

Design & Development of Advanced Harmonic Mitigation Techniques for Grid-Connected Electric Vehicle Charging Stations

Rupali Somkuwar¹, Kunal Sawalakhe², Ganesh Wakte³,
Pritesh Mhaiskar⁴, Ritesh Banpurkar⁵, Akanksha.Sontakke⁶

^{1,2,3,4,6}Department of Electrical Engineering
Tulsiramji Gaikwad Patil College of Engineering & Technology,
Nagpur, India

⁵Department of Mechanical Engineering
Tulsiramji Gaikwad Patil College of Engineering & Technology,
Nagpur, India

Abstract

The overall harmony distortion (THD) values recorded during the charging of numerous production electric cars at various starting states of charge—when possible—using both the 13A & 32A recharging modes—are reported in this study. The total harmonic distortion (THD) of several electric vehicles with comparably powerful on-board chargers varies, however they all largely remained within the law. For one type of onboard charger, the measured total harmonic distortion (THD) ranged from 2 to 4%, while for a different kind, it reached up to 12%. 32A chargers using 13A mode exceeded the harmonic voltage limitations established for 13A chargers, even though individual harmonics of current met with standards. Using an Indian sample network, the study also ran simulations to evaluate the effects of distortion caused by harmonics on small-voltage networks. The findings suggested that there was little chance of noticeable voltage harmonic distortion on the substation. Certain vehicle types have the capacity to charge at each residence without resulting in severe voltage harmonic distortion; the vehicle type with the lowest performance can charge at up to 87% of houses at the same time. Nevertheless, because chargers outputting the maximum allowed current harmonics could result in extremely high levels of distortion, the investigation revealed shortcomings in the UK laws covering 32A vehicle chargers. This emphasizes the necessity of reviewing regulatory requirements to handle possible problems brought on by harmonic distortion in the systems that charge electric vehicles.

Keywords— Total Harmonic Distortion; Harmonic; Power Quality; Electric Vehicle Chargin etc.

1. INTRODUCTION

The number of electric vehicle (EVs) linked to low voltage systems, especially those on the grid, has significantly increased in recent years. The increasing popularity of electric vehicles contributes significantly to the future transition to cleaner energy. Interest has been piqued by the potential that

electric mobility presents for the Smart Grid, as well as the convergence of the energy and automotive industries. Two million electric automobiles are expected to use between four and five TWh of electricity in France in 2020.

The expected rise in the overall fleet of EVs raises concerns about potential technical issues and repercussions on power systems, especially with regarding distribution-level reliability of power interruptions. The growing number of battery-powered cars might lead to instability and harmonic interference through charging winds; therefore, rules such as EN 50160, which cap the overall harmonic distortion of the supply voltage at 8%, must be followed.

Electric vehicles have different charging modes. Normal charging can run for up to 8 hours at 3 kW (16 A), whereas fast charging can run for 20 to 30 minutes at 43 kW (63 A). For instance, the Renault Zoe comes with a single AC/DC converter, charger, and charging port. In auto-adaptive mode, it can accept a wide range of current inputs, from 400V 63A 3-stages (43 kW) to 230V 10A 1-stage.

Voltage quality is greatly affected by fast charging because it consumes a lot of electricity, particularly at the connection point. Research has employed load flow modelling and statistical techniques to address the harmonic challenges associated with EV charging. Although there are practical issues, several methods involve lowering current harmonic distortion by coordinating among vehicles in the network.

A long-term solution to cut expenses is to buy a PV solar energy system, especially considering how much fuel, natural gas, electricity, and other petroleum products are costing now. Photovoltaic (PV) systems for electric vehicle charging are a viable choice, especially as fast charging often occurs during hours of maximum solar production. Ancillary services can be provided by integrating solar power plants into rapid charging stations. Advanced control strategies can reduce harmonics created by EV fast charging by using PV inverters to act as filters.

