Effect of Electrical Vehicles Charging on Distribution System with Distributed Generation

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1 Introduction

Electric vehicles are simple creations in which wheels are turned by electric motors rather than gasoline/diesel powered drive train. They are energy efficient and convert about 59–62% of the electrical energy from the grid. Whereas energy stored in gasoline converted just 17–21%. It is also as old as the Internal Combustion (IC) vehicle as the first practical EV developed in 1834 by Thomas Davenport. Due to improvement in EV technology, EV shows revival of their era. Moreover, an increased focus on renewable energy [1] made it more relevant in recent time. India leaping to achieve 175 GW in terms of renewable energy by 2022 according to commitment under global climate change accord. Out of these, the target of solar energy will be of 100 GW.

There are different kind of Battery electric vehicles (BEVs); Hybrid electric vehicles (HEVs); Plug-in hybrid electric vehicles (PHEVs). A higher portion is expected to be PHEV as convenient in practical cases. The electrical distribution grid will experience an impact due to connected PHEVs. This is mainly because they consumes a large quantum of electrical energy from the distribution grid it is connected. Sudden switching for charging can result in unwanted power peaks in the electricity consumption [2, 3]. Moreover, it also leads to change and degrade the quality of the power. This is primarily in terms of change in THD, large variation in current and degradation of the voltage levels.

Distribution grid refers to 'The last stage of the electricity network in which electricity is distributed to households, industry and other end products. The main

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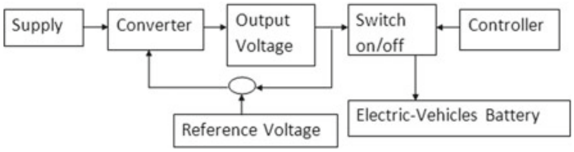

Fig. 1 Electric vehicles charging circuit

function of electric power distribution system is to supply energy to the premises of individual consumers. Electrical energy is distributed to various consumers with low voltage levels. Distribution of electric power is done by distribution network' [4].

Distributed Generation (DG) is basically generation of electricity from small energy sources less than 10 MW. Nowadays renewable sources mostly use as DG due to reduce reliance of fossil fuels, i.e., Photo-Voltaic (PV) or Solar [5].

Specification The Bharat DC-001 (Moderate level) charger has selected for Electric vehicles charging parameter according to standard. Its power rating 15 kW voltage rating 72 V or higher and current rating maximum 200 A. Converter Efficiency is greater than 92% at nominal output power [6, 7]. New lunched electric vehicle (Tata tiago and Mahindra e20 plus) have based on this parameter. For EV Lithium-ion battery used it's parameter [8]: Nominal voltage 72 V, Rated capacity 11,000 Ah [3] (Fig. 1).

Charger is power converter that performs the necessary function for charging battery [1, 9]. The charging of battery is considered in this work; however, discharging of battery in case of grid requirement is omitted. The charging conditions for any EV considered through circuit breaker depend on two conditions:

(1) Output of converter must be greater than 72.5 Voltage
(2) Battery state of charge is less than 90%.

2 Related Work and Background Information

The article [2] selects simulation of the daily load profile of China for which the EV penetration considered are 5, 10, 20%. The results of the article establish the best time of electric vehicle charging during off-peak hours. The findings are more efficient in terms of grid stress; however, its implementation is difficult as load profile varies much. The article [10] demonstrates distribution system model on Dig SILENT software. The grid connection of the PEV's has been evaluated in term of the load profile. These connections include both types of charging: controlled a dun-controlled. According to the available load profile, the article provides the concept of controlled charging. Moreover, it also finds voltage unbalance at transformer according to definition of the National Electrical Manufacture Association (NEMA) and IEEE. The unbalance of the voltage has been defined in this article as the ratio of voltage deviation (maximum) from the average voltage to the average of line voltage.

A comparison of daily load profile for winter and summer daily load for household consumers in the UK were presented in [11]. Connected EV penetration considered were 10, 20 and 30%. EV has a constant 10 A charging current for six hours to standard outlet of residential supply. EV charging with different strategies, i.e., uncontrolled, off-peak, smart charging were simulated and results were produced for obtained voltage and demand profile of each case. This article also defines and compare few terms like:

- Uncontrolled charging: may increase about 18% of maximum demand
- Off-Peak charging: This includes a simple controller that controls switching of the charger during off-peak period.
- Smart charging: In this type of charging, 'smart' charging control circuitry made demand uniform by separating (phasing) the charging cycle. This is done by dividing total charging requirement into four distinct charging schedules according to their priority.

