A grid connected PV module integrated electric vehicle charging station

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Abstract. This paper provides an insight of electric vehicle charging station which is supplied by three sources grid, photovoltaic system (PVS). Power grid, equipped with an AC/DC converter supplies a continuous and constant power to EV charging station through DC/DC converters. The significant function of the proposed inverter is to enhance the stability of a micro-grid. The proposed inverter can stabilize its grid voltage and frequency by supplying or absorbing active or reactive power to or from a micro-grid using EVs and PV generation. Moreover, the proposed inverter can automatically detect an abnormal condition of the grid, such as a blackout, and operate in the islanding mode, which can provide continuous power to local loads using EV vehicle-to-grid service and PV generation. MPPT (maximum power point tracking) technique is used to get the appropriate pulses for DC/DC converter to extract the maximum output power from PVS at different conditions. The proposed system is simulated in MATLAB/SIMULINK environment and results are discussed to validate the system.

Keywords: Electric vehicle charging station, Grid and PV source, DC/DC converters, MPPT.

I. INTRODUCTION

Renewable energy sources (RES), such as photovoltaic (PV) and wind turbine generation (WTG), have been increasing in the grid to replace conventional synchronous generators [1]. These RESs are connected to the grid through power converters such as grid-connected inverters, which can weaken the microgrid by reducing the inertia of the grid [2]. Because the weak grid has low inertia, it is difficult to cope with the grid voltage and frequency fluctuations, leading to a deterioration of grid stability and power quality [3]. Various grid codes, such as IEEE Standard 1547–2018 and UL 1741 SA, were established to solve these problems. These grid codes are guidelines for grid-connected inverters to maintain grid stability. According to the IEEE Standard 1547–2018 requirements, grid-connected inverters should be able to maintain grid stability and power quality by regulating the grid voltage and frequency through absorbing and supplying active or reactive power to the grid. Moreover, the grid-connected inverter should be able to detect abnormal conditions, such as a grid blackout, and operate in the islanding mode.

In addition to the increase in RESs, the penetration rate of electric vehicles (EVs) has increased to replace conventional fossil fuel vehicles. Therefore, the EV charging stations within the microgrid have also been increasing, as shown in Figure 1 [4]. Depending on the applications, each source and load can be connected to the microgrid through single or multi-stage power converters [5]. If many EVs are charged simultaneously from the microgrid, a power imbalance in the supply and demand may occur in the microgrid.

EVs use electricity as their main source of power for driving operations, this electric power is provided by a battery which is placed in EVs. So, EVs need to charge at certain points when their battery discharges. Hence there is a need for an EV charging station to charge up its battery. EV charging station needs a constant supply for round the clock operation. Electric grid can be used, but it is difficult to control and function if the load at the charging station increased, and also there is no benefit if the grid is supplied by conventional energy sources [4]. So there is a need for renewable energy, solar energy can be used in this scenario because it is renewable and green. The integration of an electric vehicle charging station and renewable energy source should be widely employed as suggested by environmental experts [5]. Energy harnessed from solar photovoltaic (SPV) is not reliable as it can't work through the day and its utilization is subjected to climate condition. In paper [6], a model has been proposed in which EV charging station is powered by solar PV and when these sources are unavailable, the grid and diesel generator fulfil the requirement. In paper [7], a grid-connected EV charging station has been proposed in which with the help of control scheme load demand and load fluctuations on the grid have been reduced.

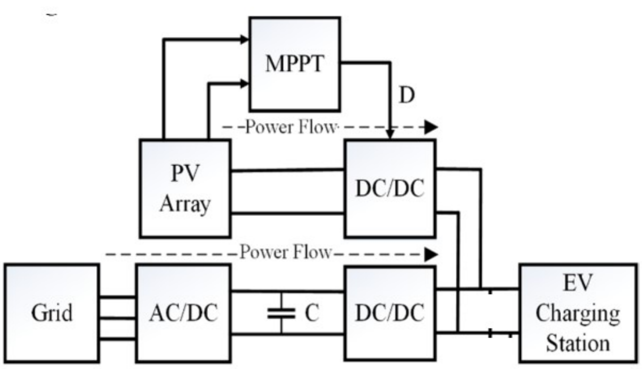

Figure 1: Proposed test system block diagram

The converters help to maintain constant output voltage and control the fluctuations by charging or discharging the BES, it is also used for energy time-shifting and load leveling. Time-shifting means it stores energy in off-peak time and gives supply to load during peak time. Load leveling means PV supports grid input power by providing some amount of power when the load demand is high. The controller provides the appropriate pulses to the PV side and grid side converters which helps in maintaining output voltage constant and to get the desired power demand to the charging station. Fig. 1 shows the block diagram of the proposed system. This proposed system is designed in MATLAB.

