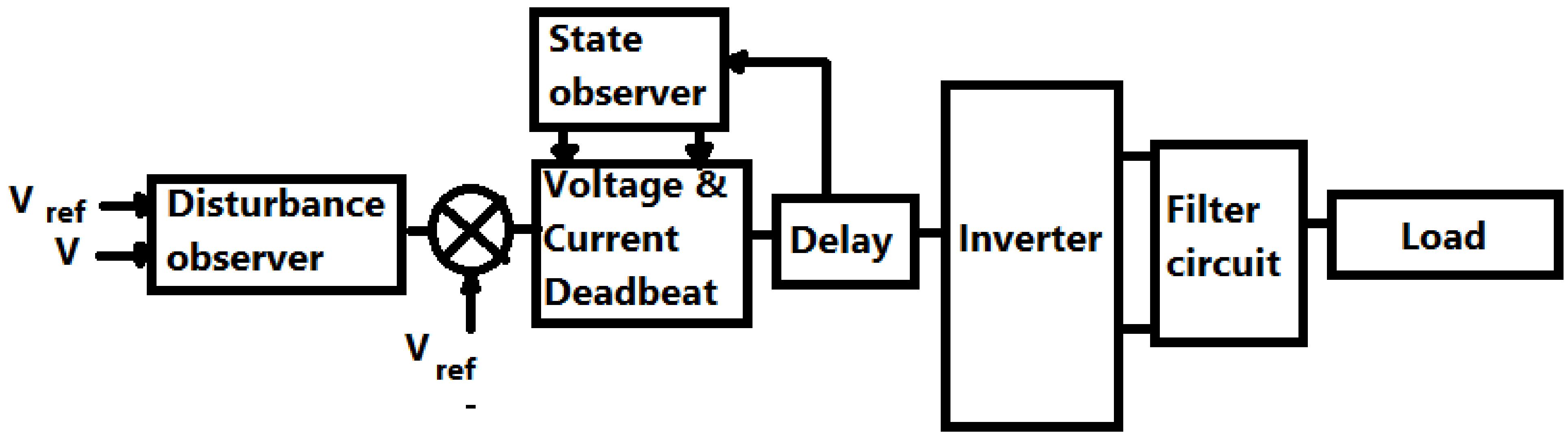

Fig. 7. Deadbeat Control for UPS system

ii. Model Predictive Control (MPC)

This method is also known as receding horizon control, which provides high performance and stability to UPS systems [29]. Major advantage of MPC is the flexibility to include system constrains as current and voltage limitation, switching states, and non-linarites. A cost function is formulated considering different variables and weighting factor and a switching state is selected to minimize the cost function and applied in the next switching state. Fig. 8. [30] Shows Model Predictive control for UPS system.

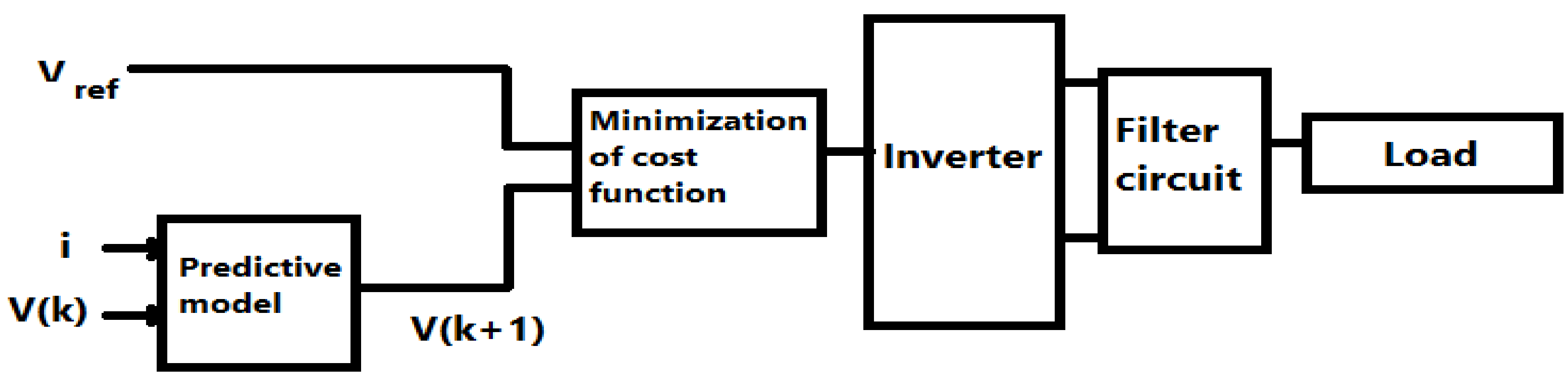

Fig. 8. Model Predictive control for UPS system

2. Proportional Resonant Controller

Proportion integration (PI) control method is widely utilized to control the grid-connected inverter, an important issue in the inverter control is the load current regulation. Proportional Integral (PI) controller, which is normally used in the current controlled Voltage Source Inverter (VSI) [31], cannot be a satisfactory controller for an AC system due to the steady-state error and the poor disturbance rejection, especially in high frequency range. Compared with conventional PI controller Proportional Resonant (PR) controller can introduce an infinite gain at the fundamental frequency of the AC source; hence it can achieve the zero steady-state error [32] without requiring the complex transformation. Due to its capability to track sinusoidal reference signal with zero steady state error this controller can be used in outer voltage loop in multi loop control scheme will produce excellent output voltage regulation in UPS inverter [33].

