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A Proposed Cuk Converter based Dual Input Hybrid Converter Topology as EV Charging Station

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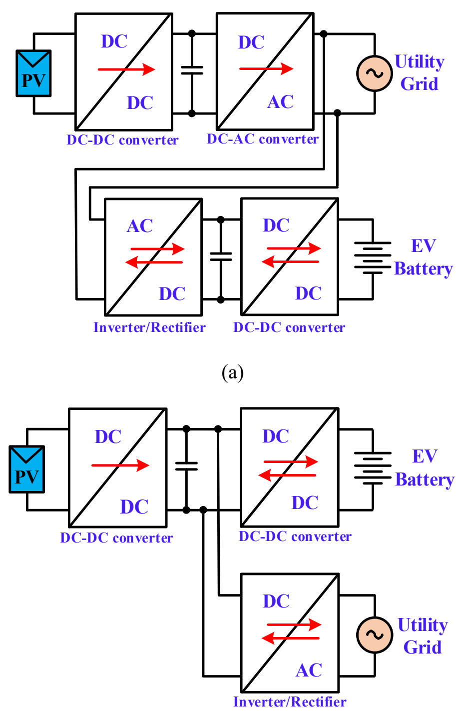
***Abstract*—The considerable advancement in electric vehicles (EVs) and constant reduction of prices for solar photovoltaic (PV) modules has raised interest in integrating PV modules to the EV chargers. In this paper a new Cuk based hybrid converter topology (CHCT) is proposed as an EV charger. The proposed CHCT consists of a PV source and 1-ϕ AC grid as two main energy sources. The main advantage of CHCT configuration is that it uses the optimal number of power components (i.e., five power switches, three inductors and one auxiliary capacitor) in the system. To control the CHCT configuration a simple modulation/switching strategy is proposed. Further, the control strategy to extract the maximum power available from PV source, controlling the power fed/extracted from the AC grid and charging the EV battery are also presented. In addition, the CHCT is tested under various scenarios such as the distribution of power between the two sources (AC grid and PV under wide variation of weather conditions), sending the power from PV to AC grid when EV battery is full or EV is not available, feeding power from PV to EV battery when AC grid is not available, and feeding power from AC grid to the EV battery during the absence of PV source. The MATLAB/Simulink is used to verify the proposed CHCT configuration under various circumstances at a power rating of 10kVA. The experimental testing of laboratory prototype of proposed EV charger is still under way. All the analysis and results of the proposed work will be presented in future papers.**

Keywords*—*Electric vehicle, Cuk converter, EV battery, EV charger, maximum power point, solar PV.



(b)

Fig. 1 Schematic diagrams of conventional Hybrid (PV grid integrated) EV charging stations.

I. INTRODUCTION

These days the popularity of the sustainable energy sources has been growing due to increase in global warming. On other side, EVs are encouraged to decrease the release of harmful gases into atmosphere. However, many EV charging stations incorporate non-renewable energy sources as the primary energy source [1]. With the increase in quantity of EVs on this planet the power demand on the utility grid is rising rapidly which is affecting the existing energy sources [2]. The alternative for the stable EV charging stations is to use the solar PV system as one of the energy sources. The integration of on-site PV systems into EV charging stations assists in supporting the excess power demand [3]-[13]. Generally, the charging of

EV battery is achieved either through AC charging or DC charging ports.

Fig. 1 shows the traditional schematic diagrams of the hybrid (PV and grid) EV charging station. The PV power is transferred to either AC grid or EV battery at the point of common connection (PCC) as shown in Fig. 1(a). However, in Fig. 1(b) the DC power from PV is directly delivered to EV battery which reduces the requirement of various power conversion stages unlike in Fig. 1(a). It can be understood that the EV charging station in Fig. 1(b) is considered as a better Hybrid charging station for EVs due to fewer power conversion stages. In Fig. 1, it can also be noticed that the PV source has a devoted DC-DC converter to track maximum power point (MPP). For charging the EV battery the charging station in Fig. 1(a) necessitates an extra AC-DC converter along with a DC-DC converter. However, the charging station in Fig. 1(b) eliminates the additional AC-DC converter stage as the ratings of PV and EV battery port are same.