II. CHARGING MODULE

The charging system has a three-phase source as input. Thus, the system includes a three-phase AC/DC converter. In this paper, we adopt a bi-directional converter based on IGBT switches. Considering vehicle to grid (V2G) services, we apply VDC/Q control. The VDC/Q control can regulate the DC bus voltage and the reactive power from grid. The VDC/Q control structure is shown in Fig. 2. The controller has two inputs: reactive power measurement and DC bus voltage measurement. Two PI controllers are used to make sure the measurements track their reference values. The outputs from the PI controllers are dq-axis current orders. This dq-reference frame is aligned with the input voltage space vector. Angle of the input voltage space vector (θ) is obtained through a PLL. This angle is used for abc–dq and dq–abc conversion.

The dq-axis current orders are converted to abc three-phase current orders, notated in Fig. 2 as $i*grid$. Three proportional resonant (PR) controllers are then used to guarantee that the abc current measurements track the grid current orders. The outputs of the PR controllers are abc-frame converter voltages. After scaling, these signals will be used to generate PWM signals. Grid voltage va, vb and vc are transformed to the dq frame by using Park transformation and θ from phase-locked-loop (PLL) [8].

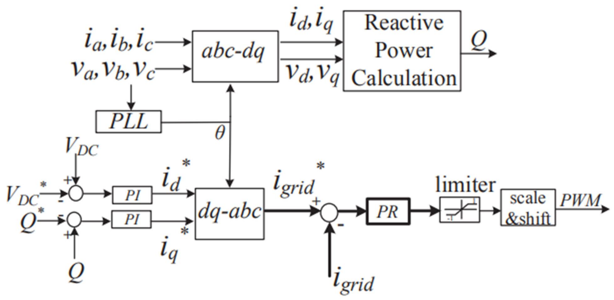

Figure 2: Three-phase rectifier controller

The transformed voltage and current are used to calculate three-phase reactive power as shown follows:

$$Q = \frac{3}{2}(V_q i_d - V_d i_q) \qquad (1)$$

The inputs of PLL are three-phase grid voltages va, vb, and vc. They are converted into dq-axis voltages based on the angle θ obtained from PLL. PLL works to synchronize the charging system to the grid.The parameters of the Level 3 charging system are given in Table IV.

TABLE I: PARAMETERS OF LEVEL 3 CHARGING SYSTEM

R_{grid}	0.003 Ω
L_{grid}	3 mH
V_{grid}	150 V 3-phase
PLL	$k_p = 180,\ k_i = 3200$
V_{DC}^{*}	330 V
V_{DC} PI controller	$0.1 + \frac{10}{s}$
Reactive power PI controller	$0.1 + \frac{1}{s}$
PR controller	$k_p = 500,\ k_r = 50,\ \omega = 2\pi \times 60$

A. *Active full bridge controller*

There are several charging methods that can be applied in EV battery charging. The three basic methods are constant-current (CC), constant-voltage (CV) and taper-current (TC) charging [10]. The CC method charges a battery using a constant charging current while voltage varies. When the voltage reaches a preset value, the charging process will stop. However, the charging current level needs to be considered carefully because low current is not suitable for fast charging while high current may cause excessive damage. The CV method limits the voltage to a specific level by varying current. The charging stops until current drops to almost zero. The TC method charging a battery with a decreasing current while the voltage is rising. The method rarely used since batteries have different characteristics in real application.CC/CV charging is combination of CC and CV, and intends to enhance the reliability and efficiency. The CC method is usually used in the initial stage of charging to avoid over current. The CV method is used following the initial stage. Fig. 3 shows a simple illustration of CC/CV charging.

Firstly the battery charging is operated at CC mode, where charging current is kept as constant and charging voltage is increasing. The control will change to CV mode when voltage reaches a preset value. When the current drops to cut-off value, the charging will stop. Usually the CV mode takes same or longer time than CC. The control implementation is shown in Fig. 3 [10]. The CC/CV selector compares the battery voltage with a preset value to switch charging mode.