3. Non-linear Control Schemes

Non-linear controllers are more robust in operation [34], as compared to linear controllers, and shows good performance also. But implementation of this system is very complex. The most common non-linear control system is sliding mode control and adaptive control for the UPS inverter control.

i. Sliding Mode Control (SMC)

Sliding mode control [35, 36] has been widely implemented in the power inverters due to its improved performance against non-linear system with uncertainties. Due to its robustness, good dynamic response, stability, and easy implementation SMC gained special attention for non-linear loads. SMC has also disadvantages, mainly the chattering which is the oscillation at a frequency with certain amplitude that decreases control accuracy [37, 38]. But the chattering can be eliminated by using smoothed control law in narrow boundary layer and this control method yields only 1.7% of total harmonic distortion even in non-linear load conditions. So by selecting non-linear sliding mode control for the inner loop control of current in UPS inverter will have so many above advantages [39].

The type and selection of battery for UPS will affect its inverter performances, during the absence of supply mains, to power critical or domestic loads inverter itself uses some of the energy stored in battery to run the internal circuits and some of are lost due to cabling and connections inside the inverter. Currently there are different types and sizes of battery systems are available commercially, even though we use maintenance free sealed, deep cycle lead acid battery system by considering their cost and longevity. Now as a new technology for lead acid battery systems, valve regulated lead acid (VRLA) [40-43] batteries are introduced in market with higher performance compared to conventional lead acid battery systems. Main features of commercially available UPS are already described in Table 1 and the battery sizing of the UPS are given in Table II.

TABLE II
TYPES OF COMMERCIALLY AVAILABLE UPS AND THEIR FEATURES

Model	**Watt**	**Recommended battery**		**After 1 hour load shedding**	**With max battery 2 hour backup at regular load shedding**
700 VA	450W	2 Batt 24V	100Ah MAX	1 Ceiling fan & 2 Energy saver	3 Ceiling fan & 3 Energy saver
1000 VA	670W	2 Batt 24V	130Ah MAX	2 Ceiling fan & 4 Energy saver	4 Ceiling fan & 5 Energy saver
1400 VA	950W	2 Batt 24V	140Ah MAX	3 Ceiling fan & 5 Energy saver	5 Ceiling fan & 7 Energy saver
1500 VA	980W	2 Batt 24V	150Ah MAX	3 Ceiling fan & 6 Energy saver	5 Ceiling fan & 8 Energy saver
2200 VA	1600W	4 Batt 48V	130Ah MAX Or ++	5 Ceiling fan & 7 Energy saver	11 Ceiling fan & 12 Energy saver
3000 VA	2250W / 2700W	4 Batt 48V	150Ah MAX Or ++	8 Ceiling fan & 10 Energy saver	15 Ceiling fan & 16 Energy saver

IV. CONCLUSION

In this paper, a review of UPS systems has been presented to explain the various configurations, control strategies, and comparisons of important UPS topologies. A topological classification of the UPS system has been discussed with their performance, efficiency, advantages, and disadvantages. Comparative analysis of different systems and their control schemes have been presented to provide useful information, that would help in selection of control scheme for a multiple loop control for the UPS system as, outer voltage loop using the PR control while the inner loop uses the SMC, where the Chattering in the SMC can be removed by using smoothed control law in narrow boundary layer condition

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A Review on Control of DC Microgrid

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Abstract: The Microgrid is a small power grid consists of small group of loads, micro sources, energy storage elements, controllers and power electronic interference. Nowadays, majority of load and energy storage devices are in DC form. In modern power system DC microgrids are in maintain electric power system integrated with renewable energy source (RESs) and DC loads with the help of interfacing power electronic converters. The control and stability are the main challenges of the DC microgrid. To accomplish appropriate functionality of DC microgrids due to various operating conditions and non-steady nature of renewable micro source control strategy is must. This paper presents an overview of the control strategies used in DC microgrid, the performance of DC microgrid and power management is analysed with different control strategies.

Keywords: DC microgrid, Hierarchical Control, Energy management, Power Electronic Converter.

