International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 05 | May 2021 www.irjet.net p-ISSN: 2395-0072

Dual Input LLC converter for Home Appliances

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Abstract - *This paper proposes a dc-dc dual input LLC converter which can be controlled using a MPPT technique. The dual input LLC converter has PV array and an energy source connected to it. This topology has two half-bridges connected in series. This converter has four switches and the two sources have a single resonant tank. The converter operates in four modes; PV to load, battery to load, PV and battery to load and PV to battery and load. The control of this converter is implemented using maximum power point tracking (MPPT). The duty ratio, switching frequency and phase shift are controlled using MPPT algorithm. The converter is simulated using MATLAB SIMULINK.*

***Key Words*: DC-DC converter, Dual-Input LLC converter, soft switching, MPPT algorithm, I&C algorithm, Phase shift control.**

1.INTRODUCTION

The utilization of fossil fuels has increased in the last decade, which has led to the environmental contamination and increased cost of the system. Due to these reasons the demand for renewable energy sources has increased. Solar energy, wind energy, tidal energy, biomass energy are some of the renewable energy resources. Among these, solar energy is widely used due to its availability. Solar energy can be converted into electricity using solar panels which are made up of silicon photovoltaic (PV) cells. The conventional DC-DC converters are used in photovoltaic generating systems as an interface between the PV panel and the load.

The conventional converters have problem in the tracking under various combinations of load, radiations and temperature. They have high reactive components. To overcome these drawbacks, resonant converters are used [1-2]. The turn-on and turn-off transitions of the semiconductor devices occurs at zero crossing of tank voltage or tank current. This is the soft switching technique.

The dual input LLC converter is suitable for home appliances which uses a dc voltage of 400V. The applications include fluorescent lamps (400V), induction heating cooktop (380V), computers (230V), air conditioners (308V), DC fans (200V), water heaters (380V), LED lights (240V) and many more.

1.1 Literature Review

In [1] three types of isolated bidirectional DC-DC converters are used as backup for PV system as battery charge control. Isolated bi-directional cúk converter, isolated bidirectional full-bridge and isolated bidirectional half-bridge converter are the three converters used. In [2] active Bridges based BD Converters is designed for solar PV panel. This bridge is more convenient for transferring the regulated power flow in both directions of the system. In [3] three level, three port, bidirectional converter is proposed. This converter reduced the voltage stress across the switching devices and are suitable for medium and high voltage applications. [4] proposes the current and voltage control loops of a ZVS-PWM three-phase current-fed push-pull DC-DC converter. The converter is able to reverse power and maintain voltage at the desired level. [5] proposes decoupled control design for an isolated three-port DC-DC converter. It uses an input voltage control (IVC) and an output voltage control (OVC) have been designed to regulate the voltage of the PV panel and the output voltage of the converter. [6] presents a control method for series half-bridge LLC converter. The control is achieved by DC-link capacitor voltage balance. By adjusting the neutral point current, the neutral point voltage is controlled. In [7] a half-bridge LLC converter is designed for PV applications. It uses zero voltage switching (ZVS) and zero current switching (ZCS) techniques. It is applied to boost the PV array terminal voltage. PV system efficiency varies with the variation of irradiation. To improve the PV system efficiency maximum power point tracking (MPPT) is used. [8] compares the performance of the PV system with perturb and observe (P&O) and incremental conductance method (I&C). Incremental conductance method is more accurate with increased tracking step and decreased starting complexity.

2. Block Diagram of the Converter

Fig.1 shows the block diagram of dual input LLC converter. For this converter two half bridges are connected in series and the two sources share the same resonant tank. PV panel and the battery source are connected to the resonant tank and the output is given to the rectifier. The output from the converter is given to the load.

