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Design and Develop for PV Powered Bidirectional Charger for Electric Vehicle

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ABSTRACT: This paper presents the development of a 10kW EV charger that can be powered from both a PV array and the three-phase AC grid. The goal is to realize a high power density and high-efficiency three-port power converter that integrates the EV, PV, grid and meets the Chademo and CCS/Combo EV charging standards. The EV port is designed to be isolated and bidirectional, so that both charging and vehicle-to-Grid (V2G) can be implemented. As PV and EV are both DC by nature, the converter uses a central DC-link to exchange power between the EV and PV, thereby increasing efficiency. The use of silicon carbide devices and powdered alloy core inductors enables high switching frequency and power density. The closed-loop control allows four different power flows: PV to EV, EV to grid, grid to EV and PV to grid.

INTRODUCTION

The charging of EVs from photovoltaic (PV) panels is a sustainable proposition for the future [2]–[5].

At the same time, PV generation is characterized by both diurnal and seasonal variations. This necessitates a grid connection to ensure reliable power supply for charging the EVs. Workplaces like office buildings, factories and industrial area are ideal places to facilitate solar EV charging where the building rooftops and car parks can be installed with photovoltaic (PV) panels. There are several advantages to charging EVs from PV:

- Long parking time of EVs at workplaces results in low charging power requirements and enables implementing Vehicle-to-Grid (V2G) technology, where the EVs acts as a controllable generator [7], [8].

A 10-kW, non-isolated, bidirectional converter to charge EV from PV is presented in [23]. A 575V DC-bus is used to integrate EV, PV and grid and the closed-loop control are designed to reduce PV intermittency. A symmetrically isolated 5kW Z-source converter was used for EV charging from PV in [24]. The performance was compared with transformer-less and high-frequency transformer-isolated topologies indicating the overall superiority of the Z-source converter.

II. EV-PV POWER CONVERTER

A. Specifications

Table I shows the specifications of the three-phase, grid-connected EV-PV power converter. The voltage range, isolation and ripple requirements are compatible with the EV charging standards [11], [13]. A 10kW_p PV array connected to the PV port is the primary power source. The internal DC-link voltage is rated at 750V. As the maximum EV current, I_{ev} is 30A, power curtailment occurs at low EV voltages, as shown in Fig. 2.

B. Topology

Fig. 3 shows the topology of the three sub-converters in the EV-PV charger: an interleaved boost converter (IBC) for the PV, an interleaved bidirectional flyback converter (IBFC) for the EV and a three-phase voltage source inverter for the AC grid. The neutral of the AC grid is connected to the mid-point of the DC-link. The flyback converter is operated in a quasi-resonant mode to achieve soft switching, while the PV and grid converter are operated with hard switching

C. Achieving high efficiency and high power density

The EV-PV power converter has four different power flows: PV to EV, PV to Grid, Grid to EV and EV to Grid. It is hence essential to ensure high efficiency for the four power flows. In particular, high partial-load efficiency is vital as smart charging is done by controlling the charging power below the rated power. Secondly, it is crucial that the

converter has a high power density and occupies less space when installed at the parking lot. In order to achieve the Two objectives, three techniques are implemented: interleaving, use of silicon carbide devices and powdered alloy core inductors.

Interleaving is used in the both PV and EV DC/DC converters, with the use of three and four interleaved stages, respectively. Interleaving has four advantages:

1. Current through the switches and inductors in each leg is reduced by a factor of $(1/N_i)$ where N_i is the number of interleaved stages. Thus smaller inductors and lower-rated switches can be used.
2. The volume L_{vol} of an inductor is directly proportional to the energy it processes as given by $L_{vol} \propto LI^2$. By interleaving, the total volume $L_{vol}(n)$ of all the interleaving inductors reduces by a factor N_i .
3. Effective frequency as seen at the input is increased by a factor of N_i . This facilitates the operation of each leg at a lower frequency, thus lowering the switching losses.
4. As the currents in each leg are phase shifted by an angle of $3600/N$, the input current ripple is reduced by a factor of $(1/N_i)$ and the voltage ripple $(1/N_i)^2$.

To achieve high power density, it is crucial to increase the switching frequency while still maintaining high efficiency. Silicon carbide (SiC) represents a revolution in power semiconductor technology, which can help realize high switching frequency [30], [31].