Result of this article shows the charging operation by restricting the voltage profile within 20% of its regular level with the on-load tap changer. The article [12] shows impact of EV charging on IEEE 34 node test feeder. The simulation was provided with electrical distribution design (EDD) software with summer season load curve for the California Independent System Operator (CAISO). The load flow analysis was conducted for each of the cases and monitors transformer loading limit; current rating; voltage limit; line loading limit. The findings were provided with randomly increased 10% load for every load bus to find out the system limit. Then finally, increment of load by 5–20% of load in each step to find out maximum loading that system can withstand. They concluded that larger size transformers are needed to solve EV connection or may connect Distribution Generator (DG).

The article [13] analyzes impact of EV charging in terms of power quality with a distribution grid of fifteen houses. Fundamentally, the non-linear current consumed by load will positively affect the quality of the power. Results show that the THD in current taken by load has been reduced to 1.8% for smart charges than 51.6% for a traditional EV charger. The reduction in the voltage level is of 7.3% has been reported for the most distinct home from the distribution transformed. This will result in malfunctioning of the equipment in that house. Another article mostly focuses on current limit, harmonic, effect on transformer and a maximum loading capacity [14].

From the system operator point of view, in the distribution system, the losses occur due to charging are a major concern on the economic front. Moreover, it also can result in overloads that eventually results in change of Voltage profile; Unbalance of current; THD; Transformer loading limit; reduced efficiency; Difficulty operation control; Stress on customer equipment; new requirement for distribution network planning.

3 System Simulation

3.1 Analysis of IEEE-15 BUS System

To check the effect of plug-in EV charger on the distribution grid, an IEEE-15 bus system has been simulated with inclusion of EV charger [15–18]. IEEE-15 bus system is a well-defined distribution network; its parameters are provided in Table 2. The model of distribution grid is simulated on MATLAB software with rated voltage 11 kV. It's consists sources is rated 1.26 MW and total load is connected on bus 1.23 MW [19, 20].