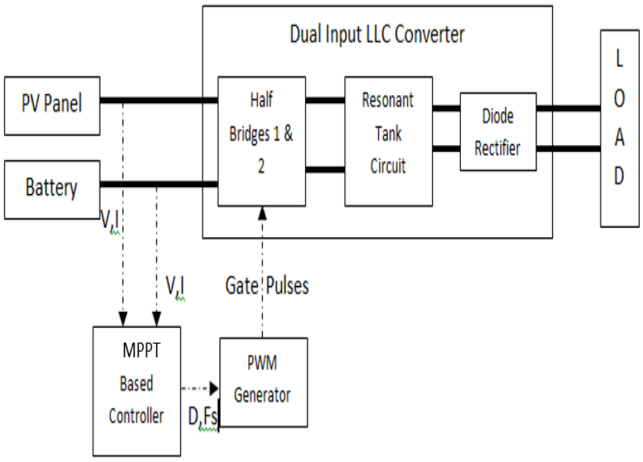

Fig.1. Block diagram of dual-input LLC converter

The converter control is obtained by using the maximum power tracking (MPPT) technique. From the block diagram we can see that the PV voltage, current, battery voltage and current are given to the MPPT based controller. The controller uses these inputs to generate duty ratio and switching frequency control for the converter. These outputs control the PWM generator which will control the switches to maintain a constant output voltage.

MPPT algorithm is used to achieve maximum power output from the converter and the incremental conductance (I&C) algorithm is employed for the converter control. Fig.2 shows the flow chart of the I&C algorithm. I&C compares the incremental conductance to the instantaneous conductance in a PV system.

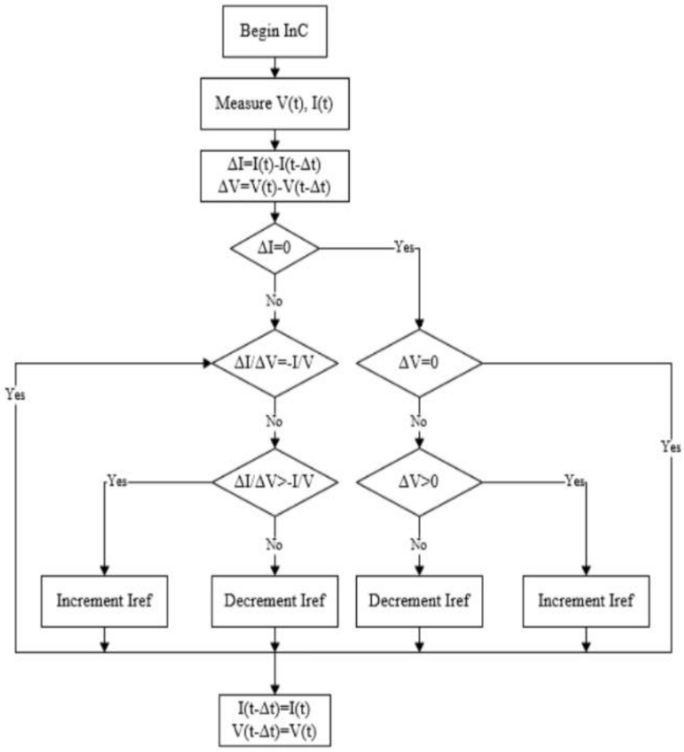

Fig.2 Control algorithm for the converter

2.1 OPERATION OF DUAL INPUT LLC CONVERTER

Circuit diagram of dual input LLC converter is given in Fig.3. The circuit consists of 4 mosfet switches, a resonant tank, PV and battery connected to it. Switches S_1 and S_2 are connected to PV, switches S_3 and S_4 are connected to battery. Two half-bridges are connected in series at the primary side of the transformer. The converter operates in four modes.

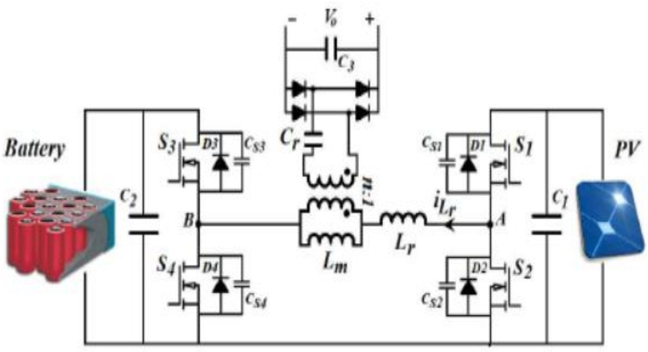

Fig.3 Circuit diagram of dual-input LLC converter

- **MODE 1** – PV to load
  In this mode switches S_1 and S_4 are ON. PV source is connected to the resonant tank and charges the resonant tank. The battery source is disconnected in this mode. The converter operates in half-bridge mode. PV provides voltage to the load. Fig.4 represents this mode.