Several researchers in the previous works discussed the PV integrated EV charging stations [4]-[13]. The various configurations of PV integrated EV charging stations are discussed in [4]. The [5], [6] and [7] use the configuration given in Fig. 1(a) whereas [8], [9] and [10] use the configuration in Fig. 1(b) to charge the EV battery from the PV and the utility grid. The configuration for grid integrated EV charging station presented in [5] is modular and it has capability to accommodate several PV sources and EVs through a common DC link. Because of its modularity this configuration can certainly be expanded to accommodate more EVs. In [6], ultracapacitors based PV integrated hybrid EV charging configuration is introduced. In this configuration, ultracapacitors are used to assist the battery during overcharging for a short interval of time to protect the battery life. A battery current control technique which examines the impact of high load demands on the grid is introduced in [7]. In [8], an individual controller-based PV integrated common DC link EV charging station is discussed. Here, DC link voltage is maintained by using power conversion stages of PV, grid, and battery sources. An interleaved DC-DC bi-directional converter-based PV integrated EV charging configuration is introduced in [9] for reducing current ripple in the battery. The [10], discusses the charging technique for numerous EVs by using only one battery charger and state of charge (SOC) of individual batteries. To integrate PV, AC grid and battery, a three port EV charging configuration is introduced in [11]. This configuration uses extra battery storage for reducing the current drawn from the AC grid while charging EV. In addition, this configuration requires several power switches due to matrix converter and six leg inverters are used as power conversion stages for AC grid and EV battery respectively. A new single stage EV charging configuration is introduced in [12] by adding additional switches to the conventional three-phase inverter. This configuration can be used for charging the EV battery either from the AC grid or PV source. In addition, a dedicated PWM technique is used to charge the EV battery while reducing the battery current ripple. To interface PV source, battery and DC load, a three port DC-DC configuration is introduced in [13]. In this configuration, all the input currents at the PV, battery and load are maintained in continuous mode of operation for reducing the EMI/EMC issues. A multiple converters based three port EV charging configuration is proposed in [14]. In this configuration, SiC power devices are used to operate the converter at high frequencies for reducing the size of inductors and limiting the power losses. Therefore, the power density of the charging station is increased, and output voltage ripple is reduced. A comparison of various EV configuration in presented in Table I.

TABLE I. COMPARISON BETWEEN VARIOUS EV CONFIGURATION

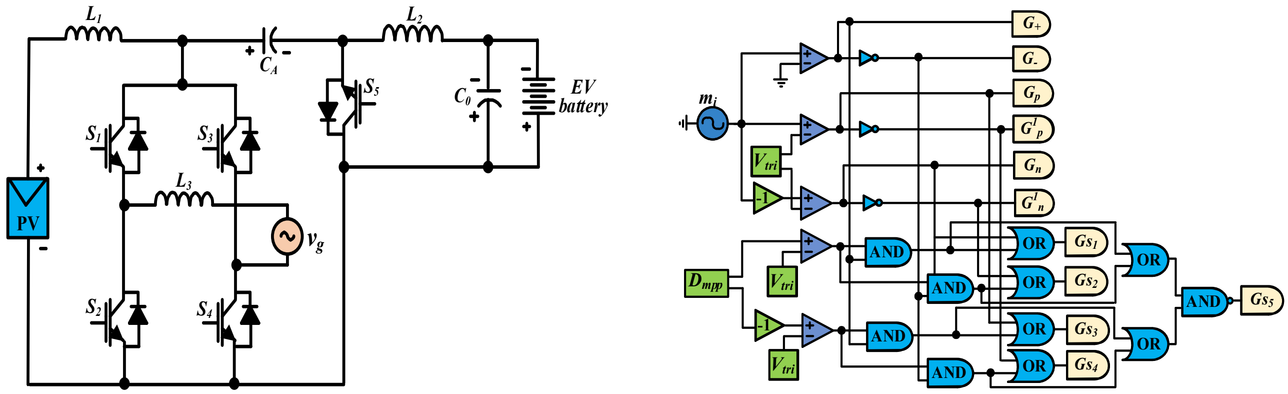
Parameters	**CHCT**	**[8]**	**[9]**	**[10]**	**[11]**	**[12]**	**[13]**
Switches	5	6	5	5	5	4	4
Diodes	0	2	1	2	4	2	1
Inductors	2	2	3	2	2	1	2
Capacitors	1	2	2	4	2	1	1
Gate driver	3	4	3	3	3	3	2
Sensors	4	4	4	6	6	5	6
Total components	15	20	18	22	22	16	12
Boosting capability	Yes	Yes	Yes	Yes	Yes	No	No
Symmetry	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DC offset	No	No	No	No	No	No	No

