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Modified Z-Source PV D-STATCOM for power quality improvement of EV charging station

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ABSTRACT

Over the year power quality has remained in the area of hotspot research for researchers, engineers and designers as the integration of renewables with grid involves large no. of power electronics switching devices. Many power quality improvement devices and compensation devices have been developed over the year and recently a shunt connected device called STATCOM has attracted huge amount of research because of its total compensation capability. It offers the capabilities of voltage regulation, power factor improvement, reactive power compensation and harmonic mitigation. Many researchers have worked on STATCOM, their configurations, control strategies and applications to address power quality issues. This paper discusses a modified Z- source PV D-STATCOM for mitigation of harmonics arising in a grid connected electric vehicle charging station. The operation of PV D-STATCOM is controlled with a novel controller. The power flow operating modes of the system are discussed and results are presented for each of the operating mode.

Keywords: PV D-STATCOM, harmonics, EV charging, V2G, G2V

INTRODUCTION

The effects of electric vehicle charging and grid integration of PV system on the stability of grid and power quality have interconnected relationships.[1] The negative effect on grid stability and power quality are observed with intermittent nature of PV system and uncertainty of electric vehicle loads during battery charging when they are considered as individual. Key points for dealing with the unpredictable nature of renewable energy are to be kept in mind[2] for achieving the 100% renewable energy grid. The renewable energy integration also addresses grid stability criteria's such as inertia, voltage regulation, active and reactive power control and fault ride through capability. According to the stability analysis by Remon et al.,[3] the grid connected PV power plant with synchronous power controller increases the damping from 2 to 6%. The also cause frequency deviation up to 10%. The behavior of EV charging is never the same for all week days and is dependent on users charging requirement. Hence daily peak power requirement also changes. In the night time, the charging requirements are fulfilled by the grid. A battery energy storage system integrated with PV system can significantly reduce this impact.[4]

The basic component of grid connected electric vehicle charger is AC to DC converter often referred as rectifier. A rectifier does not follow linear voltage – current relationship hence it is a nonlinear load. The harmonics in battery charger hampers transformer life. To have reasonable life expectancy of the transformer, the THD of battery charger should be limited to 20%.[5] The adoption of electric vehicles has resulted in a progressive growth in the scale of nonlinear charging infrastructure in the form of charging stations, which will pollute the distribution system with significant harmonics. As a result, electric vehicle battery charging system designers must be aware of the possible influence of their designs on harmonic emission in order to take suitable steps. If more than one EV chargers are connected in the system, the

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summation effect takes place to further increase harmonics.[6] A general method for prediction of harmonic current generated by increased concentration of EV battery chargers has been presented by Yanxia et.al.[7] The harmonic current of clusters of EV chargers is taken for analysis and current THD was found to be 45%. The MATLAB simulation of EV chargers[8] shows that the 3rd order harmonics is dominant and next dominant is 9th order harmonic. The PWM based EV charger provides flexibility of operation. The findings suggest that if electric vehicle charges are properly regulated, harmonic cancellation owing to diversity effects may be accomplished. This might be a good way to decrease harmonic pollution caused by EV charges.[9]

To negate the ill effects of the nonlinear loading formed for the EV charging, a compensation solutions have been proposed by many researchers, designers and engineers through numerous FACT devices. A STATCOM in many ways appears as a near best solution. The higher penetration of EV charging station introduces voltage sag. Zaidi et. al.[10] have demonstrated a control technique to mitigation of voltage drop with D-STATCOM deploying reactive power compensation. The use of VSI fed D-STATCOM of Sawan et. al.[11] has demonstrated reduction of harmonics from 35. 88% to 3.88%. The control technique of STATCOM[12] assures constant voltage in case of sags as well as swells. In a system where electric vehicle battery is operating in V2G and G2V mode, a STATCOM can be deployed for regulating PCC voltage by supplying reactive power through STATCOM. The control techniques for active power control, reactive power control and harmonic and imbalance reduction can be deployed independently to improve power quality of distribution system.[13] The performance analysis of distribution system with D-STATCOM shows a stable voltage profile despite occurrence of any fault.[13]

The connectivity of Electric Vehicle to grid for exchange of real and reactive power makes the system smart[14] and explore updates in EV infrastructure. The STATCOM's power control strategies can assist grid integration of renewable energy systems.[15] A STATCOM[16] with ANFIS based IRP control and HCC regulates the THD below 5% which is in accordance with the IEEE 519 standards. Since the STATCOM seems to be the best possible solution for improving power quality of the power system, it is proposed to mitigate the harmonics produced by grid connected EV charging station through a modified Z-source PV D-STATCOM.