III. DC/DC CONVERTER FOR PV

The DC/DC PV converter is built using an interleaved boost converter with three interleaved stages as shown in Fig. 3 [31], [35]. The detailed design of the converter and its comparison to an IGBT and ferrite based design are shown in [31]. SiC Schottky diodes (CREE C4D15120A), SiC MOSFETs (CREE C2M0080120D) and KoolM μ 40 μ powdered alloy inductors are used in each leg. Each leg operates at a switching frequency, f_{sw} of 47kHz.

A. Operation of the interleaved boost converter

Operating waveforms of the IBC are shown in Fig. 4. The input PV current is shared equally between the three legs, and the average inductor current is given by $I_L(ave) = I_{PV}/3$. When the switch is ON from 0 to (DT) , the current in the inductor rises from $I_L(min)$ to $I_L(max)$ due to the positive PV voltage. When the switch is OFF, the inductor current decreases and flows through the diode. The voltage ratio of input and output voltage is the same as a normal boost converter for continuous conduction mode (CCM) and discontinuous conduction mode (DCM): $V_{dc}/V_{PV} = d/1-D$ where D is the duty cycle of the switches and d is the period when current flows through the diode. In CCM, $d = 1-D$. The inductor ripple is vital in designing the PV converter as it directly translates to the input capacitor sizing, inductor size and the efficiency of the MPPT operation. The peak-to-peak inductor ripple ΔI_L is: $\Delta I_L = V_{PV} D f_{sw} L = (V_{dc} - V_{PV}) d f_{sw} L = I_L(max) - I_L(min)$ (3) where $I_L(max)$, $I_L(min)$, are the maximum and minimum inductor current and L is the inductance, respectively. It can be seen from (3) that we either need to use a high switching frequency or a large inductor in order to have a low ripple. Both these methods have the drawback of increased switching losses, increased inductor losses and require a larger inductor core and heat sink. The benefit of interleaving is that the maximum input current ripple ΔI_{in} is $(1/N_i)$ of the maximum inductor ripple, $\Delta I_{in}(D) = V_{PV} f_{sw} L (Non - N_i D - 1) / N_i (N_i D - Non + 1)$ (4) where Non is the maximum number of switches that are simultaneously ON for the given duty cycle. Fig. 5 shows the input ripple as a function of duty cycle for different numbers of interleaved stages. The peak input ripple occurs at $D = (1/2N_i)$, and the input ripple is zero when $D = (1/N_i)$.

The main advantage of the much lower core losses and saturation flux density of KoolM μ is that only a single core set is required per inductor. Using other powdered alloy core inductors will lead to much higher core losses while using ferrites will require two parallel E65 core sets. Secondly, the powder cores exhibit a gradual reduction in inductance under a fault condition, which makes the control of the converter easier and robust. Thirdly, powder cores have a distributed air gap which causes very low copper losses because of the fringing flux.

IV. ISOLATED BIDIRECTIONAL DC/DC CONVERTER FOR EV

The bidirectional, isolated DC/DC converter for the EV is composed of four interleaved flyback converters (Fig. 3). MOSFETs and anti-parallel diodes are used on both sides of the transformer for bidirectional operation. Each 2.5kW

flyback module has a three-winding transformer (1:1:1 turns ratio) with two series-connected windings on the DC-link side (primary) and a third winding on the EV battery side (secondary), as shown in Fig.

The secondary side voltage ranges between 50-500V while the primary voltage is $V_m = 750V$. This difference in primary and secondary voltages leads to high secondary side currents (up to 30A). Therefore, two MOSFETs are connected in parallel at the secondary side to reduce the conduction losses. The flyback uses C4D15120A diodes and C2M0080120D MOSFETs with 20Ω turn-on and 10Ω turn-off gate resistance.