2. EXISTING CONFIGURATION

Plug-in electric cars are becoming more and more popular because they provide cleaner technology, more efficient generators, and vehicle-to-grid capability. These features allow the grid to store excess energy and provide support during peak hours. Emissions of greenhouse gases have decreased as a result of public opinion and federal restrictions. However, the non-linearity of electricity transmission at charging stations and the quick spread of electric vehicles have made voltage quality & harmonic distortion problems worse, which is affecting smart grid power transmission networks & sources of clean energy (such solar and wind). Major power quality issues with delivery feeders have included flicker, resonance, equipment disruption, line losses, temperature, vibrations, noise, malfunctions, and flaws in sensitive/metering systems. It has been found that sinusoidal and non-sinusoidal charging station currents significantly increase harmonic and fundamental inefficiencies.

An active filter needs to be used in conjunction with the charging stations to lessen the harmonics that the stations introduce, offset any temperature rises, and prevent further damage. Plug-in electric cars, also known as PEVs, are typically charged within the house, at public parking lots, or at power outlets. This is a fundamental part of smart network modernization, It aims to modify distribution system

architectures that date back more than a century in order to satisfy changing electrical demands. Distribution systems are under pressure since charging points are planned to be deployed in household or light industrial locations due to their high ratings for swiftly recharging PEVs during brief periods of charging.

Moreover, the fluctuating price of crude oil has affected the marketplace for electric vehicles (EVs), which makes EVs a viable alternative. As a result, more charging stations have unintentionally been built across the distribution network. On the other side, installing a lot of haphazard chargers can result in an increase of electrical losses. Harmonic distortion, which happens when electronic control systems in charging stations convert alternating electricity into direct current, exacerbates the issue even more. Numerous negative consequences, such as decreased productivity, a lower energy factor, greater insulation degree voltage, longer insulation life, plus increased thermal losses, might result from this harmonic distortion. One field of research focuses on the transmission of reactive power, total harmonic distortion, and voltage redistribution profile changes all at once. Several studies have been carried out to incorporate client-side demands into smart grids with the aim of reducing demand during peak times while improving the system's load profiles [11], [12].

3. PROPOSED CONFIGURATION WORK

A. Network to study

There are five electric car fast chargers on display at the fast power source shown in Fig. 1. To link the network with the rapid charging station, a 250 kVA transformer operating at 20/0.4 volts and a 100 metre line hookup are utilised. Five EVs can have at a maximum combined output of 215 kW. At the same giving station, a 50 kW energy-efficient electric power station has been erected. The PV system is built with a high switching rate to power the charger in order to makeup for high order harmonics. Reducing the sine waves each and every of these EVs conveys is the aim of a PV converter in order.

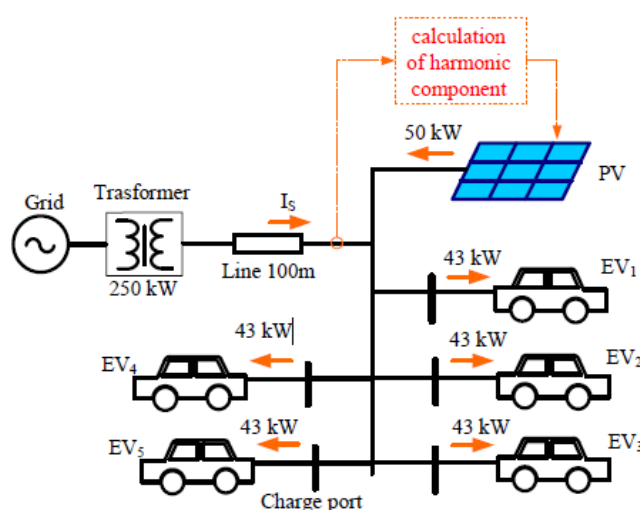


Figure 1. Five electric cars in a fleet with a PV system and a rapid charging station

B. Control of PV systems and EV systems

The quick on-board chargers for batteries, which employs an electric motor as a sort of filter or identical conversion machinery for both charging and propulsion mode, is the essential component of the overall electric architecture in electric vehicles [12] [14] and [15].