This paper proposes a novel Cuk converter based dual input hybrid converter topology as EV charger station. To control the proposed configuration, a modified PWM technique is introduced to maintain the voltage across battery port with or without connecting EV. The proposed dual input EV charger configuration is verified through MATLAB simulations and validated through CHIL experiments for various conditions. All the key results, operating modes and the design of power components are presented in the paper.

II. PROPOSED CUK BASED DUAL INPUT EV CHARGER CONFIGURATION

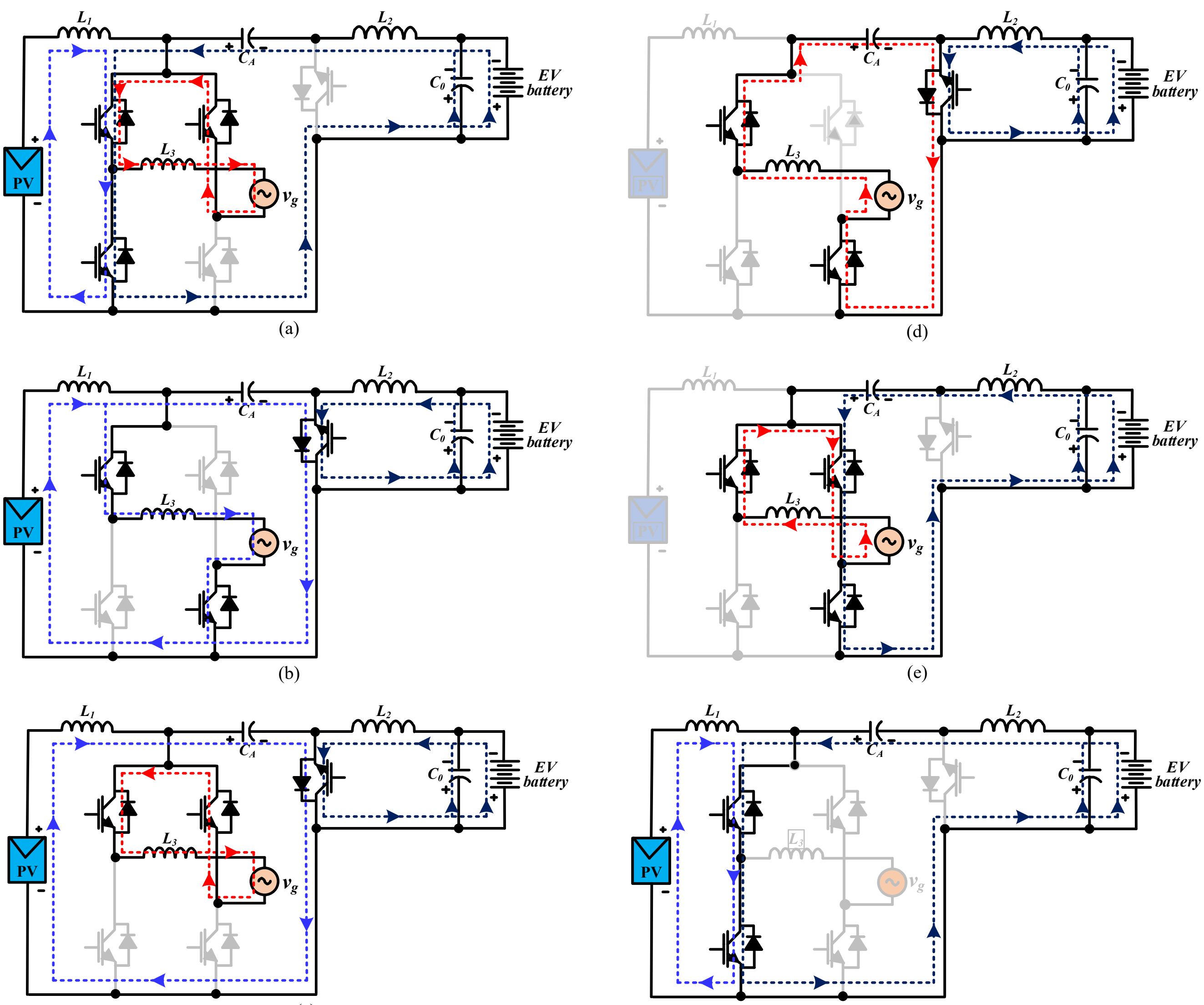
A. *Proposed Configuration*

The configuration of proposed Cuk based hybrid converter topology (CHCT) is shown in Fig. 2(a). It has PV source and AC grid as dual inputs. The CHCT uses the controllable power switches S_1 to S_4 for MPPT and boosting the input voltage. It can be achieved by storing the energy in input inductor L_1 from PV source by appropriately controlling either the switches $S_{1,2}$ or $S_{3,4}$. The duty cycle of the switches S_1 to S_5 determines the voltage across the EV battery port. Further, the power