I. INTRODUCTION

The microgrid provides a new paradigm for the power generation and delivery. It taken as a promising building block for the future smart power system. Currently whole world looking forward towards low carbon foot prints, indirectly maximum renewable presence in any power system will be of high importance and to achieve these goals especially country like India wheremaximum solar penetration expected in next five to ten years. Though it is a huge challenge but the concept of DC microgrid look varypotential in the presence of renewable energy where the generation especially the PV which is comingin the form of DC and the most of the important loads are also DC in nature. DC Microgrid is an electrical system that can efficiently distributed, consume and potentially create and store. Direct current (DC) electricity to power a wide variety of electrical devices in and around the building when connected to a utility grid or as an island. DC microgrid comprises (i) DC power source which including PV solar, wind, fuel cell, rectifier connected to utility grid etc. (ii) DC power distribution network (iii) DC devices such that lighting, computers, electronic equipment, motor etc. (iv) control or monitoring. DC based solution can achieve higher efficiency by eliminating the extra ac/dc and dc/ac conversion stages because, many renewable DGs, energy storage system and loads directly utilize the power. DC microgrid is more advantages over an AC microgrid in terms of scalability, reliability, efficiency, controllability and cost. The power carrying capability of AC lines depends on the thermal limits and required reactive power, while the capacity of DC lines mainly depends on the therm. Due to the absence of the reactive current component, the current magnitude and cable losses are reduced when DC system used. It is easily scalable as compared to AC microgrid due to the absence of limiting equipment like transformer and relay. DC microgrid has highly efficient due to energy efficient DC appliances in house hold purpose that is BLDC motors used instead of induction motor. The number of converters required is less and heat, losses and system cost are reduced. Due to lack of skin effect in DC cables, the cable losses can be decreased by 15 to 20 percentage [1]. The control of DC voltage is easy in comparison with AC grid voltage and frequency. But the installation cost of DC micro grid is higher.One of the main challenges in DC microgrid is control and stability issue, arising due to power imbalance. The key challenges presented in a DC microgrid are, proper load current sharing and better voltage regulation simultaneously is a challenge which should be achieved with less complicated and cost effective control strategies, microgrid control should always operate the system in optimal condition, communication technique used for the control operation of DC microgrid should be cost effective, less complex and viable in remote locations as well, control strategy for batteries should also encounter the extreme phenomenon of overcharge during charging and undercharge during discharging, multiple stack of batteries should always have equal state of charge distribution among them, the control strategy should not lead to the overcharge and gasification of one battery because of unequal distribution of charges, the coordinated control functions and local control should always maintain the grid connected and islanded system in stable condition and seamlessly transfer between the two systems, an optimal grounding that minimize the DC stray current and maximize the personnel safety is a challenge, and designing of cost-effective circuit breaker is a challenge due to non-zero crossing of DC current.PV is mostly used in renewable energy source for power generation, due to the availability and power conversion cost is less compared to other resources. Battery is the popular energy storage system in the distributed network because of its simple implementation and independent nature of geography as compared to existing various type of storage technique and having high energy density and low power density. Fig.1 shows the architecture of PV system.

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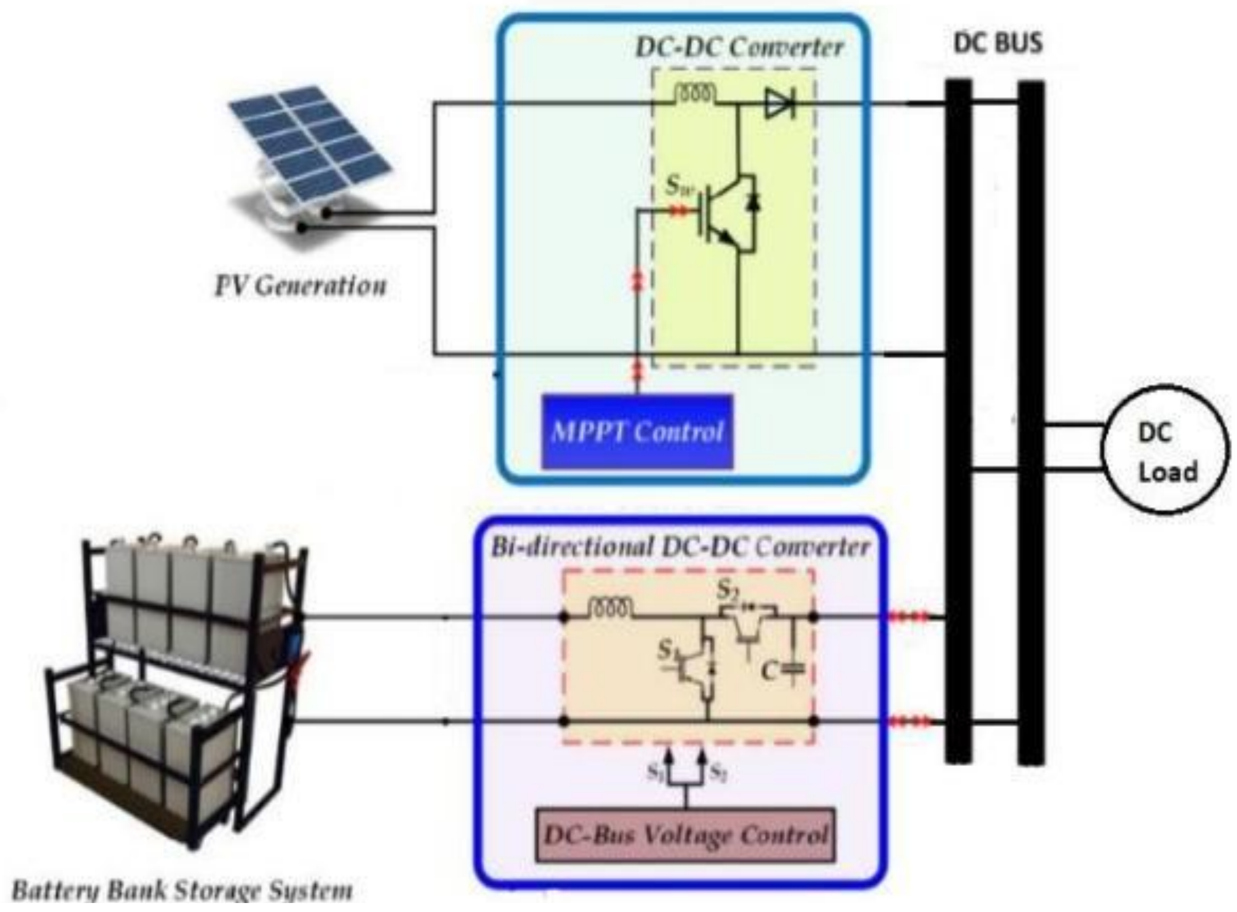