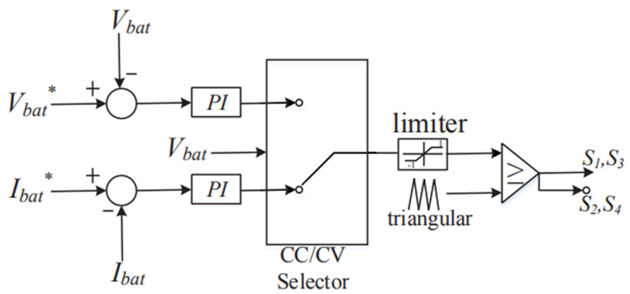

Figure 3: Active full bridge control scheme

III. MODELING OF PV MODULE

PV module is a renewable source which generates electricity in DC voltage by solar irradiation. The panel comprises of semi-conductor materials of n-type and p-type placed on top and bottom respectively [11]. The semi-conductor material is doped with silicon material to ensure release of electron from the silicon atom when solar irradiation strikes the panel. The released electron passes through the load or any converter to reach the bottom side of the panel which is doped with p-type silicon material.

A DC-DC booster converter is connected to the PV module. The DC-DC booster converter comprises of a single power electronic device (either IGBT or MOSFET). This power electronic device in the converter is controlled by MPPT algorithm. This algorithm generates required duty ratio (D) for the power electronic switch to operate. A simple DC-DC booster converter connected to PV module can be seen below in fig. 4.

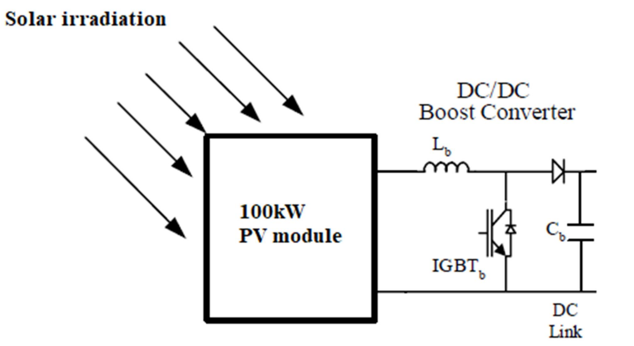

Figure 4: PVA module connected to DC-DC converter

In the above figure the DC-DC booster converter include a boosting inductor (L_b), ripple reduction capacitor (C_b) and a power electronic device ($IGBT_b$). A diode is also connected at the output side which avoids reverse current conduction from the grid side. The $IGBT_b$ is controlled by MPPT technique which changes the ON time of the $IGBT_b$, changing the charge time of the inductor L_b which makes the output voltage of the converter to vary. The MPPT algorithm used is P&O (Perturb and Observe) method [12] which is considered as simple and basic technique used in most of the PV applications. The algorithm of P&O method MPPT is shown below in fig. 5.

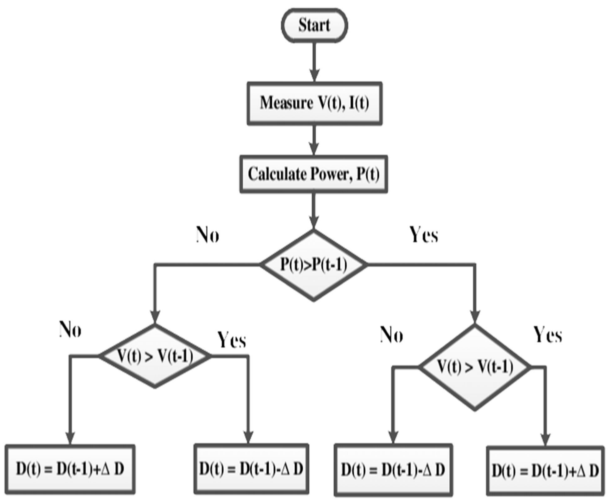

Figure 5: P&O MPPT algorithm flow chart

The MPPT algorithm needs V(t) and I(t) measurement which are present measured voltage of PV module and present measured current of PV module respectively. With these measured values present power output P(t) [12] of the PV module is calculated as

$$P(t) = V(t) * I(t) \quad (2)$$

Now the present value of power P(t) is compared to previous or past value of the power given as P(t-1) using a relational operator as given below.