from the PV source can be shared between the EV battery and the AC grid by operating the switches S_1 to S_4 as normal voltage source inverter (Figs. 3(a)-(c)). The important modes correspond to AC grid to EV battery and PV to EV battery are also shown in Figs. 3(d)-(g). In addition, by regulating the voltage across EV port the power from EV battery can be sent to the AC grid as shown in Figs. 3(h) & 3(i). The diode across switch (S_5) present in the CHCT configuration is utilized to transfer stored energy in the inductor L_1 to the EV battery via auxiliary capacitor C_A. Even when the EV battery is not connected to the EV port the voltage across EV port is regulated at the reference battery voltage ($v_{b(ref)}$). Therefore, it prevents the building up of the voltage across EV port and ensures the smooth operation of the CHCT configuration by protecting the output capacitor (C_0). The



(a) Proposed EV charging station. (b) Developed PWM technique.

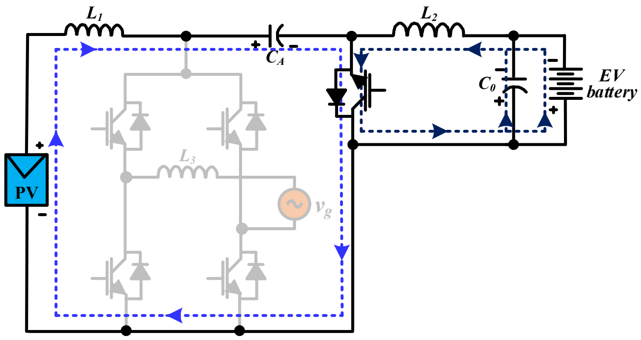
Fig. 2 PV grid integrated Hybrid converter topology as EV charging station.



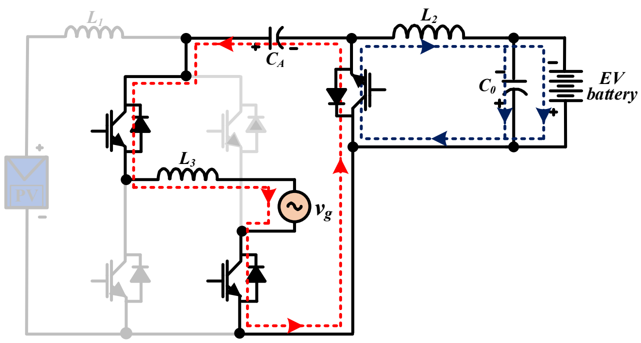
(a) (d)

(b) (e)