Grid Connected EV Charging Station with PV D-STATCOM Compensation

The proposed system of grid connected EV charging station with PV D-STATCOM compensation is shown in figure 1. It consists of bidirectional AC-DC and bidirectional DC-DC Converter for charging electric vehicle through grid.[17] These converters configure the EV charging station for power flow from grid to vehicle (G2V) and vehicle to grid (V2G). On the other hand, a DC bus is formed to integrate the DC battery charging devices and auxiliary battery which is charged by a PV array. The modified Z- source PV D-STATCOM is fed through PV panel and DC bus. The Z source configuration for inverter STATCOM is selected on account of its advantages like improved reliability, lower harmonics distortion and improved fault tolerance. The operating modes of the PV D-STATCOM are configured according to the available light intensity during daytime and night time. A controller is developed to control all the operations in the system. The detailed specifications of the proposed system are mentioned in table 1.

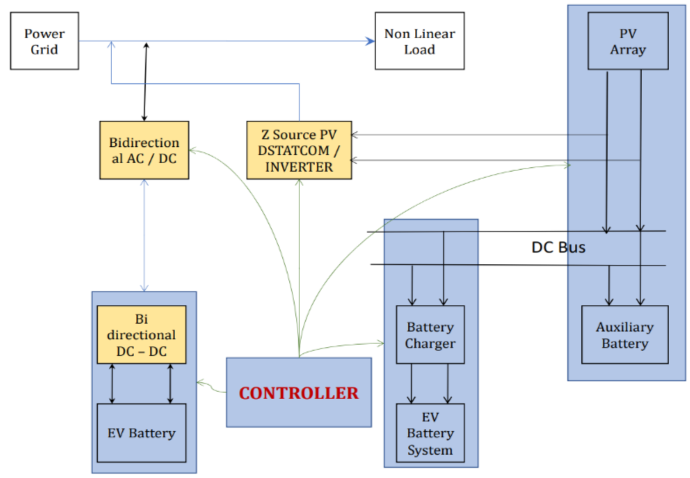

Figure 1: Block diagram of Grid Connected EV Charging Station with PV D-STATCOM

Table 1: System Specifications

Source	**11KV, 50HZ**
Transformer	Y-Y Grounded, 100MVA, 50Hz, 11KV/415V
Electric Vehicle Interface	
LCL Filter	
L1-C1-L2	5mH, 30µF, 5Mh
Inverter DC Link capacitor	5600µF
Buck Boost Converter	
Inductor	20mH
Capacitor	6.25µF
Switching Frequency (DC-DC converter)	10KHz
EV Battery	360V, 300AH
Non-linear load	Diode bridge rectifier with RL P = 10KW Q = 100VAR
PV STATCOM	
PV array @ 25°C, Maximum radiations = 1000W/m^2	No. of series cells (Ns) = 1905 No. of parallel cells (Np) = 10 Voltage per cell = 0.42V MPPT – Incremental Conductance Fmppt = 10KHz Max Power = 16.2MW
Control Technique	SRF (DQ) Theory
Switching frequency (STATCOM)	Fs = 5000Hz
DC link battery	1000V, 750AH
Z source parameters	Lz = 1.41mH (4 nos.) Cz = 1000µF (2 nos.)
LCL Filter for STATCOM	L1 = 0.1mH C = 800µF L2 = 5mH
Coupling transformer	Y-grounded D11, 100MVA, 50Hz 415 / 11KV