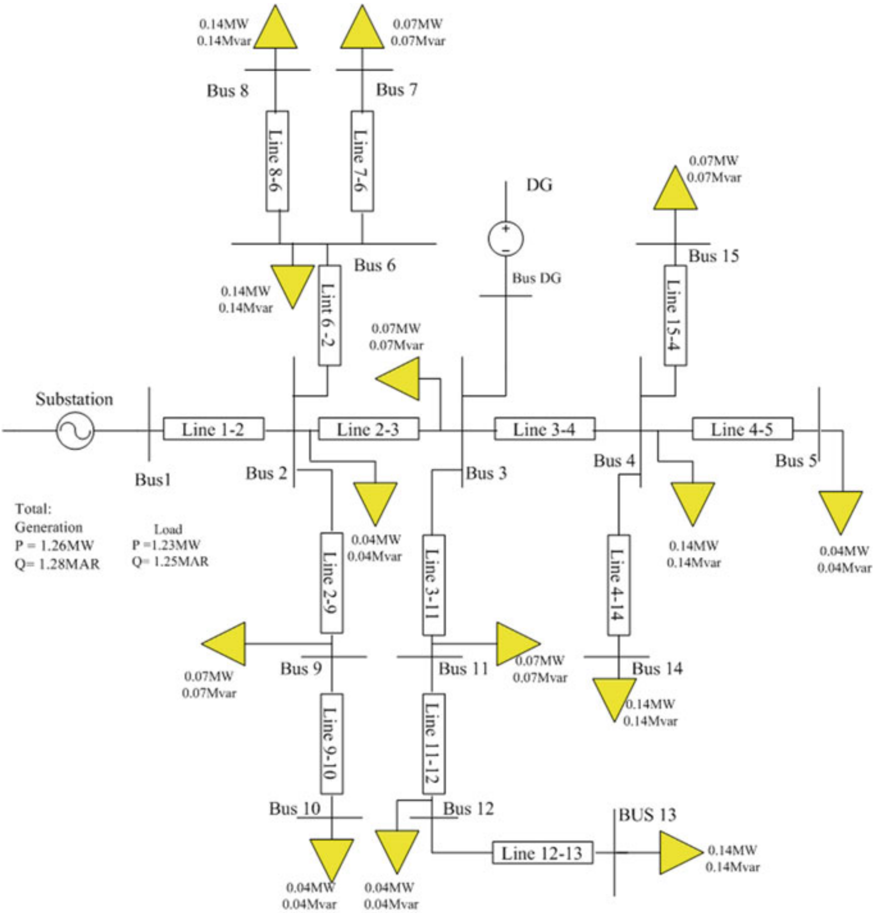

Fig. 2 IEEE 15 distribution system

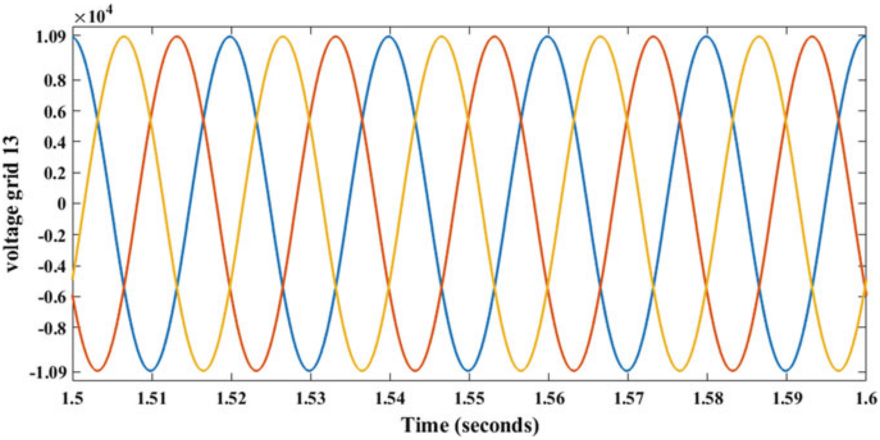

Fig. 3 Bus voltage waveform without PV charging or DG

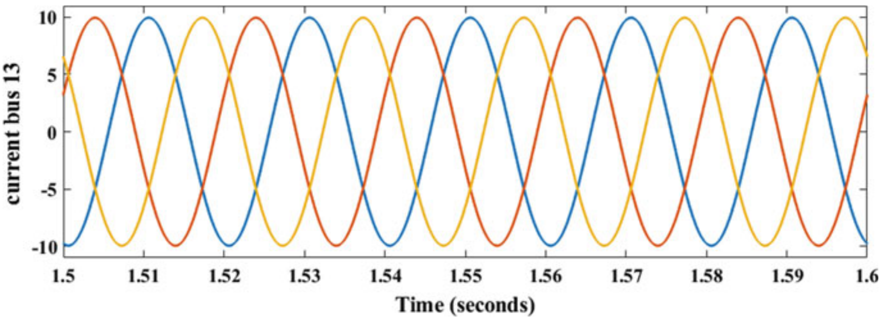

Fig. 4 Bus current waveform without PV charging or DG

The simulation of IEEE-15 bus system has been shown in Fig. 2. This is simulated without inclusion of any PV or EV charger. The waveform of the bus voltage and bus current at bus number 13 (the weakest bus) is shown in Figs. 3 and 4 (Table 1).

3.2 IEEE-15 Bus System with EVC

Now, to evaluate the effect of the electric vehicle based charger with converter, it has been integrated with IEEE-15 bus systems as shown Fig. 5. The EV charging module is group of electronic circuitry. It converts available AC distribution power into DC of appropriate level to charge vehicle batteries. Usually these chargers can work with multiple voltage and power levels to increase its operation universally. With progress in technology, charges can perform multiple operations for better grid integration, mainly taking into account the power quality [19, 21] (Fig. 6).

Table 1 Line and load data

S. No.	Line	*R*	*L*	*P* (kW)	*Q* (kW)
1	1–2	1.3	0.0035	44.1	44.99
2	2–3	1.17	0.0030	70	71.41
3	2–6	2.557	0.004	140	142.82
4	2–9	2.013	0.003	70	71.41
5	3–4	0.84	0.0021	140	142
6	3–11	1.79	0.0032	70	71.41
7	4–5	1.53	0.00275	44.1	44.99
8	4–14	2.2308	0.00399	140	142.82
9	4–15	1.197	0.00214	70	71.41
10	6–7	1.088	0.0019	70	71.41
11	6–8	1.25	0.002	140	142.82
12	9–10	1.68	0.0031	44.1	44.99
13	11–12	2.448	0.004	44.1	44.99
14	12–13	2.01	0.003	150	150.82