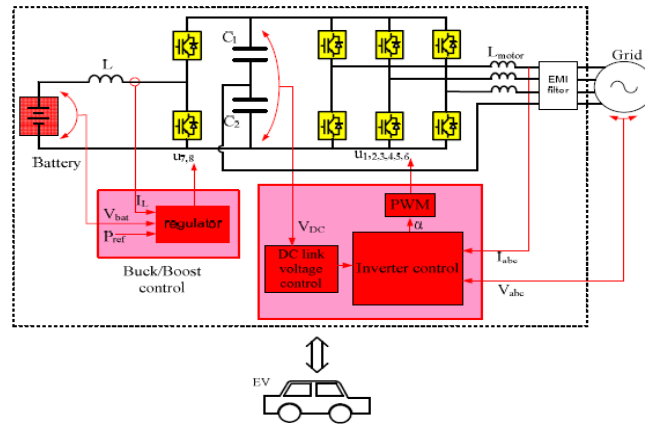


Figure 2. Design and management of battery chargers for electric vehicles

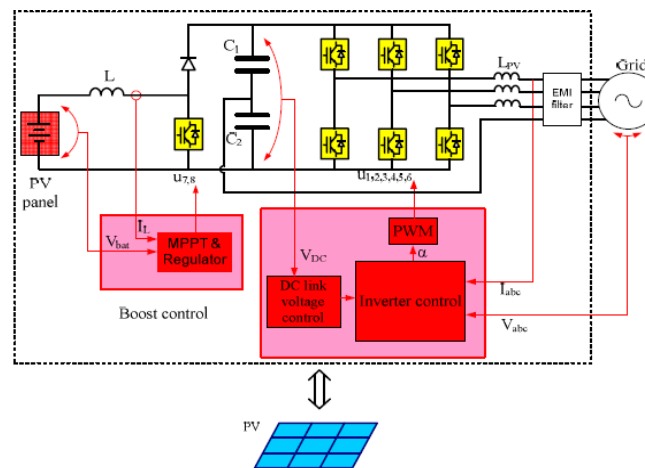


Figure 3. Architecture and setup of PV systems

There are two stages in the charger structure (Fig. 2). DC into DC and nearly DC to AC convertibles. In this study, the converter which converts DC charges the battery by acting as a concurrent chopper. The main grid has a relationship to a three-phase mighty Source Inverter. Grid currents are viewed to reduce the part with a high using an EMI filter. Fig. illustrates the control organisation and structure of the PV system. 3. Figure. The converter for the EV charger control loop, shown in figure 4, transforms DC to DC. The converter regulates the course of an electrical IL for fast charging of electric vehicles using the beginning of the energy $P_{ref} = 43kW$ [12]. To guarantee for the photovoltaic inverter which produces the highest possible power output, Fig. 5 illustrates how the current reference is used by the chopper to improve the current IL. IPPT provided $I^* \cdot L_{ref}$. [13].

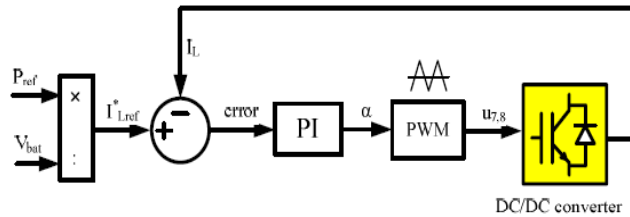


Figure 4. Control of DC/DC links in an automobile powered by electricity

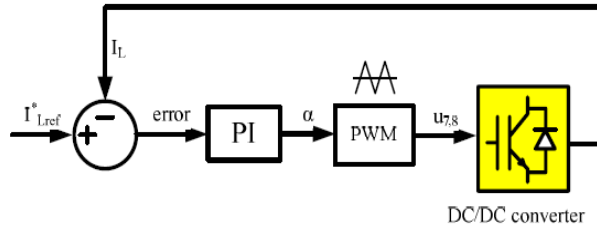


Figure 5. PV inverter control with DC/DC link

The two separate parts of the DC/AC currency converter system of control are the regulation for the voltage of the DC bus (outer loop) and present (inner loop) (Fig. 6). Use the SSFH controller to remove the tuned frequency's steady-state inaccuracy [16]. The PV converter uses DC/AC power conversion management throughout the EV charger (Fig. 6).