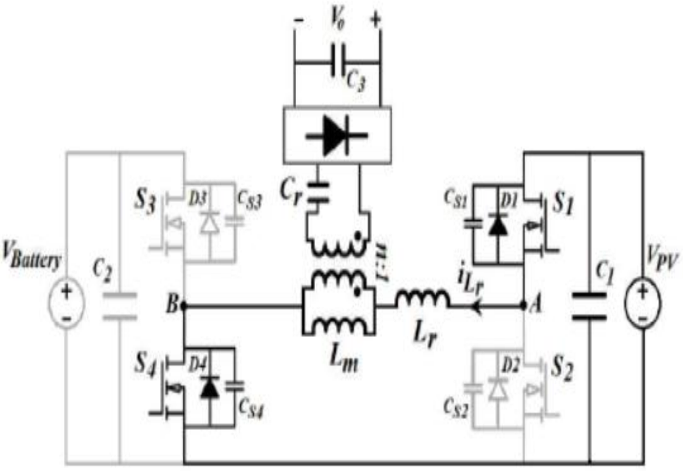

Fig.4 Mode 1 of operation of dual-input LLC converter

- **MODE 2** – Battery to load

In this mode switches S_2 and S_3 are ON. Battery source is connected to the resonant tank and charges the resonant tank. Here PV source is not connected to the resonant tank. The converter operates in half-bridge LLC mode. Fig.5 shows the circuit for mode 2 operation. Battery provides voltage to the load.

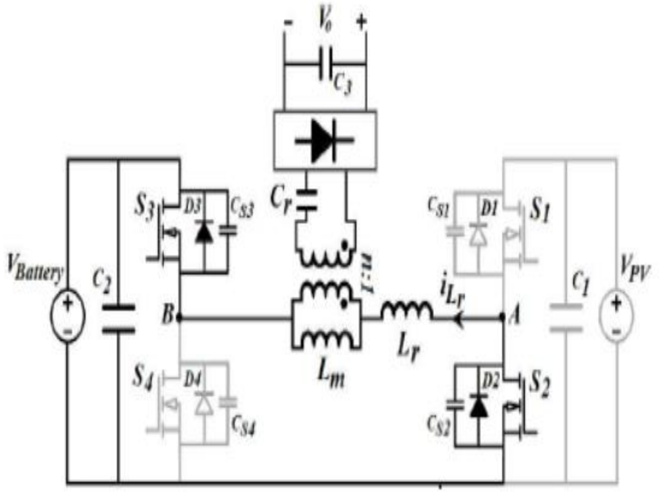

Fig.5 Mode 2 of operation of dual-input LLC converter

- **MODE 3** – PV and battery to load

Fig.6 shows mode 3 of operation. In this mode switches S_2 and S_4 are ON. In this mode the voltage applied to the resonant tank is zero. The duty ratio is controlled using incremental conductance (I&C) method of MPPT to have an average inductor current of zero amperes in this mode.