. Fig. 1 Architecture of PV system.

It consists of PV panels connected to DC link through boost converter. Controller for boost converter is designed in such a way that it will operate in the input voltage control mode, provide boosting action to the PV voltage. Battery is connected to the DC link through bidirectional converter. It operates in output voltage control mode to maintain the DC link voltage irrespective of the PV power, load variations. Constant power loads (CPL) introduce a destabilizing effect in DC microgrid that cause their main bus voltages instability. DC microgrid have typically cascaded distributed power architecture in which power electronic converters actas interfaces between system portions with different voltages. These points of load (POL) converters act as an instantaneousCPLs. It introduces destabilizing effect into the system. In [19] proposed a stabilization strategy to prevent the destabilizing effect in the system like adding filters, adding energy storage elements directly connected to the main bus or load shedding and it depends on control techniques linear and nonlinear controllers.

- Addition of filters: By reducing the oscillation in dc bus voltage, increasing the capacitance or reducing inductances of line regulating converters (LRC). The reducing inductance value is not practical. Usually, a capacitor was added in parallel to the CPL, the value of capacitance is large value, moreover increasing capacitance in a dc microgrid, which is expected to operate at a few hundred volts. Output capacitance of LRCs may improve fault detection and clearance.

- Addition of bulk energy storage devices directly connected to the system main buses:Adding bulk energy storage deviceslike battery, supper capacitors or ultra capacitors to the system buses eliminate CPL oscillation. But the bulk energy storage devices connected with dc bus by interfacing with LRCs, it makes solution ineffective. By improve the operation system, replacing bulk energy storage by local power generation. Hence, adding more energy storage through feasible may compromise some microgrid benefits.

- Load Shedding: Load shedding means reduce the constant power load, but this way only be effective at the expense of low efficiency.

- Linear controller: Linear controllers are the simplest strategy to achieve a regulated dc voltage at the microgrid main bus.There are PID controllers, that controlling LRC duty cycles to regulate the output voltage.

- Nonlinear controller: The nonlinear control loop is used to connect CPL loop with a feedback gain.

Active damping methods, that depends on reshaping the VSC impedance by injecting internal model based active damping signal at the inner, intermediate and outer loops of the VSC is proposed in [20] to stabilize the system due to destabilizing effect of CPLs.The changes in the demand, intermittent generation sources and variations in the system control parameters lead to instability of DC microgrid system. The objective of this paper to provide an overview of control and management of DC MGs. The multilevel control scheme in DC microgrid is provided in section II. Section III, IV, V presents control algorithm applied in primary, secondary and tertiary levels. The power electronics converters and its application are discussed in Section VI.Finally, conclusion is given in section VII.

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II. MULTILEVEL CONTROL SCHEME

New power electronic devices will dominate the electrical grid in the nowadays, the voltage and current regulations, power flow control, development and increasing utilization of power electronics devices can be realized in MGs by properly operating the interfacing power converter. [2],[3] proposed a multilevel control scheme, which widely accepted as standardized solution forefficient MGs management. It includes three principal level control level shown in Fig.2 Based on the same hierarchy [3] proposed a hierarchical control of Dc MGs consists of three level. Primary control level consists of resistive virtual output impedance loop, integrating the soft start approach, it improves the dynamic performance of the output voltage and control the parallel operation of the converters. The secondary level control is consisting of external common controller to restore the voltage deviation inside the DC MGs. The tertiary control regulates the current flow from or to a distribution or dc/ac converters connected in MGs. These control levels can be centralized, decentralized and distributed as shown in Fig.3. Decentralized control (Fig.3(b)) each source operates independently using terminal quantities hence reliability inherent in the structure of a MG is maintain. However, implementing a control law to operate the system in an optimal fashion is impossible, since each node is unaware of the other nodes in the system.