$$P(t) > P(t-1) \quad (3)$$

For either of the cases (YES or NO) the algorithm further gets down to comparison of present and past value of PV module voltage with a relational operator given as

$$V(t) > V(t-1) \quad (4)$$

For the YES case in (4) and YES case in (5), the change in the duty ratio (ΔD) is added to the past value of duty ratio D(t-1) and subtracted if the case is NO in (5). The change in duty ratio is added if case in (4) and (5) is NO, and if (5) is YES and (4) is NO then ΔD is subtracted. The updated duty ratio (D) is given as

$$D(t) = D(t-1) \pm \Delta D \qquad (5)$$

With the above comparison of present and past values of the PV module the duty ratio [12] is updated continuously for every instant of time. The updated duty ratio is compared to a high frequency sawtooth wave to generated pulse to the $IGBT_b$ switch connected in the DC-DC booster converter. The pulse produced by the updated duty ratio D(t) is shown below.

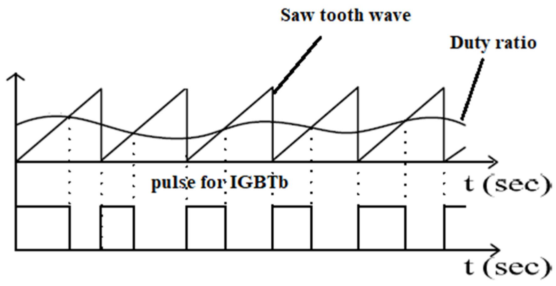

Figure 6: Pulse generated from MPPT to $IGBT_b$

IV. SIMULATION RESULTS

With the above modules the modeling of the proposed test system shown in figure 1 is modeled using Simulink library block sets from Powersystems. The parameters of the system are taken from table 1. The below figure 7 is the modeling of the proposed test system.

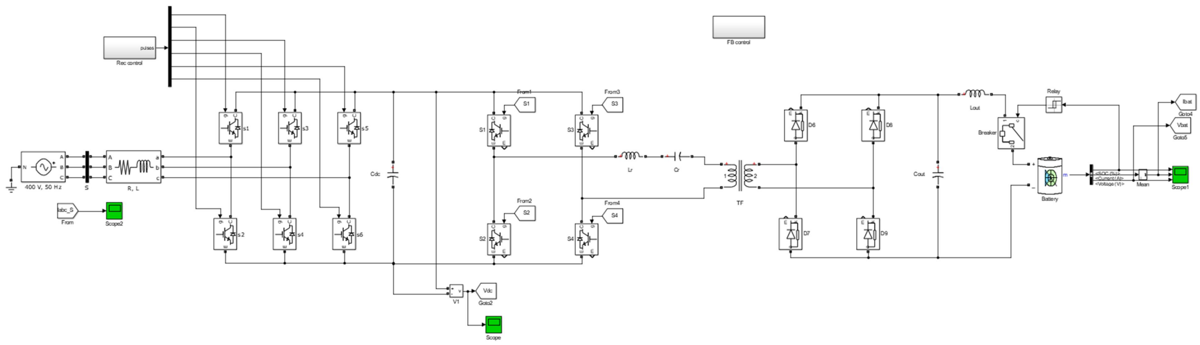

Figure 7: Modeling of proposed test system

After the modeling the simulation is run for time of 3sec and the graphs of each module are plotted with respect to time as shown below. The below graph is the grid current measured at the initial state of the model.

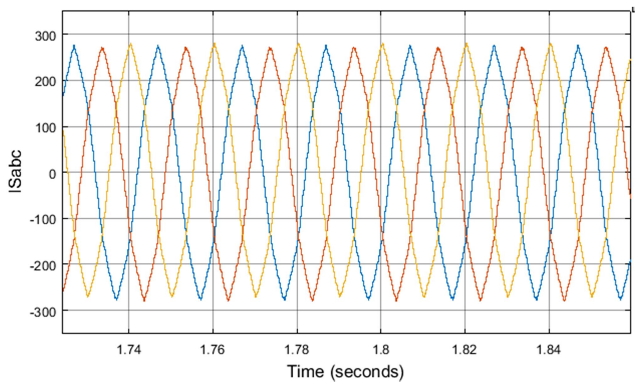

Figure 8: 3-ph Grid currents

The output of the 3-ph controlled rectifier can be seen below with developed magnitude of 1000V.