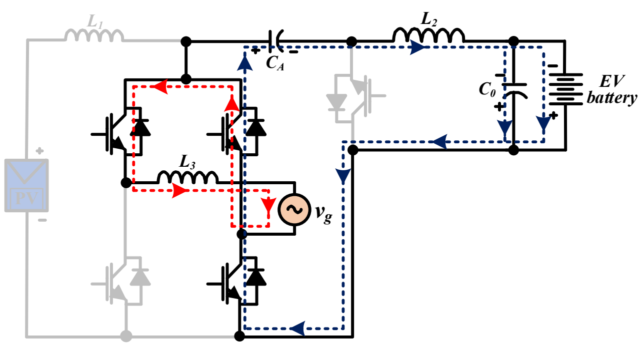
(c) (f)



(g)



(h)



(i)

Fig. 3 Operating modes of the Cuk based dual input Hybrid converter configuration.

voltage regulation across C_0 can be achieved by appropriately controlling the switch S_5. In addition, the power switch S_5 facilitates the vehicle to grid (i.e., EV battery to AC grid) operation. The suitable PWM technique developed to control the CHCT is shown in Fig. 2(b).

B. Expressions for EV Battery Voltage and AC rms Output Voltage

The expression for EV battery voltage can be expressed as

$$V_{batt} = \left(\frac{D_{mpp}}{1-D_{mpp}}\right) \times V_{PV} \tag{1}$$

Here, V_{pv} and V_{batt} are the voltages across PV source and EV battery. D_{mpp} is the duty for the maximum power point (MPP) operation. The expression for the AC output voltage of the CHCT configuration can be obtained as

$$\left.\begin{aligned} \hat{V}_{AC} &= \hat{M}_i\left(\frac{D_{mpp}}{1-D_{mpp}}\right) \times V_{PV} \\ V_{AC(rms)} &= \frac{\hat{M}_i}{\sqrt{2}}\left(\frac{D_{mpp}}{1-D_{mpp}}\right) \times V_{PV} \\ \hat{V}_{AC} &= \left(\frac{\hat{M}_i}{1-\hat{M}_i}\right) \times V_{batt} \\ V_{AC(rms)} &= \left(\frac{\hat{M}_i}{1-\hat{M}_i}\right) \times \frac{V_{batt}}{\sqrt{2}} \end{aligned}\right\} \tag{2}$$

Where $\hat{V}_{AC}$ and $V_{AC\,(rms)}$ are the maximum and rms values of the AC output voltage. $\hat{M}_i$ is the peak value of the modulation index of sine-triangle pulse width modulation (STPWM). In STPWN, to overcome the over modulation issue, the following condition must always be satisfied.

$$\hat{M}_i + D_{mpp} \leq 1 \tag{3}$$

C. Design of Various Power Components in CHCT Configuration

The voltage across output capacitor (V_{C0}) experiences double the grid frequency variation (i.e. 2×50 Hz =100 Hz) [15]. The value of output capacitor C_0 can be expressed below.

$$C_0 = \frac{P_{max}}{2\pi f \times V_{batt(max)} \times \Delta V_{batt}} \tag{4}$$

Where P_{max}, $V_{batt(max)}$, ΔV_{batt} and f are the rated power capability, maximum voltage across EV battery, voltage ripple in EV battery and frequency of the grid of CHCT configuration. For limiting the ripple in the EV battery voltage caused by double frequency power pulsation, a 4000μF capacitor (C_0) is connected across EV battery [16]. The average PV current of proposed CHCT configuration can be expressed as follows:

$$I_{PV(avg)} = \frac{P_{batt}}{V_{batt}} + \frac{P_{AC}}{V_{AC}} \tag{5}$$

Where P_{batt} and P_{AC} are the power transferred to the EV battery and AC grid. It can be understood that the input inductor current ripple (Δi_{L1}) and output capacitor voltage ripple (ΔV_{C0}) vary with variation in the AC grid power [17], [18]. Therefore, the value of input inductor can be calculated by using the expression below.

$$L_1 = \frac{V_{PV} \times V_{batt}}{f_S \times \Delta i_{L1} \times (V_{batt} + V_{PV})} \tag{6}$$

Here Δi_{L1} and f_S are the ripple in the input inductor current and switching frequency of the CHCT converter. As discussed in section II-A, the proposed CHCT configuration has various modes of operation as per the different scenarios.