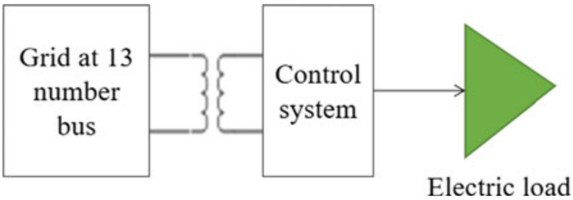

Fig. 5 Block diagram the EVC of grid connected to EVC

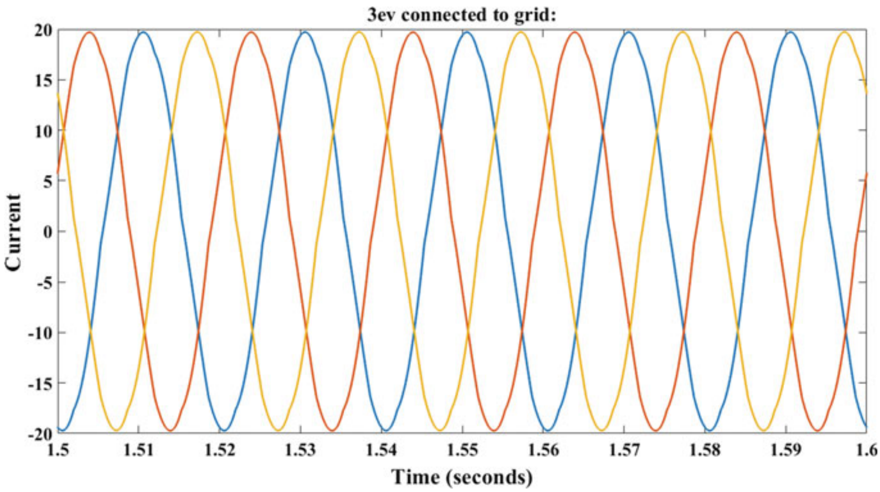

Fig. 6 Bus current waveform grid with EV

Figure 7 shown that the maximum voltage deviation during three electric vehicles charging from the grid. The analysis shows voltage (10,145 V) compare to (10,828 V) without EV charging, current (20 A) compare to (9.95 A) without EV charging, battery voltage (74.34 V) and battery current (167 A) on bus number 13. It can be observed that, the voltage has decreased considerably and current increases (Fig. 6). The voltage on the last bus (load that is more distant from the generator bus) is affected by 7.7% voltage drop, which can cause problems. Grid connected EV Charger output current waveform and voltage waveform is provided in Figs. 8 and 9 respectively.