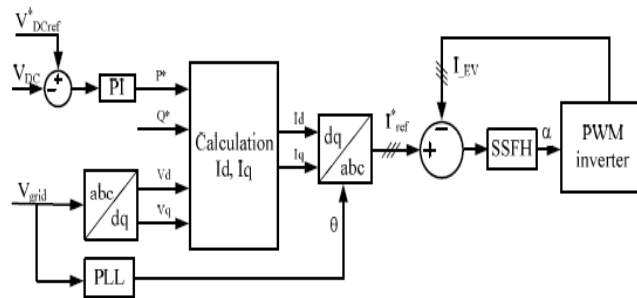


Figure 6. command of the DC/AC connections

elements that are quadrature and direct Using the following formula, we can calculate Id and Iq in Fig. 6:

$$I_d = \frac{2}{3} \cdot \frac{P^* \cdot V_d + Q^* \cdot V_q}{V_d^2 + V_q^2}; I_q = \frac{2}{3} \cdot \frac{P^* \cdot V_q - Q^* \cdot V_d}{V_d^2 + V_q^2} \quad (1)$$

Where,

Idq and Vdq stand for the current & voltage vector elements in the synchronised referent frame.

P* - The DC voltage regulator's active power reference.

Q* - the benchmark for adding reactive power to the grid; under this case, Q*=0.

C. lowering the harmonic current via managing the PV inverter

The charging current should, in theory, be sinusoidal, but this is clearly not the case in practice. Other electric vehicles with THDs between 12% with 20%, respectively, based on measurements include the SRI EDP Hyundai i-MiEV and the Nissan Leaf [17]. Among the numerous odd number harmonic in the spectrum are the third, fifth, or seventh harmonics.

The sum of each DC part, basic part, or harmonic component can be used to express a current, $i(t)$:

$$i(t) = I_0 + i_1(t) + i_h(t) \tag{2}$$

$$= I_0 + I_1\sqrt{2} \sin(\omega t + \phi_1) + \sum_{k=2}^{\infty} I_k\sqrt{2} \sin(k.\omega t + \phi_k)$$

Where,

$i_h(t)$ -total harmonic component

$$i_h(t) = \sum_{k=2}^{\infty} I_k\sqrt{2} \sin(k.\omega t + \phi_k)$$

I_0 , the direct current (DC) component, $i_1(t)$, the fundamental element, and $i_k(t)$, the harmonic component, represent the RMS value for the fundamental as well as harmonic elements.

ϕ_1, ϕ_k phase angle of the harmonic and fundamental components

$\omega = 2\pi f$ (The fundamental component's f -frequency)

One way to express the entire harmonic aberration of $i(t)$ is as:

$$THD_i = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1} .100\% \tag{3}$$

The concept of PV inverter management as a filter that is active is shown in Figure 7. Measuring every current in the conduit IS forms the basis of this principle. All cars, from EV1 to EV5, have their current harmonics compensated by the PV.

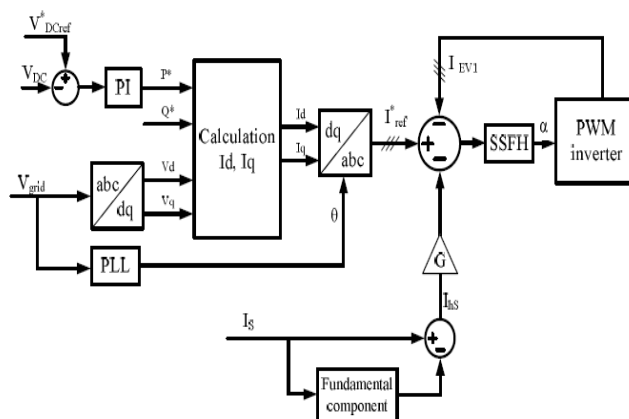


Figure 7. Controlling the DC/AC PV inverter to filter harmonics

To reduce the harmonic currents, the harmonic parts of the current required to charge I_{hS} are added to the electrically present's management circuitry (inner loop), multiplied by a certain amount of G , and subtracted, as shown in Fig. 7.