The main reason for picking the flyback for the EV converter is two-fold. Firstly, the topology provides isolation as required by EV the charging standards. Secondly, the flyback as implemented here can realize bidirectional operation with just four switches (two on the DC-link side and two in parallel on EV side). With other topologies, like a dual active bridge or a resonant converter, we would need 8 switches (or more in parallel for higher current

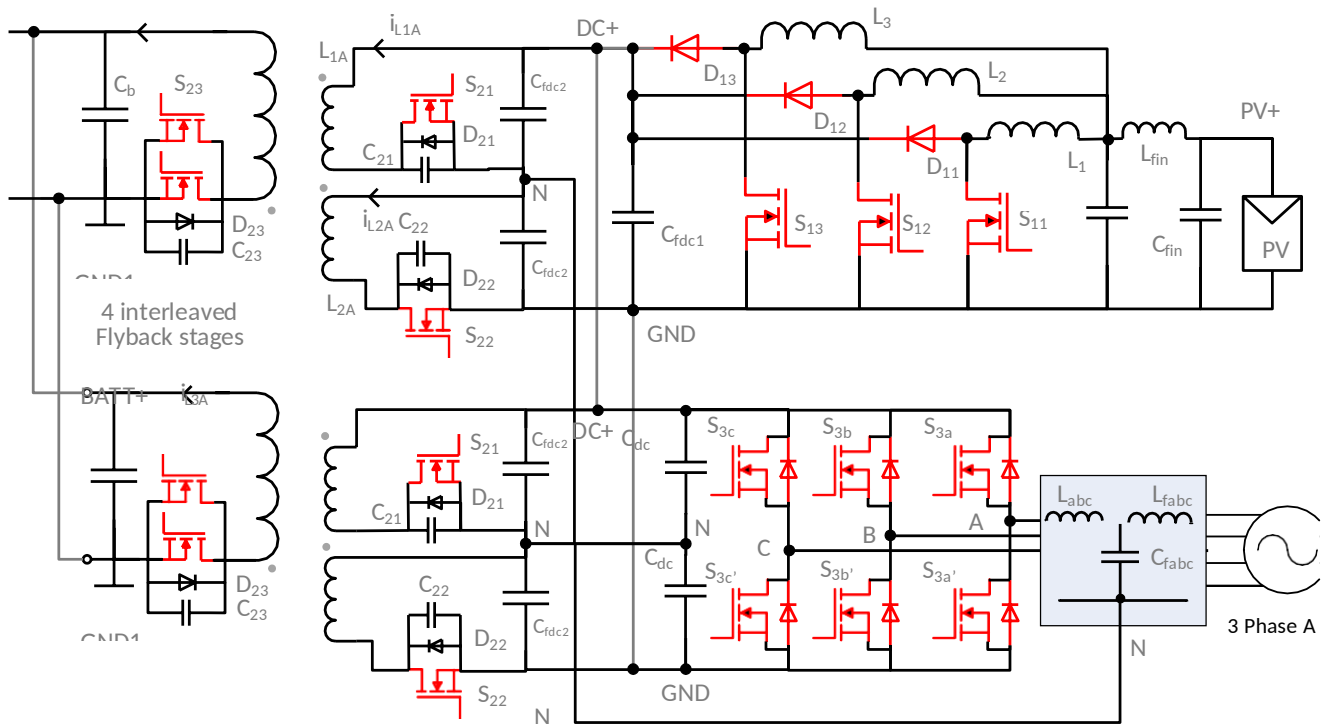


Fig. 3 – Topology of the three port EV-PV converter with a central DC-link

A. Experimental waveforms and efficiency

Fig. 14 shows the operating waveforms of the PV IBC for CCM and DCM modes, where a PV emulator is used as input. During CCM, the inductor current $I_{L(1)}$ rises when the gate voltage $V_{GS(1)}$ is ON and then begins to fall once the gate is OFF, in Fig. 14(a). In DCM, the inductor current $I_{L(1)}$ goes to zero before the end of the switching cycle, causing the drain-source voltage $V_{ds(1)}$ to oscillate as it goes from $V_{ds(on)}$ to V_{PV} , in Fig. 14(b).