D. Control Framework

The total control diagram for the proposed CHCT EV charging configuration is shown in Fig. 4.

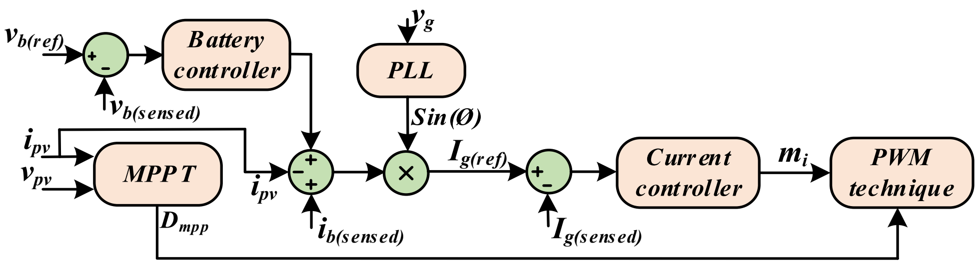


Fig. 4. Overall control strategy of the proposed PV grid integrated Hybrid converter topology.

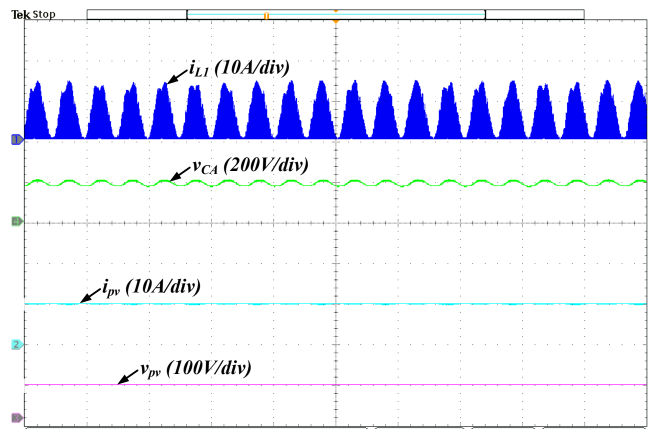
To track the maximum available power at PV source the incremental and conductance based MPPT algorithm is employed. The PV current (i_{pv}) and voltage (v_{pv}) are sensed from the PV source and fed to the MPPT algorithm. The MPPT algorithm determines the required duty cycle (D_{mpp}) to operate the PV source at MPP. In the proposed CHCT configuration, the voltage across EV port is regulated at reference voltage ($v_{b(ref)}$) through the determined D_{mpp}. To maintain the power balance, the PV current i_{pv}, battery current $i_{b(sensed)}$ and the output of battery controller (i_{bv}) are added together and used in generating reference current $I_{g(ref)}$ for the grid current controller. To synchronize with AC grid, the grid voltage v_g is sensed and passed through phase locked loop (PLL) for generating the unit sine wave ($sin(\phi)$). The output of the current controller (m_i) and D_{mpp} are given as inputs to the developed PWM technique for generating the gate pulses to the switches S_1 to S_5 of CHCT EV charging system (show in Fig. 2(b)). By using this control strategy in Fig. 4, whenever EV battery is not connected to the EV port, the total PV power is transferred to the AC grid while maintaining the voltage across EV port. In this work, with the use of single CHCT configuration, the dual inputs PV and AC grid are accommodated for charging the EV battery with the control diagram as shown in Fig. 4.

III. EXPERIMENTAL RESULTS

The proposed CHCT configuration is tested on a laboratory prototype of 10kVA system. The parameters used for the experimental study are given in Table II. The TMS320F280335 microcontroller is used to control the proposed CHCT configuration. Here, the input PV source supplies power to the EV battery and AC grid through CHCT converter. The experimental results correspond to the proposed configuration when EV battery is connected while feeding the PV power to the AC grid and EV battery (Fig. 5). Further, when PV source is not available (during nighttime) the EV battery is charged from the AC grid (Fig. 6).