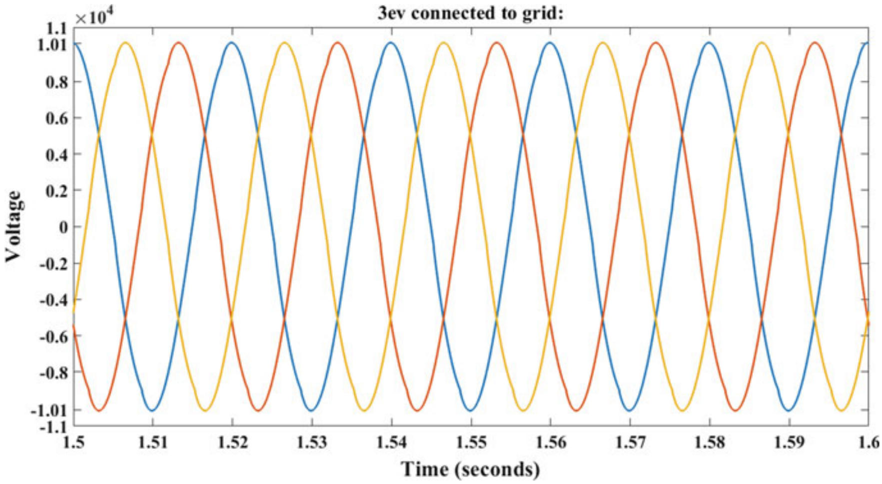

Fig. 7 Bus voltage waveform grid with EVC

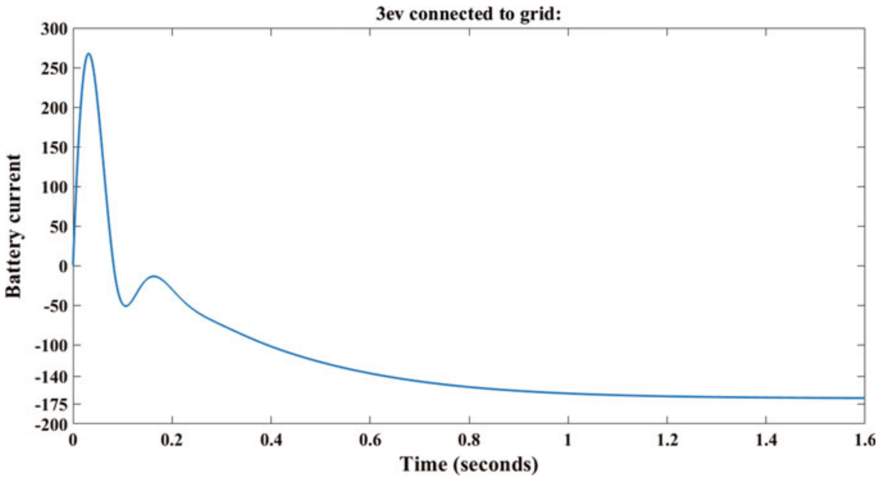

Fig. 8 Charging current of battery

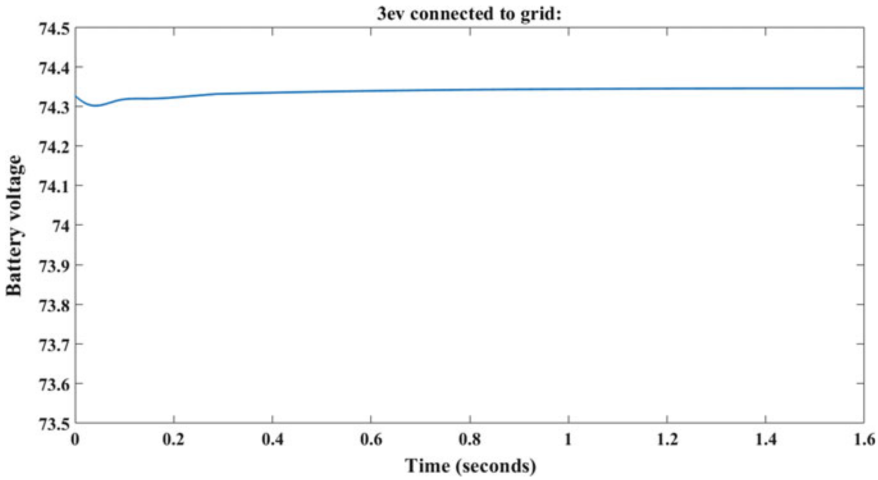

Fig. 9 Charging voltage of battery

Table 2 Total harmonic distortion voltage and current value

Distribution grid connected with EVC	
THDv	1.29%
THDi	2.26%

Simulation results from studies about voltage and current THD during EVC connected to Grid shown Table 2. Total Thad (1.29%) and THDi (2.26%) are inserted in the system.

3.3 Simulation of IEEE-15 Bus System With PV (Solar) as Distribution Generator

Now to analyze the effect of distributed generation on the feeder, a solar power plant rated 50 kW [15, 22] has been included in the simulated 15 bus distribution feeder. The PV has been implemented for a constant radiation of 1000 W/m^2. The solar delivers the power to the bus no 13. Other parameters of the PV system are as: Module: 1 Soltech 1 STH-215-P; Parallel string 0–4; Series-connected module per string-7; Irradiance-1000 W/m^2; Temperature-24 °C; Open circuit Voltage −36.3 V; Short circuit Current −7.84 A; Number of cell per module-60 (Fig. 10).

The topology used in this work uses buck type DC-DC converter to connect the PV with grid. The system was later simulated using simulation (MATLAB) software [19, 21]. With help of Phase Lock Loop (PLL) the output parameters of the inverter has been synchronized with the grid parameters. Harmonics in the output of the