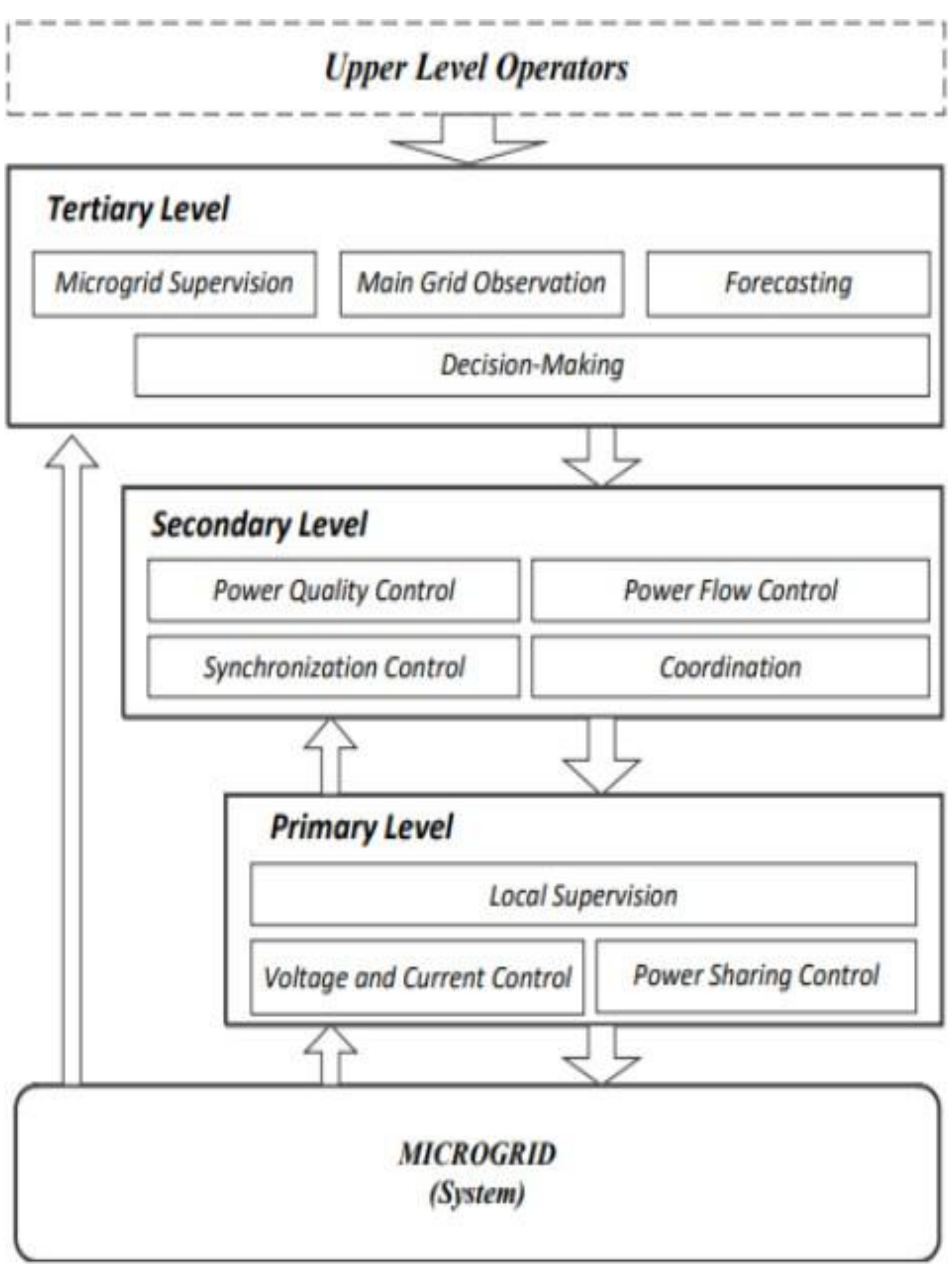

Fig 2 Hierarchical control scheme

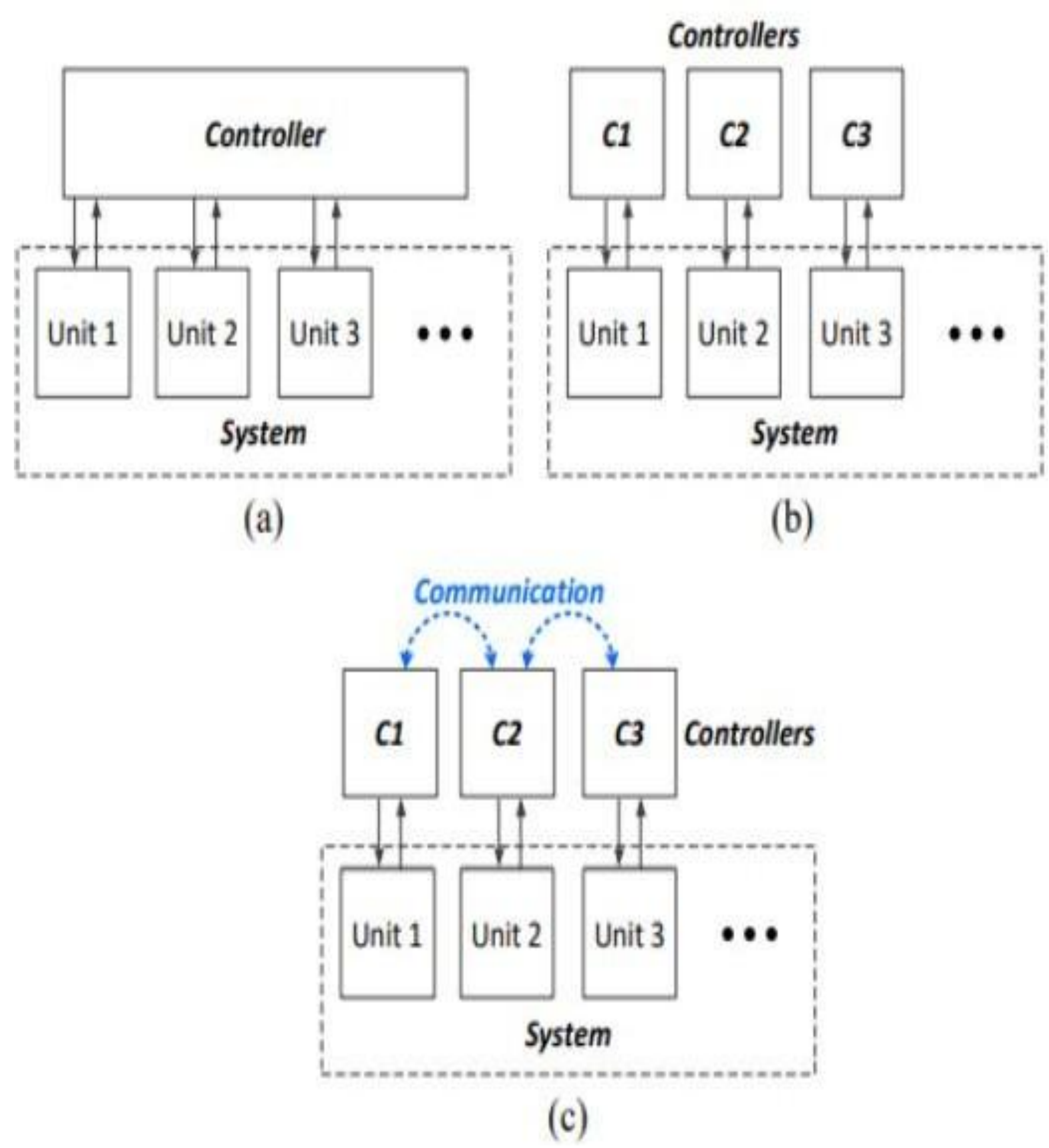

Fig 3 Basic control structure (a) Centralized (b) Decentralized (c) Distributed

In decentralized control there is no exist digital communication link and power lines are used as the only channel of communication link. The classical decentralized control including voltage/current (V/I) or voltage/power (V/P) droop control schemes. In this scheme, the deviation of the dc bus voltage is used for autonomous power sharing among different source. Decentralized control is more reliable and robust. Droop control, voltage leveling, DC bus signalling and power line signalling methods are the example of the decentralized control [4][8][9].Centralized control, shown in Fig.3(a), each source is con-trolled from a single point using a central controller and communication link. But a control law can be implemented easily as the central controller is aware of each node in the system. However, thereliability of the system is degraded as the system depends on the communication link and controller for correct operation. If the communication fails then the centralized control approach may not be work this is the main disadvantage of centralized control.Distributed control in MGs as shown in Fig.3(c), digital communication links exist they are implemented only between the units and coordinated control strategies when they are processed locally. With distributed control, the control function is distributed throughout the network, this strategy improves the reliability of the system over centralized control as the system can function even of a node fails.

III. PRIMARY CONTROL

It is the first layer in hierarchical control scheme. It is leads to local voltage and current control to meet the operation and stability requirements.