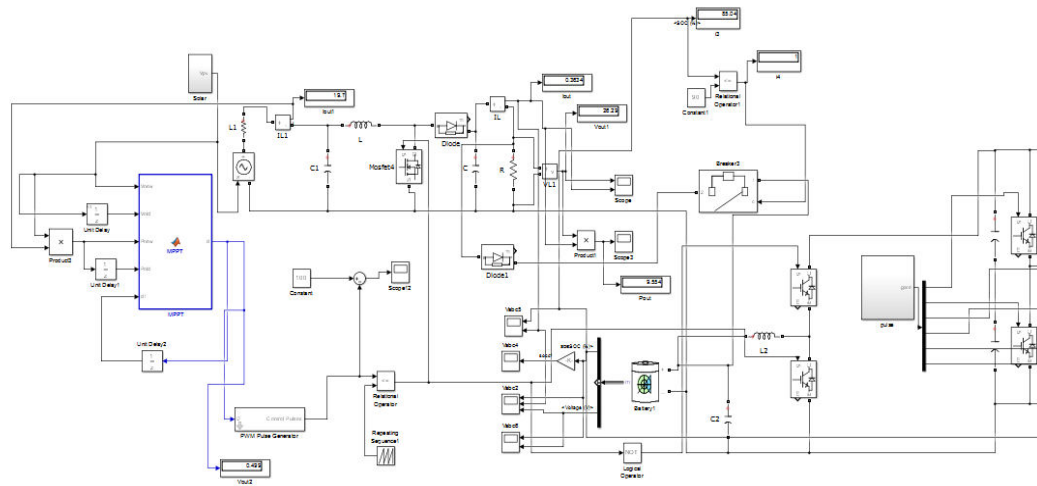


Fig. Bidirectional inverter(Simulink Diagram)