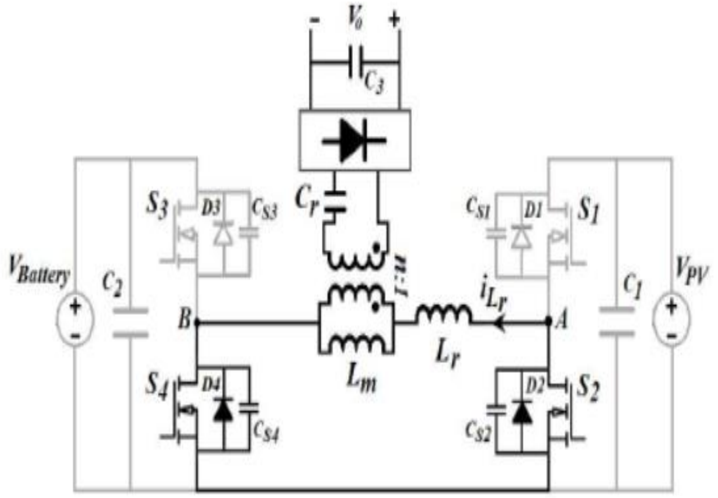

Fig.6 Mode 3 of operation of dual-input LLC converter

- **MODE 4** – PV to battery and load

Fig.7 shows the mode 4 operation of the converter. In this mode switches S_1 and S_3 are ON. The resonant tank is provided the voltage difference between the PV and battery.

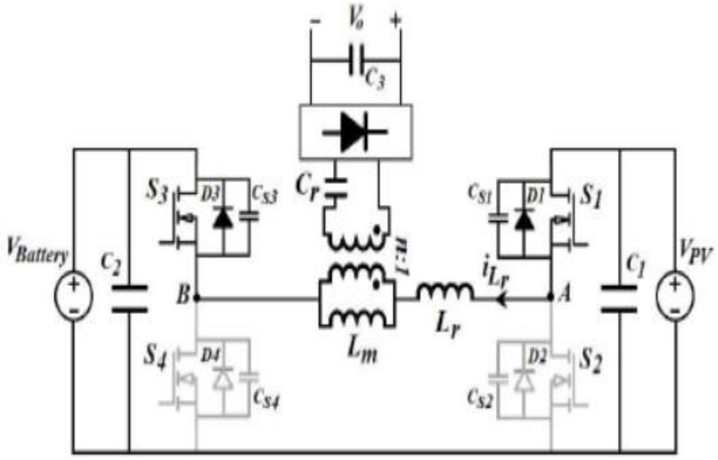

Fig.7 Mode 4 of operation of dual-input LLC converter

3. Simulations and Results

To validate the effectiveness of the converter, the dual input LLC converter is simulated using MATLAB SIMULINK. Table.1 shows the components values considered for MATLAB simulation of the circuit.

Table.1 Parameters of the dual input LLC converter considered for MATLAB simulation

Parameters	Values
PV voltage (V_{PV})	48V
Battery voltage (V_{batt})	60V

Output voltage (V_o)	400V DC
Output power (P_o)	500W
Switching frequency (f_s)	80kHz
Resonant frequency (f_r)	80kHz
Transformer turns ratio	1:8
Magnetizing inductor (L_m)	1.12mH

Fig.7 shows the battery voltage, current and battery SOC during the 4 modes of operation. During mode 1, the battery is disconnected from the resonant tank and hence the SOC remains constant. In mode 2 the battery energy is discharged and hence the SOC decreases. The SOC remains constant in mode 3 because it is disconnected. During mode 4 the battery is charged from the PV source and hence the SOC increases.

- **Mode 1**

Fig.8 shows the mode 1 output. In this mode only PV source is connected and battery source is disconnected. Switch S_3 is always ON. Switches S_1 and S_2 operate in complementary PWM mode with 50% duty ratio. A 65kHz of switching frequency is achieved. The first and second waveform corresponds to the voltage across switches S_1 and S_2 respectively. The voltage across the transformer primary and resonant current I_{lr} is represented in the next two waveforms. Here the resonant current is less than the inductor current and hence i_s is negative.