The Fourier analysis generates the harmonic component of I_hS :

$$I_hS = IS - IfS$$

Where:

The fleet vehicle's estimated current or PV in the line are referred to as IS.

Fourier analysis is used to compute IfS , the crucial component of IS.

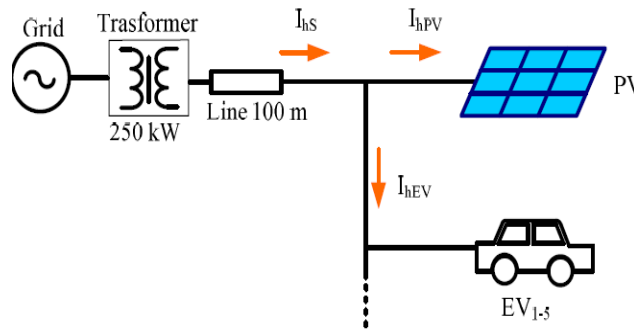


Figure 8. Harmonic current circulation in the network of order n.

We justify the factor G multiplication of the harmonic component I_h in Fig. 8 ($IEV = IEV1 + IEV2 + IEV3 + IEV4 + IEV5$). PV seems to function as a functional filter that takes up the distortion caused by the EV1-5. Taking into account the harmonic element and how it spreads throughout the network:

$$\begin{aligned} IS &= IfS + I_hS \\ IPV &= IfPV + I_hPV \quad (4) \\ IEV &= IfEV + I_hEV \end{aligned}$$

Kirchhoff's circuit rules and (4) allow us to arrive at:

$$\begin{aligned} IS &= IEV + IPV \\ IfS + I_hS &= (IfPV + I_hPV) + (IfEV + I_hEV) \\ \text{With } IfS &= IfPV + IfEV, \text{ we deduce:} \\ I_hS &= I_hPV + I_hEV \quad (5) \end{aligned}$$

where:

IS, IfS, I_hS The fundamental, instantaneous, and total harmonic components of the line current
 PV - $IPV, IfPV, I_hPV$ The current's total harmonic component, fundamental harmonic, and instantaneous value.

$IEV, IfEV, I_hEV$ are the total harmonic component (THC) and instantaneous value (EV1–5) of the five currents.

In a constant state, multiplying factor G results in:

$$I_hPV = -G \cdot I_hS \quad (6)$$

Replace (6) in (5), we obtain:

$$I_{hs} = \frac{1}{G+1} \cdot I_{hEV} \quad (7)$$

$$I_{hPV} = \frac{G}{G+1} I_{hEV} \tag{8}$$

As we observe, $I_{hS}=I_{hEV}$ when there is no filter and $G=0$. Equation (7) shows how the route's harmonic current is reduced $(G+1)$ times. Please keep in mind that the filter inductance controls the charging current's maximum fluctuations $IVE1[18]$:

$$\left[\frac{dI_{PV}}{dt}\right]_{max} \cong \frac{1}{L_{filter}} \left(\frac{V_{DC}}{2} - V_{grid}\right) \tag{9}$$

L_{filter} -inductance of filter

V_{DC} - average DC bus voltage

V_{grid} - Grid voltage amplitude value

We must restrict the allowed derivation from the present since we utilize PV so parameters like filter therefore L_{filter} can't be chosen.

$$\left[\frac{dI_{PV}}{dt}\right] = \left[\frac{dI_{hPV}}{dt}\right] + \left[\frac{dI_{hEV}}{dt}\right] \tag{10}$$

Equation shows that the PV absorbed $G/(G+1)$ times the line harmonics (8). Equation (10) demonstrates that by choosing a suitable value G for (dI_{hPV}/dt) , we can regulate the quantity in $(dIVE1/dt)$. The following section's simulation is run using factor, $G=1$.