A. Active Current Sharing

Parallel power supplied include expandability of output power high reliability, design standardization and ease of maintenance. Parallel dc-dc converter requires an explicit current sharing mechanism to achieve proper load sharing of DERs, followed their current or power ratings without current sharing, a small imbalance in modules output voltage can cause the output currents different. Current sharing can be implemented using two ways, one is droop method, but it is a poor load regulation and not suitable for high performance application. Other is an active current sharing technique, it leads to peak and average current mode control schemes provided same reference for internal current loop of each module and voltage loop error signal modification. In [5] master slave control technique belongs to the active current sharing technique. In master slave control one module is considered as masterothersare slaves, the master unit operate in voltage-controlled mode, whose output current becomes the reference for current sharing loops of slaves to establish the DC bus voltage. Slaves operate in current controlled mode.

B. Droop Control

Parallel operation of dc-dc converter having advantages such as enhanced flexibility, reduced thermal and electric stress, improving reliability. The droop control to mimic the synchronous generator which drop their frequency or voltage when activeor reactive power demands increases [6]. In virtual resistance loop, stability issues may appear when virtual resistance are changed. Three level hierarchical control scheme is proposed in parallel dc-dc converter system. In primary level droop control method, which including virtual resistance control loop. Primary loop ensures sharing and stable operation. Changing the load current causes voltage deviation, to solve this problem voltage secondary control is used. The dc bus voltage is sensed and compared with desired voltage, withthe error being set to PI controller.

C. Voltage Level Signaling

It is suitable for small renewable energy system. It is nonlinear form of voltage droop that allows source to be scheduled ina prescribed fashion [7]. Discrete voltage deviations on the busprovide information about the generation mix to facilitate source scheduling. This strategy departs from the underlying aim of voltage droop to provide power sharing with minimal voltage deviations on the bus. Significant voltage deviations are permitted as the system id power electronics based and the source and load interface can be designed to operate satisfactorily within a specific voltage window. Drawback of this methods are number of sources of system restricted by the operating window of the bus voltage and the line impedance, and adding high priority sources to the system involves changing the states of all sources within a lower priority.

D.DC Bus Signaling

DC bus signaling control scheme is similar to voltage level signaling except the system voltage decreases to the next state, when the power output from all the sources in the current state and higher states is exhausted. The sources are scheduled in groupsrather than as individual sources [8]. DBS allows more needs to be included in a system than voltage level signaling as multiple sources can operate at each state. Source can easily be added to the system by assigning the new sources to operate at existing thresholds. DBS depends only local information and does not requires any other components other than interface converters, hence it is easy to implement decentralized control method. By using DBS, the system is reliable because of dc bus itself is used as communication link.A noval distributed control strategy based on DC bus signaling is proposed [8] for the modular PV generation system, to maintain the power balance and stable operation of the system under any condition. Operation of modular PV generation system is categorized into four modes,

- Mode1: Islanding mode, dc bus voltage is regulated by battery discharging. The modular dc/dc converters for PV arraywork with maximum power point tracking.
- Mode2: The system operates with connection to ac grid through bidirectional dc/ac converters. The dc bus voltage is regulated by the dc/ac converter through rectification. Modular dc/dc converter for PV arrays work with MPPT. This mode is also known as grid-connected mode with rectification.

- Mode3: The system operates with connection to ac grid through bidirectional dc/ac converters. The bus voltage is regulated by the dc/ac converters through inversion. If the battery is fully charged, the dc/dc converter for the battery does not work, otherwise the dc/dc converter is used to charge the battery.

- Mode4: Islanding mode with dc bus voltage regulation by PV. DC bus voltage is regulated by modular dc/dc converter. Since the maximum power of the PV array is greater than local load demand. One of the modular convertersis operating with constant voltage (CV) control.

IV. Secondary Control

The concept of secondary control in DC microgrid includes voltage regulation, current sharing and energy storage management.

A. Voltage Regulation

The global voltage regulation and proportional load sharing are the two objectives of the secondary control. In DC microgrid,secondary control has been utilized for voltage regulation, current sharing and energy storage management. The secondary control measures voltage across the microgrid and accordingly updates the voltage set points for the primary controllers. In this paper proposed a cooperative secondary controller, when adjust the local voltage set point Vi. The starting point is the conventional droop mechanism, that is output impedance of converter using virtual impedance ri. The droop controller at primary control level acts on local information. The droop mechanism promptly initiates the voltage adjustment when operating condition vary. Cooperation among converters, the secondary control level can help properly fine tune the voltage set point Vi. The voltage set point for the droop control is augmented with two correction terms, these corrections are provided through cooperative among the converters. A new reference voltage may be set by the tertiary control in order to exchange power between grid and microgrid in the grid connected mode [10]. Also introduce a voltage observer to estimation and adjust the local voltage set point and provide global voltage regulation and proportional load sharing.