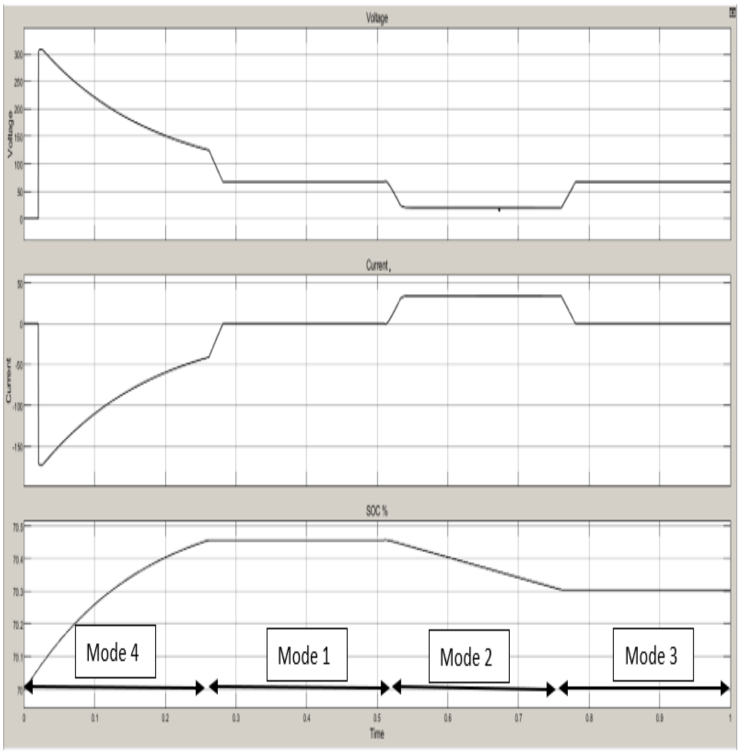

Fig.7 Battery voltage, current and SOC of the converter in different modes

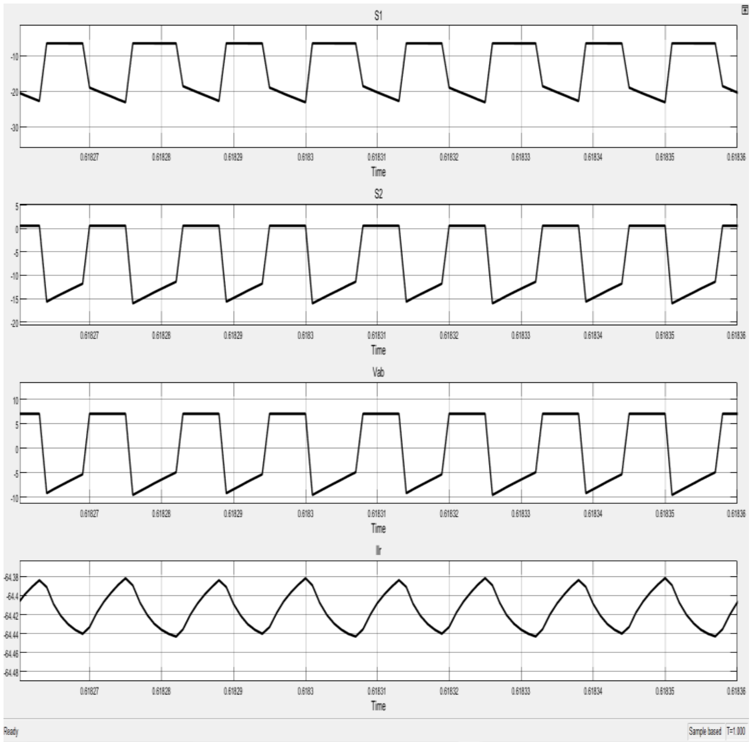

Fig.8 Operating waveforms for mode 1

- **Mode 2**

In this mode only battery source is connected and PV source is disconnected. Switch S_1 is always ON. Switches S_3

and S_4 operate in complementary PWM mode with 50% duty ratio. The switching frequency is seen to be 80kHz. Fig.9 shows the mode 2 output. The first and second waveform corresponds to the voltage across switches S_3 and S_4 respectively. The voltage across the transformer primary and resonant current I_{lr} is represented in the next two waveforms respectively. The MPPT control of the converter handles the switching frequency.