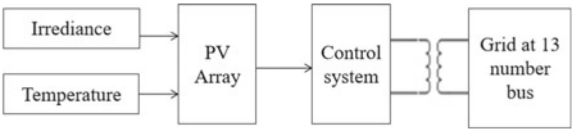

Fig. 10 Block diagram of grid with PV

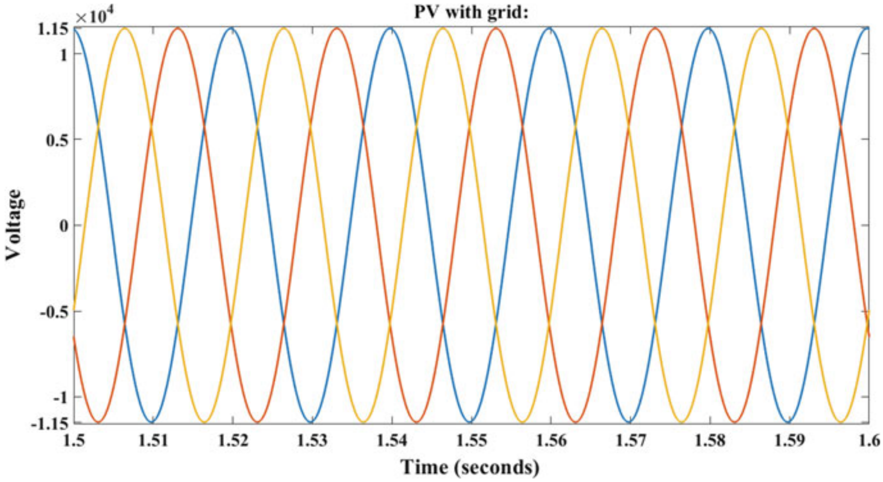

Fig. 11 Bus voltage waveform grid with PV

inverter will be taken care by inductive filters. To connect the 400 V output of the inverter, a step-up 400 V/11 kV transformer is used as interconnection to the grid.

With the inclusion of a PV generation with a constant irradiation on the IEEE-15 bus system. From Figs. 11 and 12, it can be noted that, voltage at bus 13 (11,450 V) has been increased and current at bus 13 (7.45 A) reduced. The PV is generating voltage (204 V), solar power (50 kW) with solar current (249 A). Total THD generated with proper filtration has been given in Table 3, respectively, THDv and THDi.

3.4 IEEE-15 Bus System with EVC and PV (DG)

The solar power plant is rated as 52 kW implemented with a constant radiation of 1000 W/m^2 and hence it provides constant output. The output of the PV is transformed to 11 kV with the help of a transformer. The PV is connected to bus no. 13 as in the previous case (Fig. 10).

An integration of the DG and EVC with IEEE-15 bus system is shown in Fig. 13. Figures 14 and 15 shows, time based variation in the voltage and current at Bus number 13.

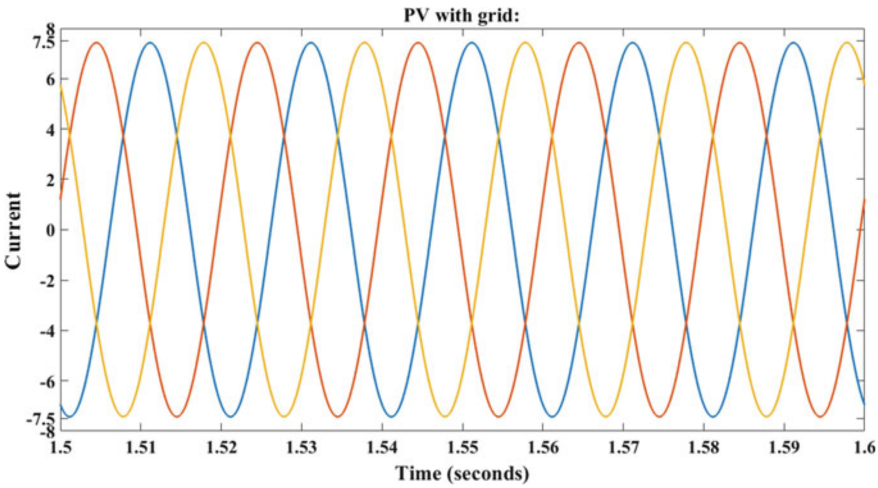

Fig. 12 Bus current waveform grid with PV

Table 3 Total harmonic distortion voltage and current value

Distribution grid connected with DG	
THDv	0.00%
THDi	0.01%

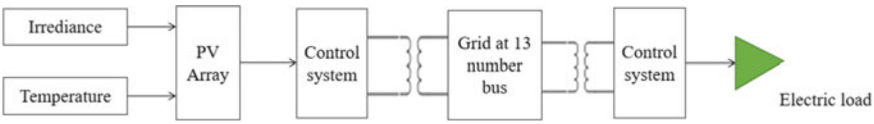

Fig. 13 Block diagram of grid connected EVC and PV

When the IEEE-15 bus standard distribution network is simulated with EV and PV simultaneously following observation are made.