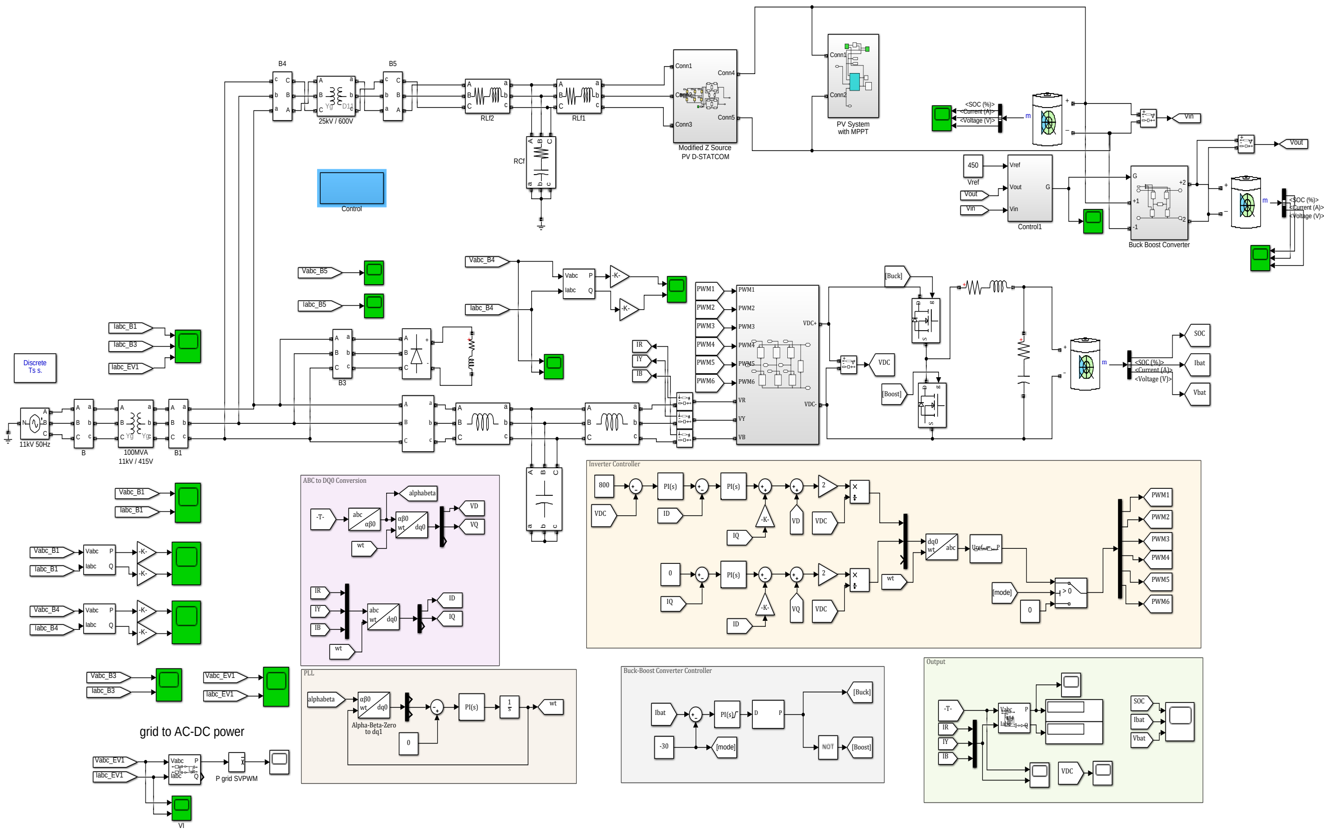

Figure 2: MATLAB Model of the system

EV on DC link	
Battery	400V, 300AH
Buck boost converter	L = 100mH Fs = 2000Hz

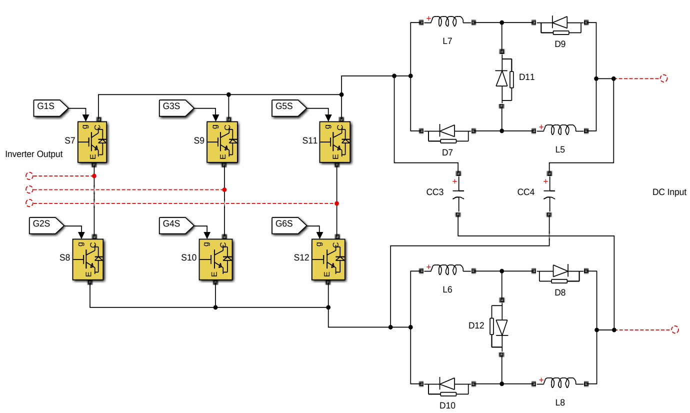

Figure 3: Modified Z source inverter

The MATLAB Model of the overall system is shown in figure 2. The system consists of the modified Z-source inverter STATCOM as a compensation device, a grid connected electric vehicle charging station and a PV based battery charging forming a DC bus. An auxiliary battery is charged over PV system only and a battery charger is incorporated for charging of electric vehicle battery which charges the EV battery through PV system if sufficient radiations are available and in case the solar radiations are absent, the EV battery is charged from auxiliary battery. A bidirectional buck boost converter is reply to provide the necessary interface between the DC bus and electric vehicle battery. The PV system is incorporated with maximum PowerPoint tracking based on P & O algorithm which ensures maximum power delivery from PV system. The DC output of PV system is fed to modified Z source inverter. The configuration of this modified Z source inverter which is further operated as STATCOM is shown in figure 3. The STATCOM is integrated with the grid consisting of a nonlinear load and a grid connected electric vehicle charging station. The EV charging station is configured through bidirectional AC-DC and DC-DC converter hence supporting vehicle to grid (V2G) and grid to vehicle (G2V) power flow.