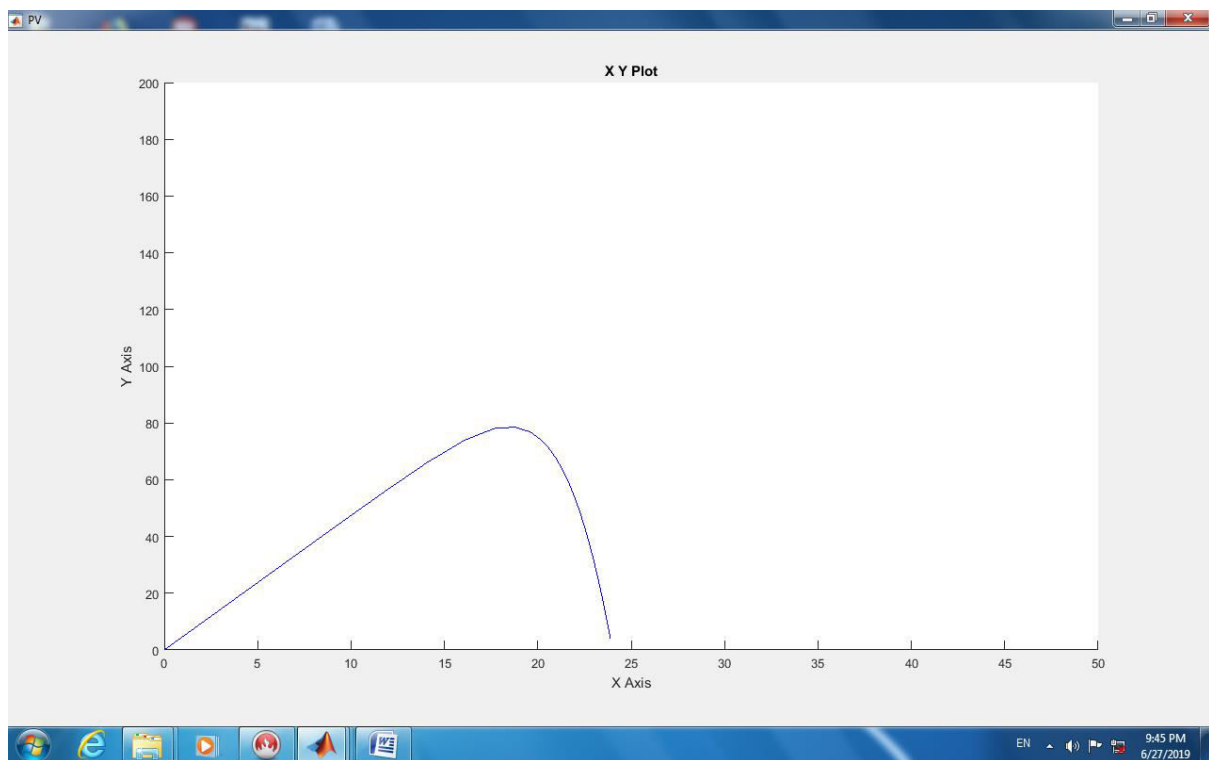


Fig. Power vs voltage graph

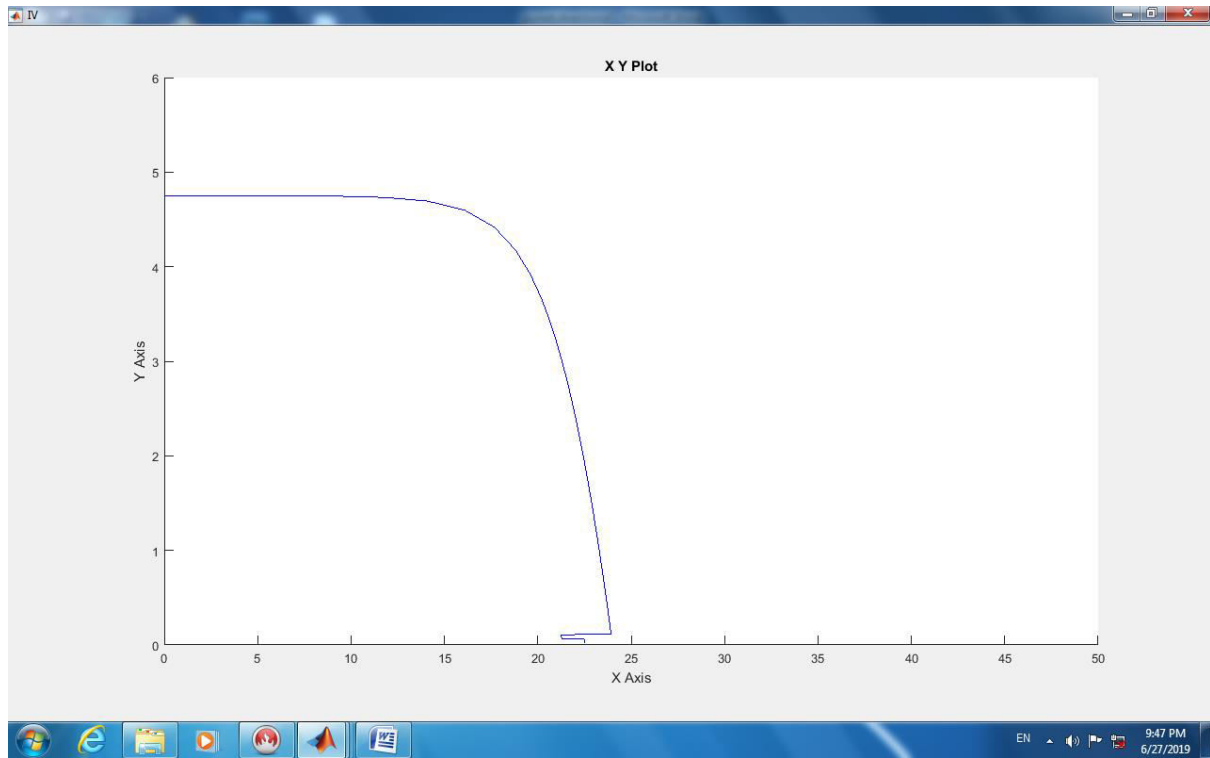


Fig. IV GRAPH(Simulation Output Result)