- The bus voltage at bus 13 (10,850 V) remains almost constant when it is with any EV charging or PV generation
- The bus is handled much more current of (18.7 A)
- EV output voltage (204 V) with solar power (52 kW)
- Battery voltage (74.35 V) and battery current (200 A) waveform are shown below for 13 number bus.
- It can be observed from these results that voltage rating of the bus is increased and current rating decreases. It can be seen in Figs. 14 and 15 respectively. Therefore, an observation can be made that, the DG at bus number 13 is supporting the grid in case of the EV charging for better maintaining of the electrical parameters.

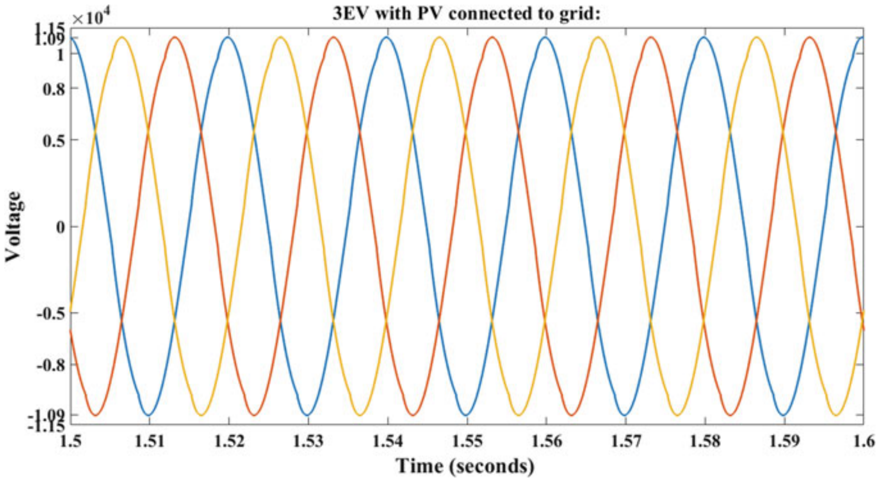

Fig. 14 Bus voltage waveform grid with EVC and PV

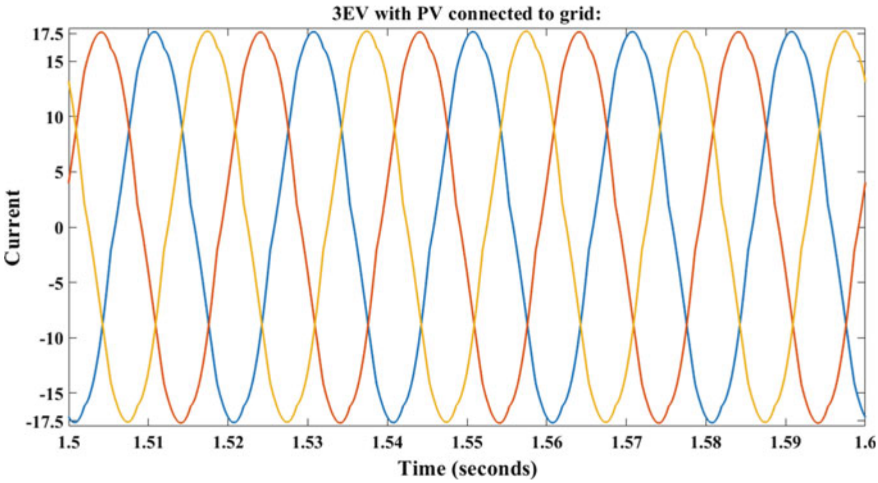

Fig. 15 Bus current waveform grid with EVC and PV

Like maintenance of the voltage level and by then reducing the requirement of current (Fig. 16).

Electrical Vehicles Charging current also increase from 167 A (EVC—Fig. 8) to 200 A (EVC with PV—Fig. 17).

Simulink system and observe THD value at bus shown Table 4 respectively with THDv and THDi. The current consumed THD is increasing from 2.26% (EVC) to 2.87% (EVC with PV) but it's within acceptable standard limit [14, 23]. A detailed