Results and Discussion

The operating modes of this system are based on solar radiations input or in other words the power output of the PV system.[18] The operation DC side of the system in demonstrated through figure 4, figure 5 and figure 6. The figure 4 indicates the proportionality of power output of PV system to solar irradiations. Based on the power output of PV system, the auxiliary battery is charged as seen through the state of charge in figure 5. In presence of sufficient solar irradiations, the EV battery as well as auxiliary battery charging takes place through PV system output whereas, in absence solar irradiations, the EV battery charging is done through auxiliary battery.[19] The indication of EV battery charging is shown in figure 6 through state of charge.

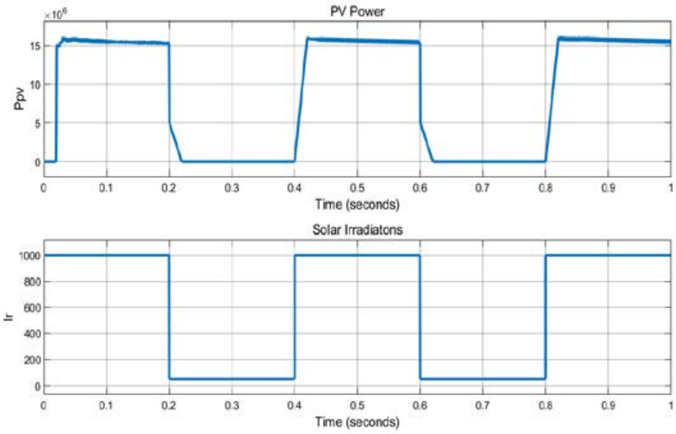

Figure 4: irradiations and PV power output

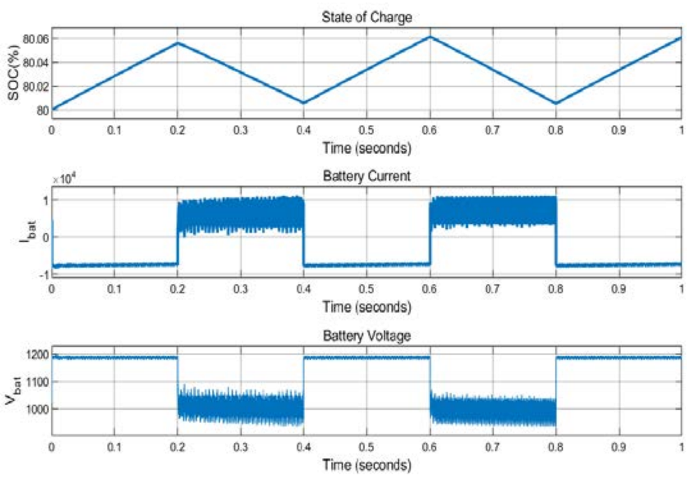

Figure 5: Auxiliary battery charging status

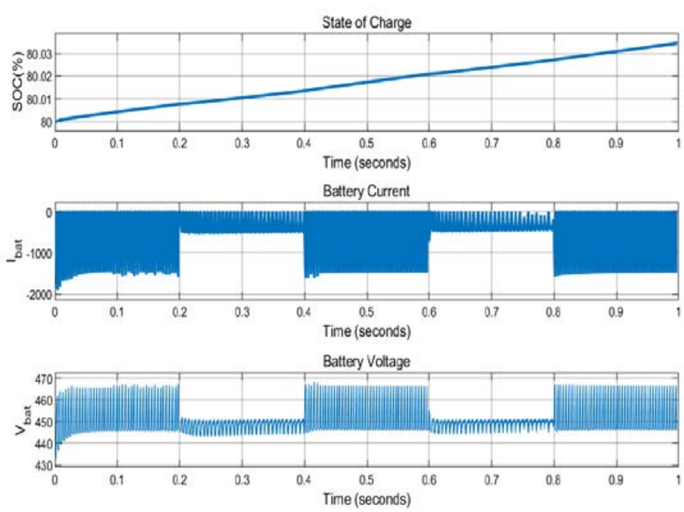

Figure 6: EV battery charging status (DC side)

In case of the grid connected EV, the interface operation is accomplished through grid connected inverter and a bidirectional buck boost converter. The vehicle to grid interface is controlled through DQ theory based on Park's and Inverse Park's transformation. The power flow operation from grid to vehicle or from vehicle to grid is based on state of the charge of electric vehicle battery and correspondingly the bidirectional converter operation is build based on the battery current. In grid to vehicle (G2V) operation mode the power is taken from grid to charge the battery. The graph of grid power is shown in figure 7 and that of battery SOC is shown in figure 8.