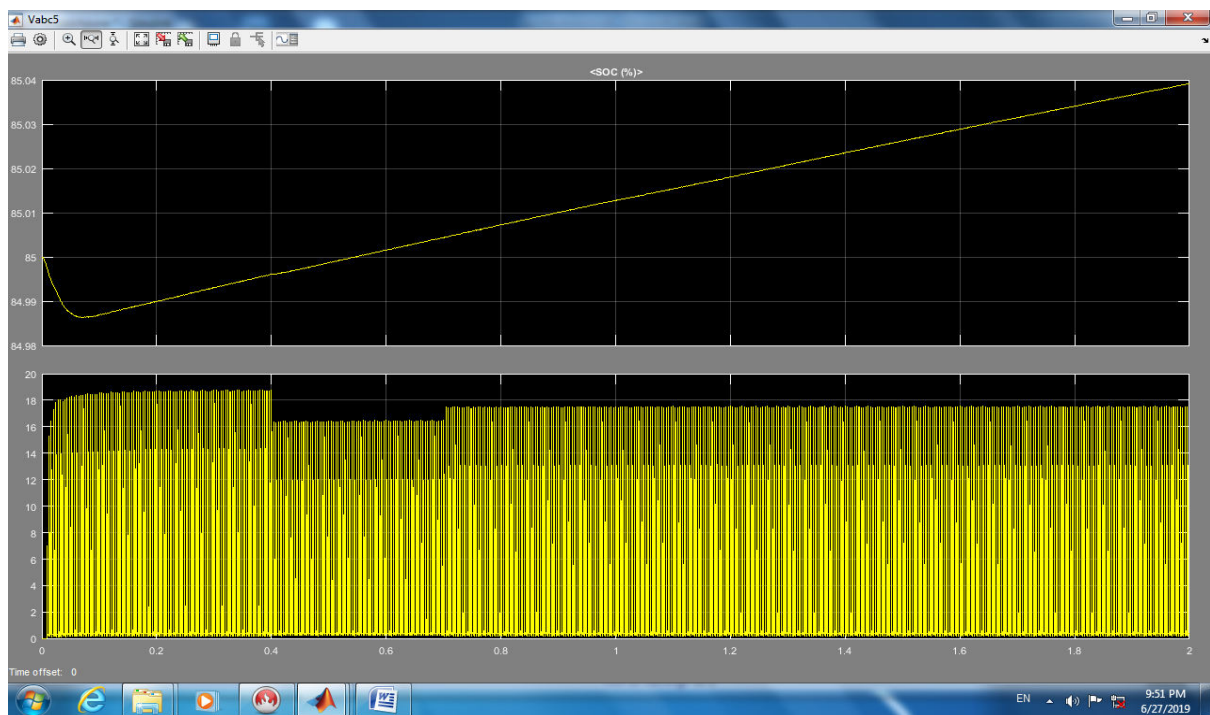


Fig. Battery charging soc(Matlab Result)