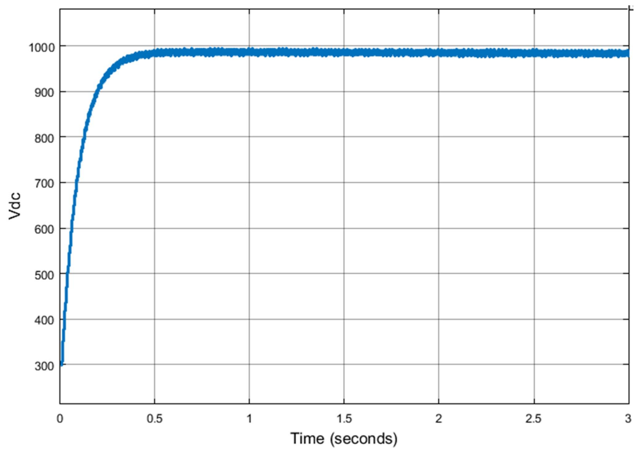

Figure 9: DC link voltage

For the given control of active full bridge converter, the below are the battery characteristics during charging from 80%. The current of the battery is noted at 10A and the voltage at 272V.

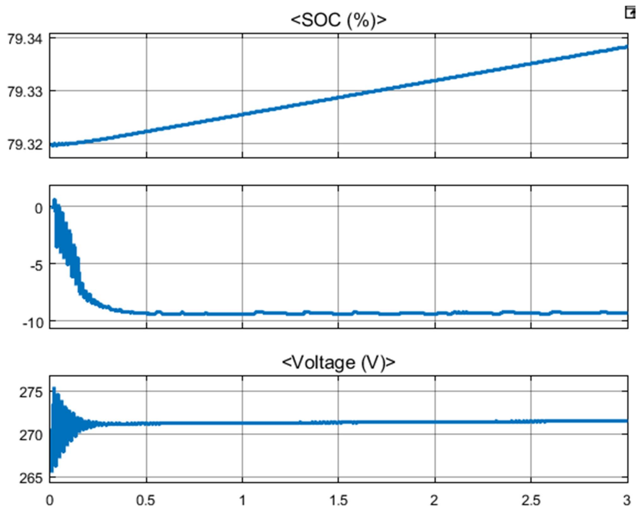

Figure 10: Battery characteristics

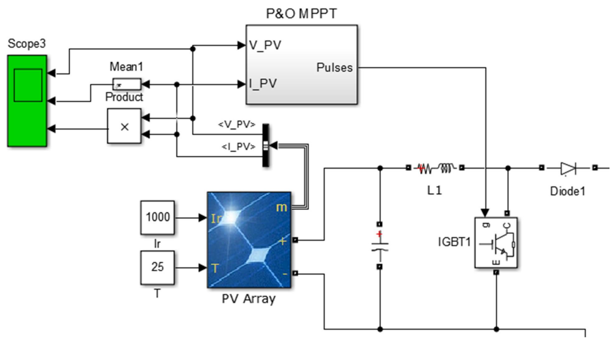

Figure 11: PV module modeling

The above is the PV module modeling with boost converter and MPPT control connected at the DC link after the 3-ph controlled rectifier. The below are the PV module characteristics for the given solar irradiation of 1000W/mt2.

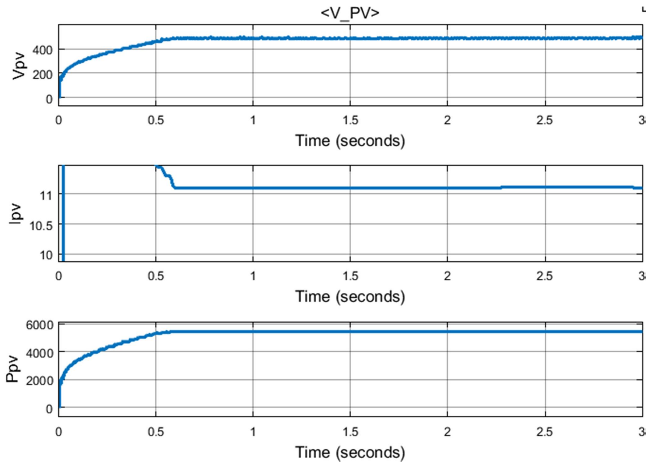

Figure 12: PV characteristics

FFT analysis is carried out on the grid currents to determine THD of the signals. As per the IEEE standard the THD of any AC signal need to be below 5% in any given condition. The below is the THD of the grid currents of phase A without the PV module connected.