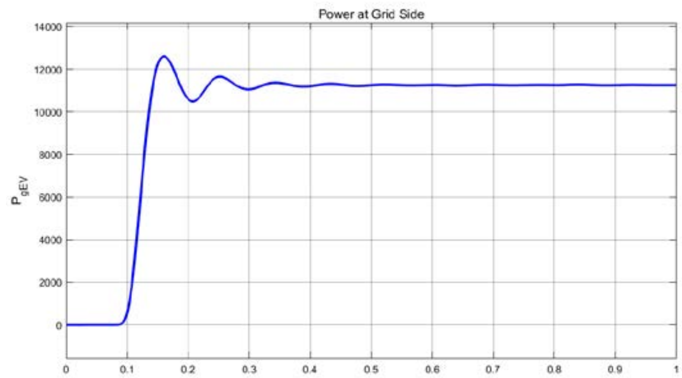

Figure 7: grid power in G2V mode

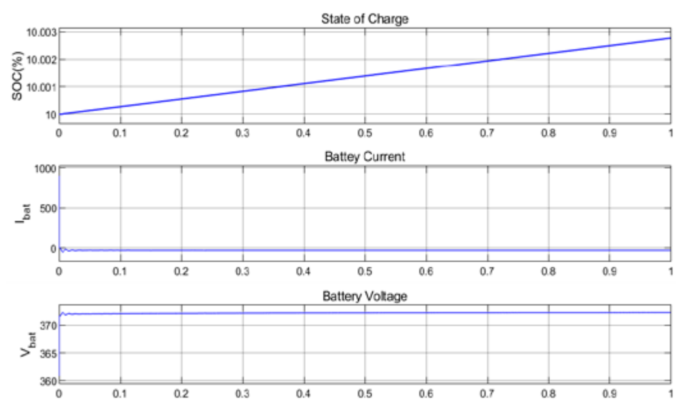

Figure 8: Battery Status in G2V mode

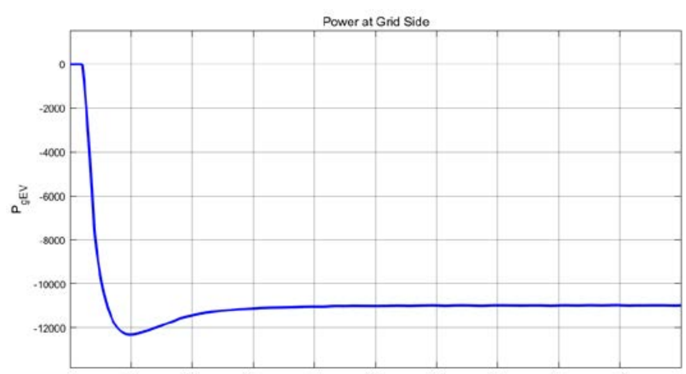

Figure 9: grid power in V2G mode

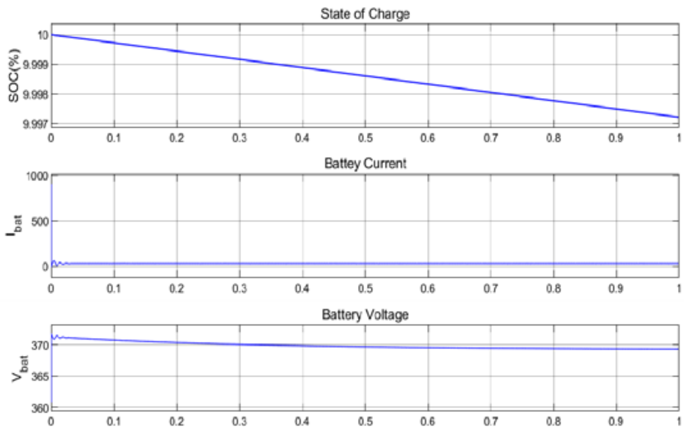

Figure 10: Battery Status in V2G mode

In case of the vehicle to grid (V2G) operation mode, the active power is fed to the grid from EV battery. For V2G operation, the graph of grid power is shown in figure 9 and that of battery status is shown in figure 10. The active and reactive components of grid power in G2V mode and V2G mode are presented in figure 11 and figure 12 respectively. The waveforms of grid current, load current and EV current in uncompensated G2V and V2G mode are shown in figure 13 and figure 14 respectively.