TABLE II. SYSTEM PARAMETERS

Parameter	Value
System power rating	10kVA
AC Grid	110V rms, 60 Hz
PV source	200V, 20A
Battery source	400V, 4kWhr
Inductors (L_1, L_2 & L_3)	3 mH, 10 mH & 4 mH
Auxiliary capacitor (C_A)	4000 µF
Power switches	IHW25N120E1XKSA1
Power diodes	RHRP15120
Micro controller	TMS320F28335
Switching frequency (f_s)	15kHz



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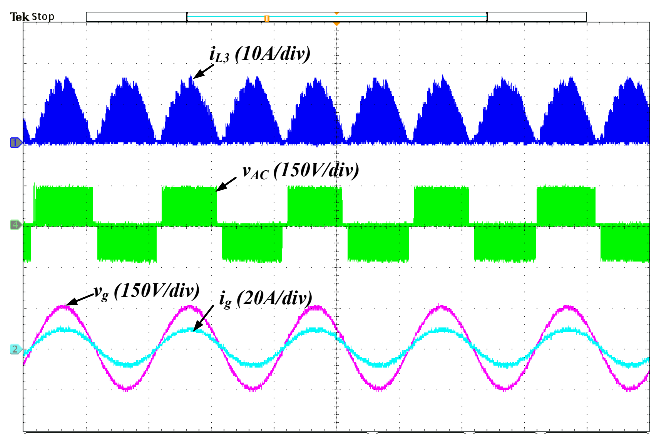
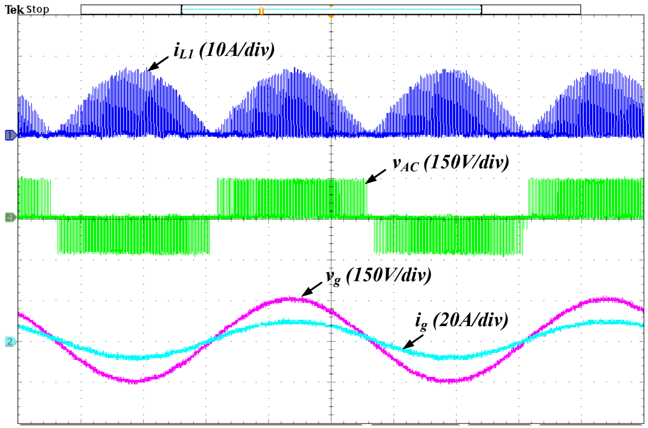


(b)

Fig. 5. Experimental results of CHCT configuration while PV charging battery and feeding power to AC grid.

IV. CONCLUSIONS

This paper proposed CHCT configuration for charging the EV battery from PV and AC grid. In this work, a single PV source is utilized to charge the EV battery (i.e. generating DC power) and feed the power to the AC grid (i.e. generating AC power) via CHCT configuration. The proposed CHCT configuration is verified and validated at 10kVA power rating. Further, the dynamic performance of the CHCT can be tested for various input PV voltages and reference powers. The CHCT configuration is tested with EV battery connected/disconnected



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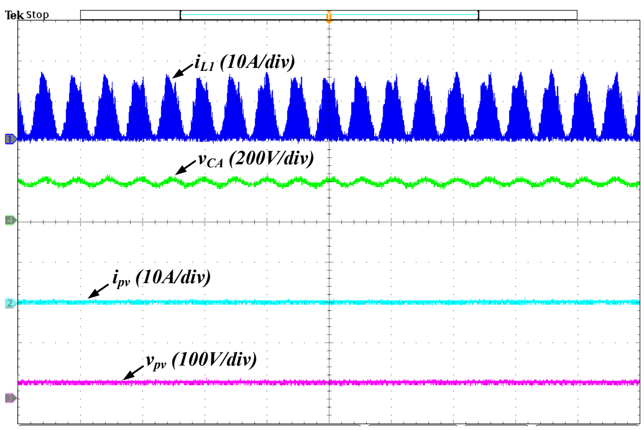

(b)

Fig. 6 Experimental results of CHCT configuration when PV source is not available and AC grid charging EV battery.

under wide varying PV conditions. The experimental studies show that the CHCT configuration provides steady power while charging EV battery and feeding AC grid. In addition, it can be understood from the performance comparison of the proposed CHCT configuration that it exhibits greater advantages over existing hybrid EV charging stations in terms power components and other performance indices.

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