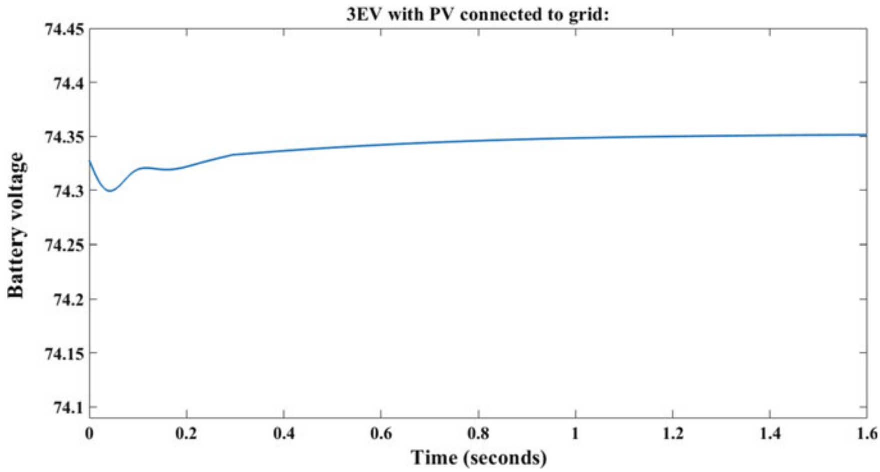

Fig. 16 Battery charging voltage

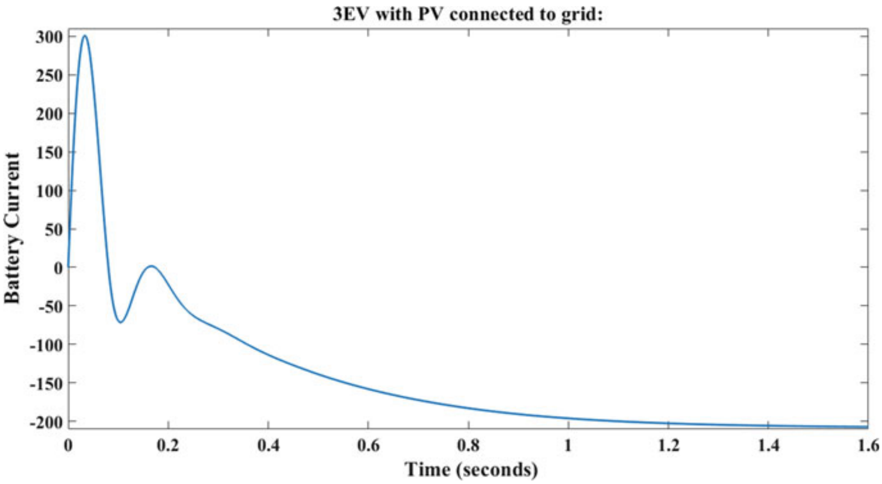

Fig. 17 Battery charging current

Table 4 Total harmonic distortion voltage and current value

Distribution grid connected with DG and EVC	
THDv	1.35%
THDi	2.87%

Table 5 Comparisons of grid with different cases

Distribution grid-bus parameter	Standard distribution-grid	Distribution grid with EVC charging	Distribution grid with PV Support	Distribution grid with EV charging and PV support
	$V = 10828$ V $I = 9.95$ A	$V = 10145$ V $I = 20$ A	$V = 11450$ V $I = 7.5$ A	$V = 10850$ V $I = 18.7$ A
Solar rating	NO PV connected	NO PV connected	$P = 50$ kW $V = 204$ V $I = 249$ A	$P = 52$ kW $V = 204$ V $I = 256$ A
EVC charging rating	NO EV connected	$V = 74.34$ V $I = 167$ A	NO EV connected	$V = 74.35$ V $I = 200$ A
THDV THDI	0% 0%	1.29% 2.26%	0% 0.01%	1.35% 2.87%

comparison of Voltage, current and THD variation for all considered four system variations has been provided in Table 5.

4 Conclusions

The distribution network affected adversely with increasing usage of electric vehicles (EV) chargers. These effects can be given as voltage deviation, power quality loss, increased losses, increased transformer loading, increasing current rating etc. This article investigates these effects of EV charging with standard charging points and observing its effect. To do so, a Simulink model of IEEE 15 bus distribution grid had been simulated. To evaluate the worst possible network condition, the EV charging station has been simulated on the weakest bus. This evaluation has been performed for the voltage, current and THD level.

To find out the solution to this problem, a solar DG has been implemented in the identical system. It can be observed from the obtained results that, with the inclusion of DG, a favorable change can be observed in the grid. The effect of EV charger will get reduced. It also proves that, the transformer rating can also be reduced with the help of DG.

Therefore, it can be reckoned that, difficulties observed during the implementation of the EV charging in distribution grid can be overcome by providing ancillary services like Distributed Generation (DG).

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