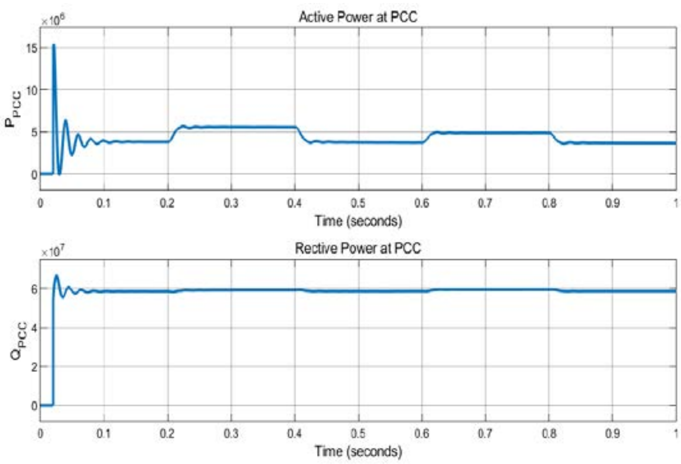

Figure 11: active and reactive power in G2V mode

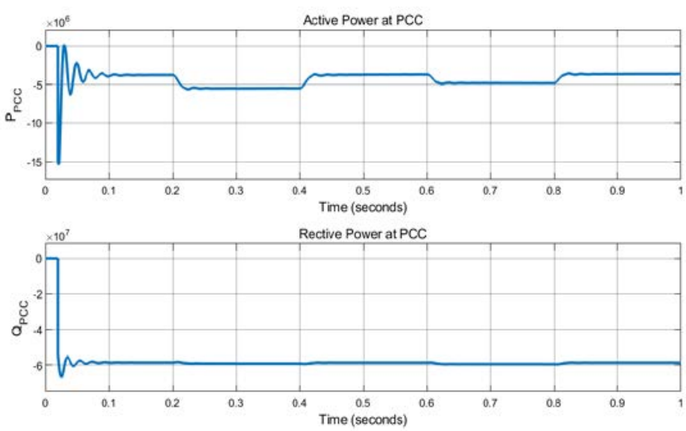

Figure 12: active and reactive power in V2G mode

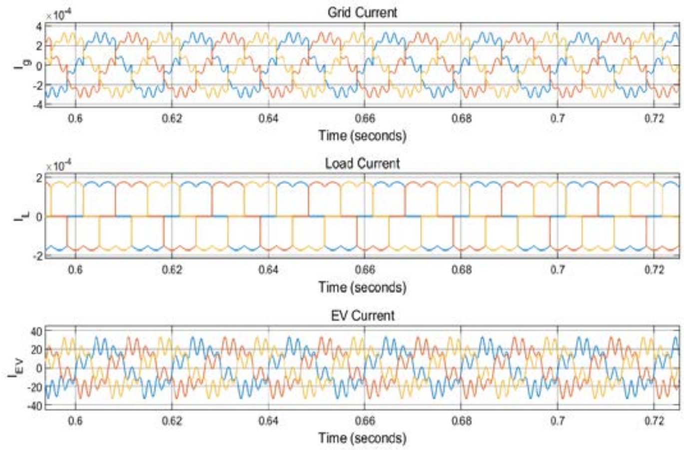

Figure 13: grid current, load current and EV current in G2V mode

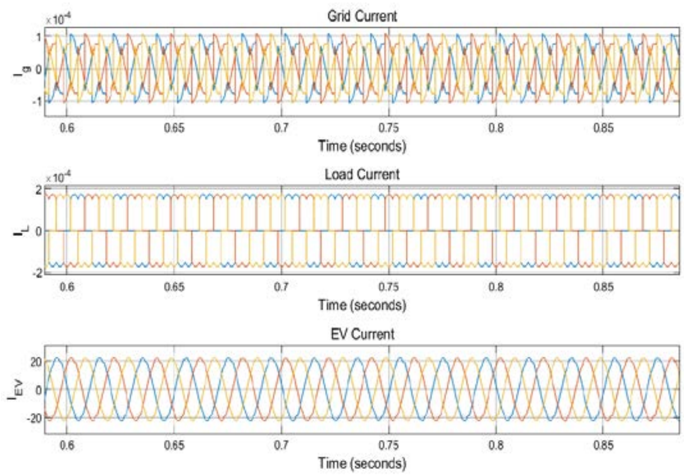

Figure 14: grid current, load current and EV current in V2G mode

During the G2V operation current THD was marked to be 20.87% as shown in figure 15 and that during V2G mode was marked to be 75.65 % as shown in figure 16 when no harmonics compensation was applied to the system.