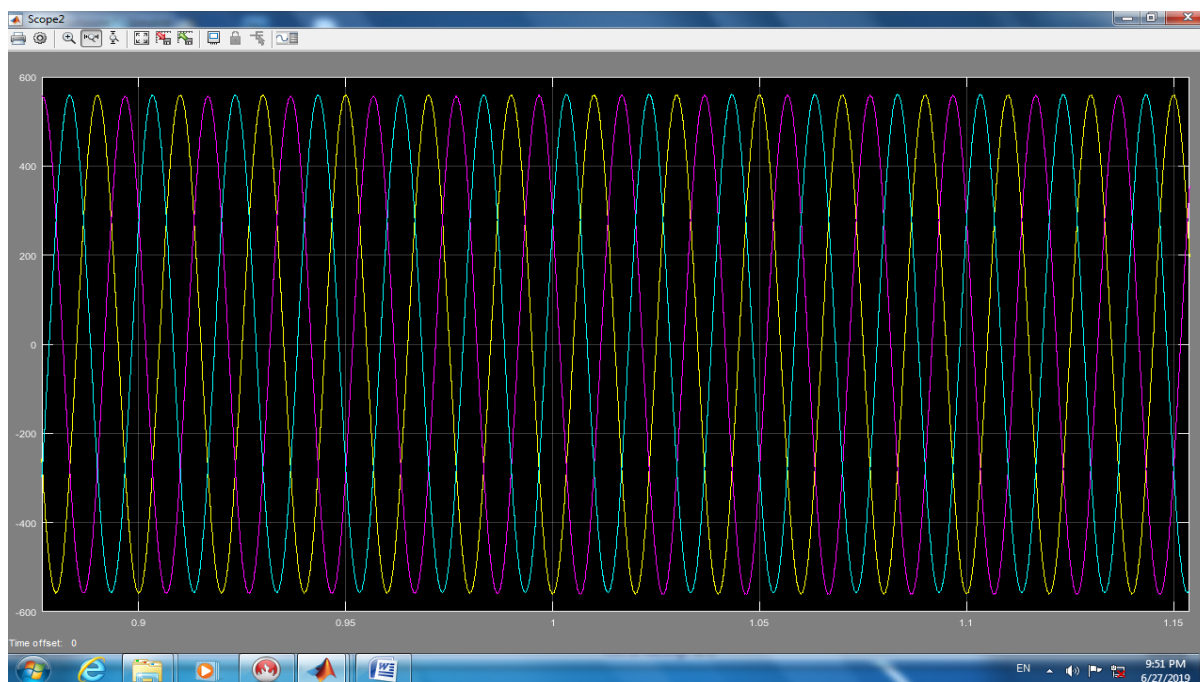


Fig .Three phase inverter output(Simulation Output)

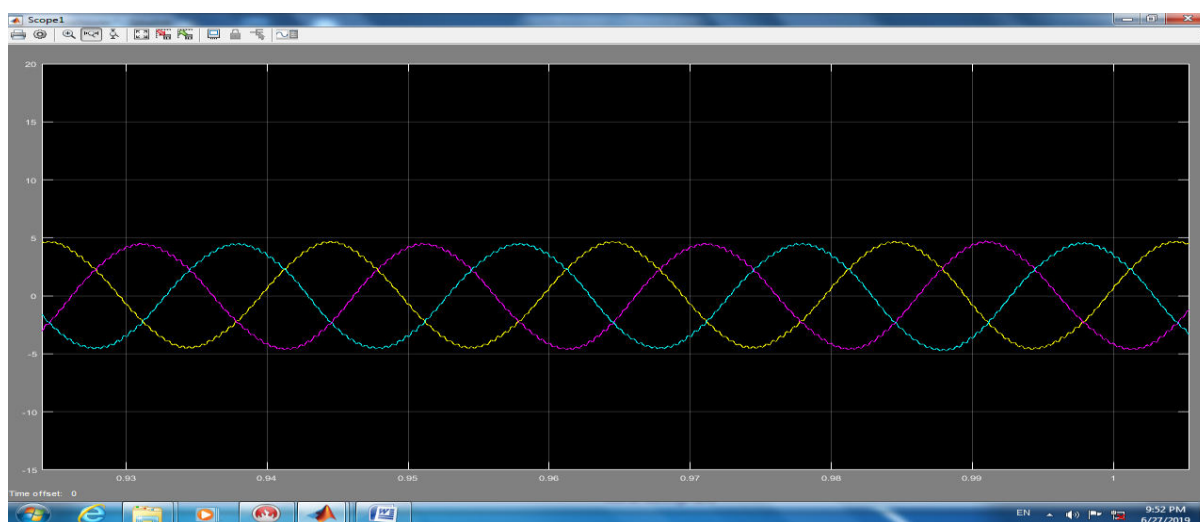


Fig..Simulation Waveform - Output current

Comparison with conventional design

Firstly, for Grid_EV the developed converter has a much higher peak and a higher partial load efficiency than the resonant topology, as seen in Fig. 17. The high partial load efficiency makes it suitable for smart charging of EVs where the EV charging power is continuously varied. Secondly, the power density of the developed charger (396W/l) is three times that of the two converters combined (134W/l). Thirdly, the proposed converter is bidirectional for V2G while the other is not. While the demand side management can be done with these nonconventional source of energy. We can achieve a smart generation and distribution with the help of highly efficient three phase converter. Most of the time when cars parked at offices and other premises that time it can supply back to grid. it helps in overall cost saving and cost reduction.



V. CONCLUSIONS

This paper presents the development of a 10kW, three-port, bidirectional converter for direct DC charging of EV from PV. The developed converter is compatible with CCS and Chademo EV charging standard and can operate with a PV array of wide voltage and power range. Interleaving of converters, Silicon carbide (SiC) devices, and powdered alloy core inductors are extensively used to increase the switching frequency, while keeping the converter losses within limits..

. Three closed loop controls were developed and tested for the three sub-converter which enables four power flows: PV to EV, EV to grid, grid to EV and PV to grid.. The charge and V2G operation at 10kW were tested with a Nissan Leaf EV with a Chademo charge controller.

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