4. SIMULATION RESULTS

A. Matlab/Simulink modelling

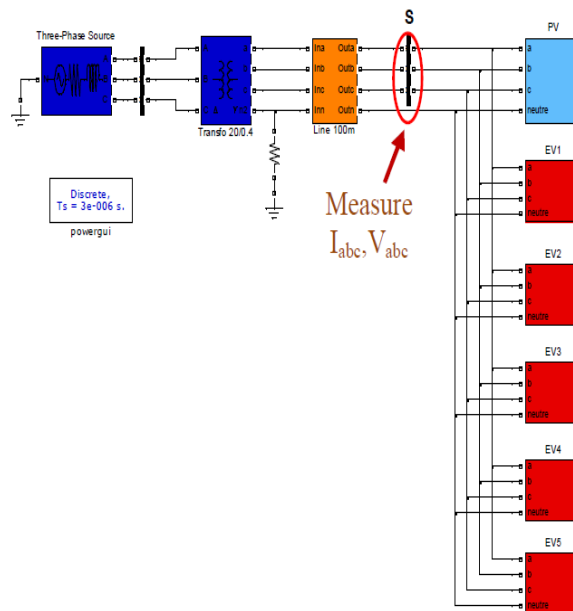


Figure 9. Network of simulation in Matlab/Simulink

Fig. 9 simulates the assortment of electric cars depicted in Fig. 1. Cars are charged at 400V using a four-wire, single-phase, 20/0.4kV converter with a national electrical grid connection. It has a 250kVA battery. Tests of voltage and current are performed at bus S to assess the effectiveness of the suggested regulation (Fig. 9).

B. Results

To determine how successful the recommended control is, two scenarios are simulated:

- Not screening - Making use of the recommended PV inverter controller as a functional filter.

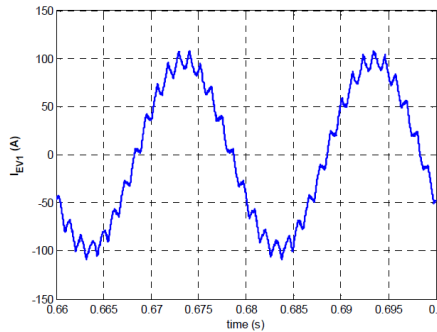


Figure 10. Present EV1 to EV5 waveform

The current waveforms between EV1 and EV5 is displayed in Fig. 10. The current's harmonic spectrum is displayed in Fig. 11. Among the harmonic parts, the 16th, 17th, the 18th, 19th, and 20th are prominent.

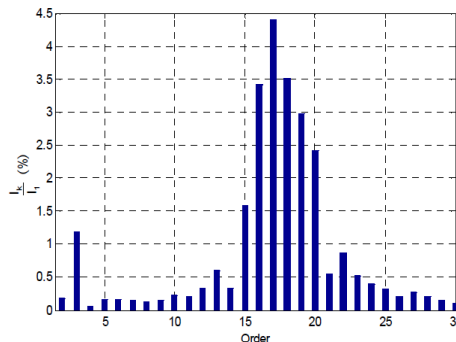


Figure 11. EV1 to EV5's current harmonic spectrum

Both within and outside of the recommended restriction, the total current measured at bus S is shown in Fig. 13. This current's spectrum is displayed in Fig. 14. It shows how the suggested control, which employs a photovoltaic inverter, distinctly reduces the harmonic content.

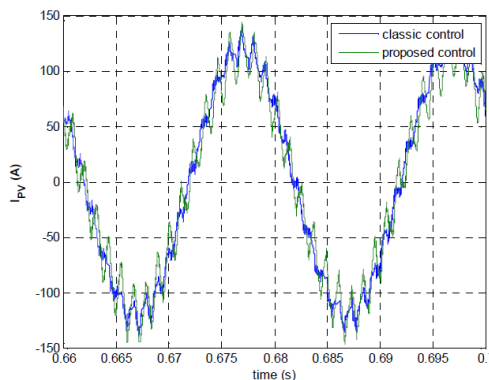


Figure 12. PV inverter's current waveform paired with or without the recommended Control

The current PV waveform is shown in Fig. 12 with as well as without the suggested adjustment.