B. Current Sharing

Proper current sharing is highly desirable features in microgrids operation to prevent circulating current and overloading ofthe converter. In order to solve the problem secondary control [11][12] has been proposed to enhance current sharing accuracy. In [12], secondary control method with enhanced dynamic performance under fast charging load current condition is proposed. It includes local average voltage controller, local average current controller and average droop coefficient con-troller. The current and average droop controller are employed to work together and regulate the droop coefficients, larger droop coefficient can be used to enhance the current sharing accuracy. When the line impedance is highly mismatched and current sharing accuracy will bedegraded. The current sharing module can update the virtual impedance ri. To manage the current sharing. In this approach the droop correction terms generated by the secondary controller, adjusts the droop mechanism.In this paper proposed a distributed secondary control scheme by using voltage shifting and slope adjusting methods simultaneously. Voltage shift method is used to eliminate the voltage deviation induced by droop control andslop adjusting method is utilized to adapt the droop coefficient of each converter and achieve equal equivalent output impedance of each interface converter, hence fast current sharing can achieve.

C. Energy Storage Management

The key component of microgrid is the energy storage system. It smoothening the intermittent behaviour of renewable energy resources. An energy storage management system provides charge or discharge monitoring and state of charge (SoC) equalization. In [13] proposed a secondary distributed control that achieve charge or discharge monitoring, SoC balancing simultaneously. It through employment of DC bus signaling power management and a secondary control layer for SoC balancing. When SoC imbalance is present, produce an output current imbalance to force charge equalization and the current difference is depends on the level of SoC disparity. In [14] describe hierarchical control of hybrid energy storage system (HESS), composed of both centralized and distributed control. The conventional HESS centralized control is refined with implementations of online iteration, secondary voltage regulation, autonomous state of charge recovery. Secondary voltage regulation applied to minimize bus voltage deviation and autonomous SoC recovery are applied to limit slack terminal SoC variation. In this paper, when communication is failure, a noval algorithm for HESS distributed control is proposed to retain system stability, reliability an operation. In hierarchical control scheme bus voltage is regarded as the global indicator for system power balance and droop imposed for energystorage control. Combined energy storage using battery and supper capacitor with high energy and power density is proposed in [17].

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V. Tertiary Control

Function of tertiary control is to manage the power and energy, with specified objectives like balanced energy storage, minimized operation cost and reduced power flow management. Energy scheduling is issued for longer time range operation providing optimal setting points for controllable units including distributed generations, load and energy storage sources [15]. Power management is developed to guarantee a continuous operation by properly coordinating the generation and storage, when energy scheduling is not necessary. In DC microgrid, [10] introduce a virtual impedance or droop control, in order to improve the calculation accuracy. Power flow analysis is considered a necessary step for the design and planning of an microgrid system in order to facilitate power flow control and protection purposes. Some autonomous power management strategies are proposed based on the energy balance between energy storage system [14].

VI. Power electronic Converters and Applications

Power converters and its application-In DC micro grid power exchanges is the power electronics converters (PEC) instead of synchronous machines in ac grid. In comparison to synchronous machine, power electronic converters have much fasterresponse due to additional control capability. Modelling and control of the PEC is a key aspect for assessment of the dynamic behaviourof multi terminal DC grid. It is major role of speed response in transient. In practical case output voltage of renewable energyresources and hybrid energy storage system are very less and are not sufficient to the DC load in DC MG to solve this issue various DC/DC converters with high gain is used like buck, boost, buck–boost converters [16]. Power converters topologies for PV, dual stage inverters, DC/DC converters is controlled by means of MPPT based control techniques in order to obtain maximum available power from PV panel while the DC/AC converter controls the grid injected current. The single stage inverter topologies do not need DC/DC converter. Energy storage system play a vital role in the MGs in order to maintain stability and robustness as well as to improve the power quality of MGs. The bidirectional dc/dc converters have been used to connect ESS to the MG in small scale system. If an ESS is connected to large scale microgrid, the cascade H-bridge (CHB) power converter is used because. It allows the connection of a huge amount of energy directly to the MGs. The modular multilevel converter (MMC)[8] which is very well suited for very high DC voltage operation connecting a huge amount of battery in series. Applicationof power converters in power systems are, Active filtering-the main function of power electronics based active filter is to synthesize and inject (absorb) specific current or voltage components, to enhance power quality in the host power system. Compensation –A function of power electronics (static) compensator in either transmission or distribution line are increase the power transfer capability of the line, maximize the efficiency of the power transfer, enhance voltage and angle stability and improve power quality. Power Conditioning –The power conditioner enables power exchange between two electrical (or electrochemical) subsystems in a controlled manner. The power conditioner also often has to ensure that specific requirements of subsystem, for example, the frequency, voltage magnitude, power factor and velocity of the rotating machines are met.

VII. Conclusion

This paper provides an overview of control of DC microgrid and relative issues. According to the review, the Dc microgrid proves to be more advantages over AC microgrid. Such as pollution, cost, performance index. Assorted control scheme isused in power electronic converters to maintain the bus voltage is constant when DC microgrid owing to the difference in supplyand load consumption, change in storage system elements and variation in control parameters. Based on the microgrid concept and its control strategy, the energy system is expected in future to be a combination of many renewable energy source microgrid formulating afully reliable and flexible grid. Additional regulation and control are also necessary in operational levels, which are regulate, control, management and stabilize the microgrid clusters.

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