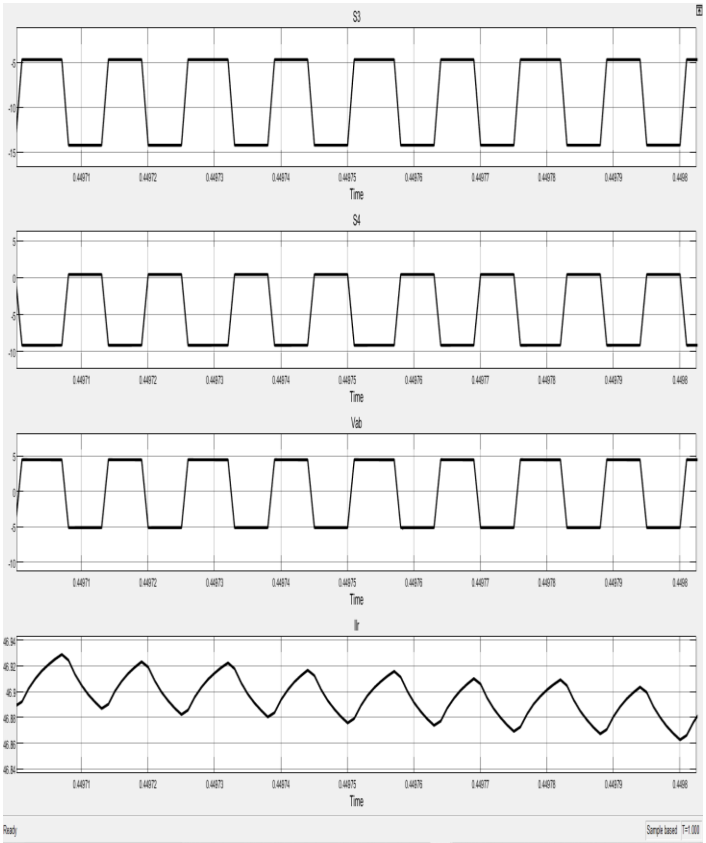

Fig.9 Operating waveforms for mode 2

- **Mode 3**

In this mode both PV source and battery source are connected. Fig.10 shows the mode 3 output. The first and second waveform corresponds to the voltage across switches S_1 and S_4 respectively. I&C based MPPT control block modulates the switching frequency and phase switch. In the control block, PI controller adjusts the duty cycle to have an average inductor current of zero ampere. Switching frequency is regulated to 169kHz. The voltage across the transformer primary and resonant current I_{lr} is represented in the next two waveforms respectively. The MPPT control of the converter handles the switching frequency.

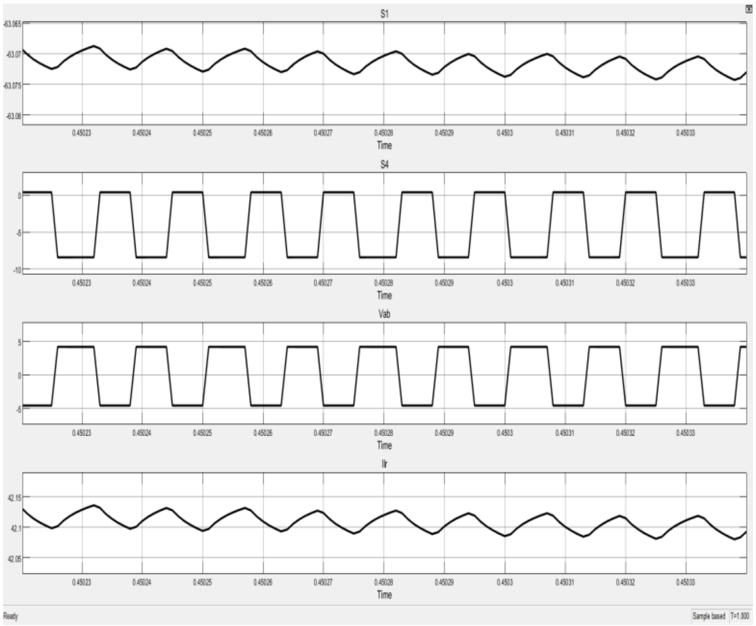

Fig.10 Operating waveforms for mode 3

- **Mode 4**

In this mode PV source provides to both battery and load. The switch S_1 is ON always and the switches S_3 and S_4 will be operating in complimentary PWM mode. The duty cycle here is given by the control block and the PI controller controls the inductor current. I&C based MPPT determines the switching frequency using the PI controller and also controls the duty ratio. Switching frequency of 125kHz is maintained to charge the battery. Fig.11 shows the operating waveforms for mode 4. First two waveform represents the battery voltage and current respectively in this mode. The third waveform is of voltage across the switch S_4. The last waveform represents the resonant current in this mode.