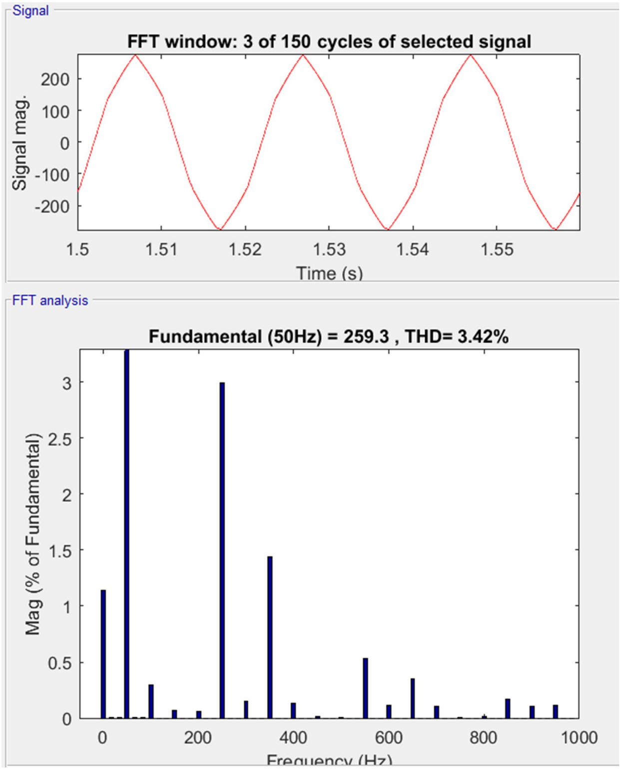

Figure 13: THD of grid current before connecting PV module

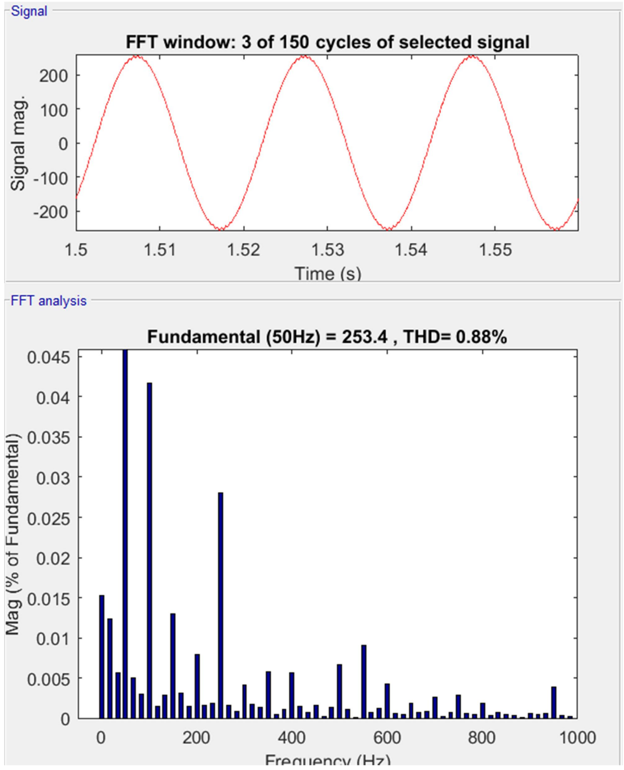

Figure 14: THD of grid current after connecting PV module

After the test system is updated with PV module at the DC link the THD of grid current is determined using the same FFT analysis tool. The below the THD of the grid current when the PV module is connected at DC link of the system.

V. CONCLUSION

The charging system uses three-phase AC source and consists of a bi-directional AC/DC converter and a dual-bridge DC/DC converter. VDC/Q control is adopted for the bidirectional AC/DC converter. CC/CV battery charging control is implemented in the DC/DC dual bridge converter. It is concluded that PV source reduces the burden on the grid and a stable and better quality power is delivered to the EV charging station. With the help of control scheme EV charging station receives nearly uninterrupted power which is used for electrical vehicle charging throughout the day. The simulation results have been shown to verify the power scenario from different sources to the charging station. With the updated of the test system by connecting PV module at the DC link the THD of the grid current is reduced to 0.88% from 3.42%. This validates that the PV module is sharing power to EV charging station reducing power consumption from grid source reducing the THD of the grid currents.

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