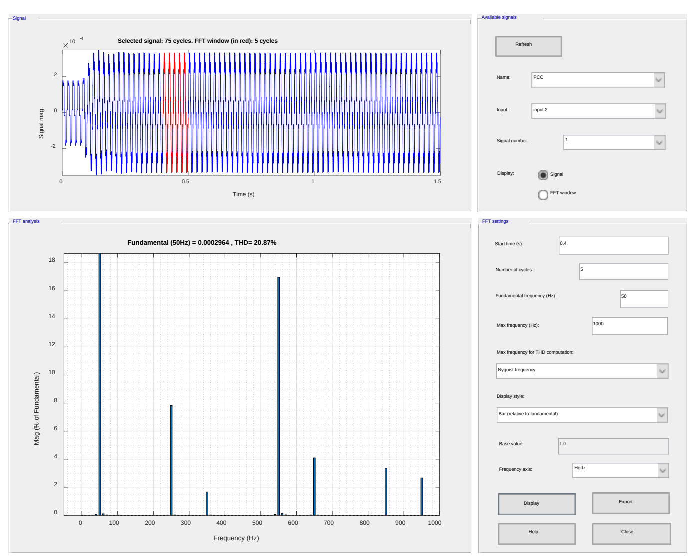

Figure 15: I_{THD} in G2V mode

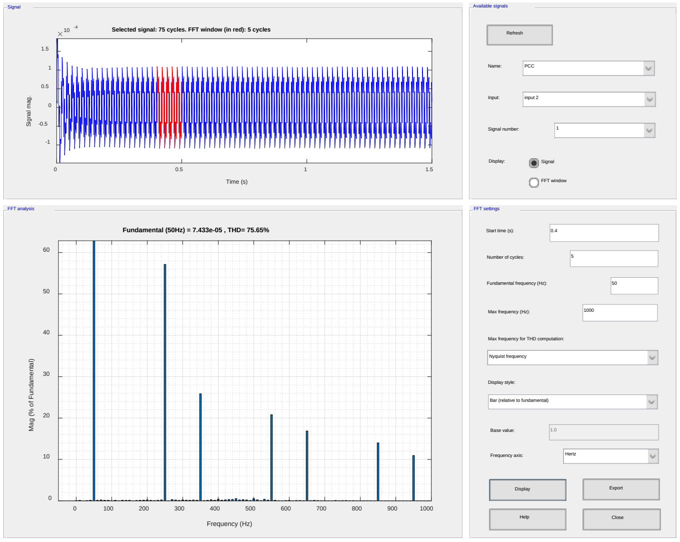

Figure 16: I_{THD} in V2G mode

Harmonics are caused by non-linear loads such as rectifiers, power electronics, and variable speed drives. The presence of harmonics in a power system can have several effects, including overloading of equipment, Power quality problems like voltage distortion, which can lead to flicker, equipment malfunctions, increased losses, interference with communication systems and safety hazards. To mitigate the effects of harmonics, it is important to design power systems with harmonic considerations in mind. This may involve the use of filters, harmonic traps, or other devices to reduce the levels of harmonics in the system. Upon compensation with modified Z-source PV D-STATCOM, the current waveforms are smoothened as shown in figure 17 for G2V mode and figure 18 for V2G mode.