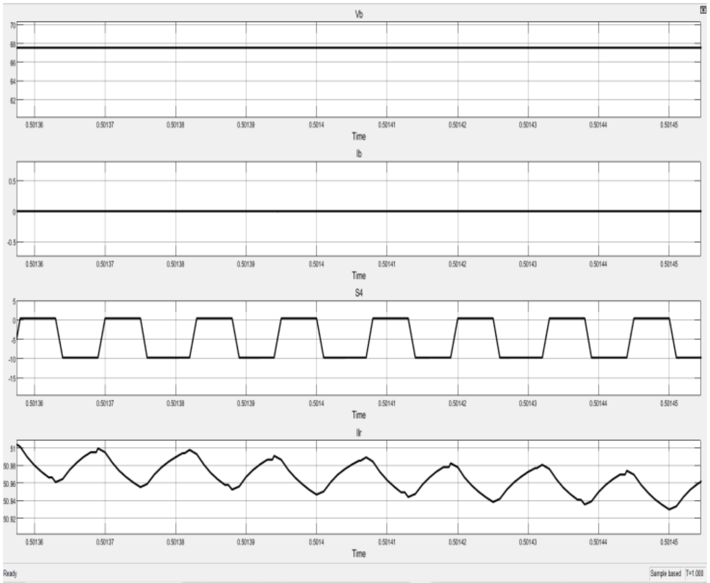

Fig.11 Operating waveforms for mode 4

Fig.12 shows the output DC voltage waveform. The output of the dual input LLC converter is a constant dc voltage of 400V.

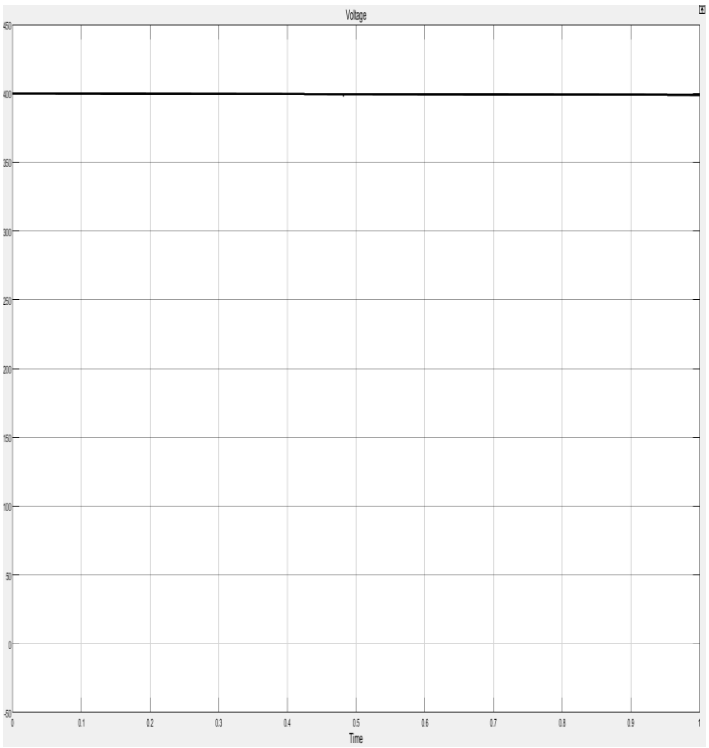

Fig.12 Output voltage of the converter

4. CONCLUSIONS

A dual input LLC converter is proposed. The converter has four switches with a single resonant tank. Two sources; PV and battery are used as two inputs to the converter. The converter is controlled using I&C algorithm of MPPT technique. The duty ratio and frequency are the control variables that are used for converter control. The converter is designed and simulated using MATLAB SIMULINK. The converter operates in four modes. The switching frequency of the converter in mode 1, 2, 3 and 4 is 65kHz, 78kHz,169kHz and 125kHz respectively. The converter gave an output voltage of 400V DC. The dual input LLC converter can be used in applications involving home appliances. The converter can be used to power LED lights, fluorescent lights, ACs, TVs, water heaters etc. The simulation results validate the performance of the converter.

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