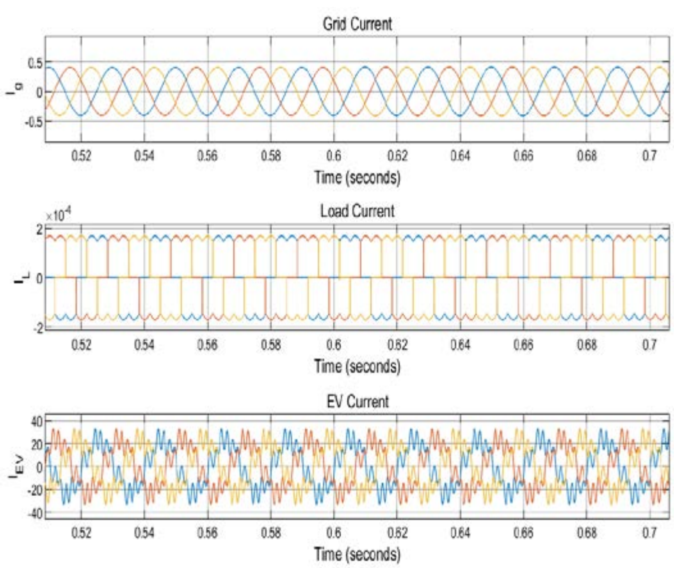

Figure 17: grid current, load current and EV current after STATCOM compensation in G2V mode of EV charging station

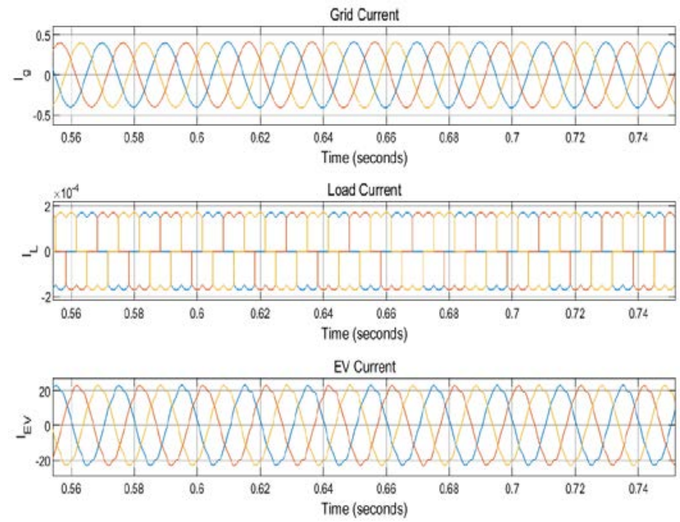

Figure 18: grid current, load current and EV current after STATCOM compensation in V2G mode of EV charging station

Figure 19: I_{THD} with STATCOM compensation in G2V Mode of charging station

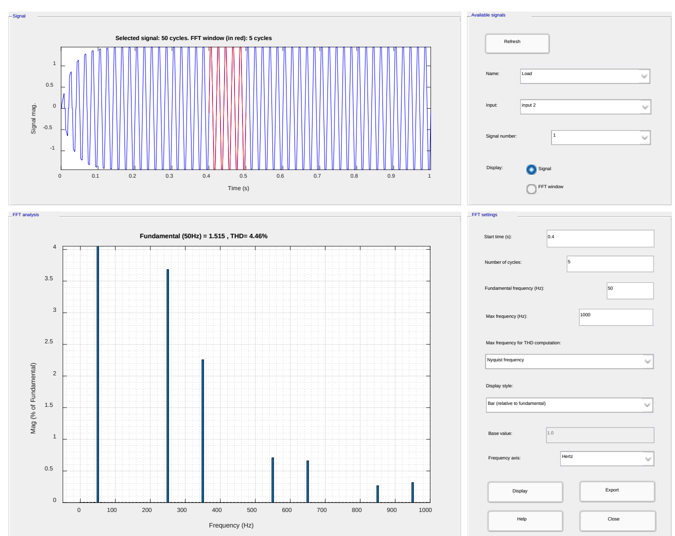

Figure 20: I_{THD} with STATCOM compensation in V2G Mode of charging station

On compensation, the THD value is reduced to 2.88% measured at PCC as shown in figure 19 for EV charging (G2V) mode. The THD value in V2G mode is 4.46%. Thus, it can be said that the harmonics value upon compensation with modified Z-source PV D-STATCOM falls within the IEEE519 power quality standards.

Conclusion

The power quality of grid connected EV system integrated with PV is disturbed due to the presence of large no. of switching devices and STATCOM and nonlinear loads of rectifiers and drives. The nonlinear loading produces harmonics which must be mitigated to a safe value. The modified Z source PV D-STATCOM based compensation is effective to limit THD value to 2.88%. In comparison with the cited literature this THD value of proposed model is much less than that of 3.88% of Kumar et.al.[12] and 3.54% of Irfan et.al.[16]; and is also within the limits specified by IEEE 519 power quality standards for harmonics.[20]

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Conflict of Interest Statement

Authors do not have any conflict of interest for publication of this work.

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