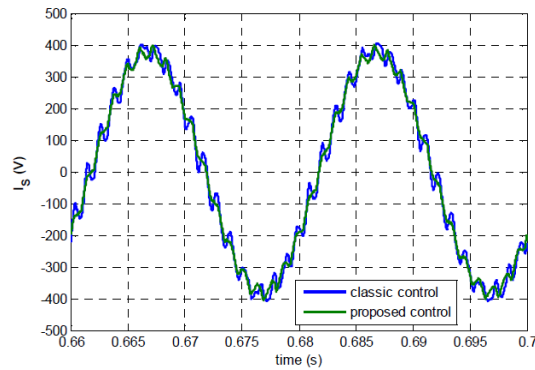


Figure 13. The overall current at board S was measured both with and without the recommended Control

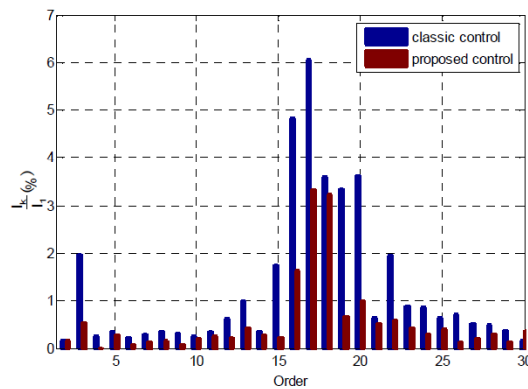


Figure 14. Current harmonic spectrum at bus S

Figs. 15 and 16 display the voltage waveform and distortion of the voltage spectrum at bus S. It shows that the output of the filtering operation makes sense with regard to of THD and wavelength. It is possible to lower this voltage's 16–20th harmonic.

Fig. 17 shows the overall harmonic distortion of voltage and current compared to the recommended. While the present time THD decreases from 12.2% to 4.1%, the voltage THD decreases from 11.4% to 5.6%. It shows that the voltage THD of the recommended control is below the upper bound (8%).

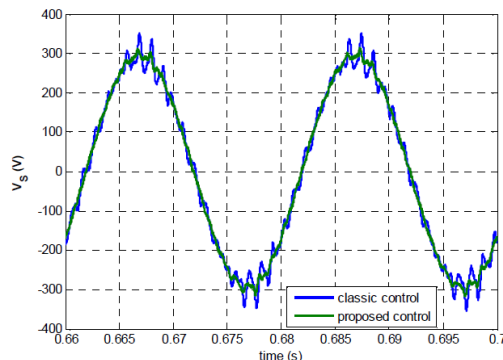


Figure 15. voltage on bus S measured both in and out of the recommended control

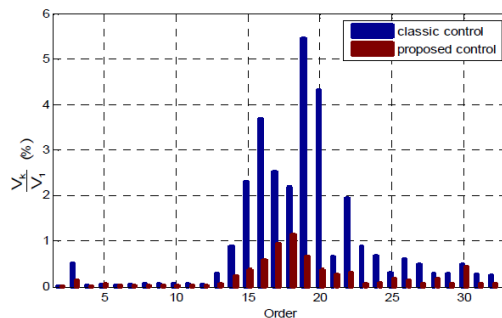


Figure 16. Spectrum of voltage harmonics

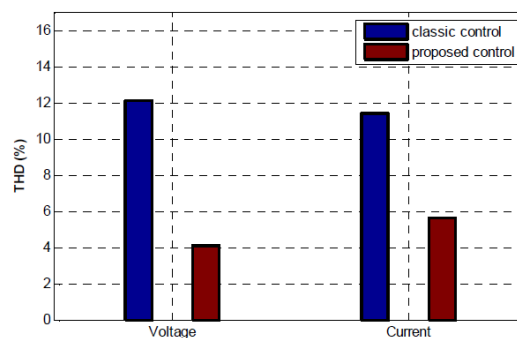


Figure 17. Voltage and current total harmonic distortion, both as well as without the recommended control

It is clear that there are benefits to filter harmonics when the suggested control is applied. Several simulations have verified this solution's performance. Nonetheless, there is reason for concern given the additional losses the charger incurs as a result of this active filtering procedure. Energy management entails trying to determine which vehicle is suitable for the activity and where it should be conducted.

5. CONCLUSION

This paper presents an examination into harmonic tracking and evaluation during electric car charging. For the measurement, two modern EV models plus golf carts are utilised. The study indicates that EVs presently generate less THDi as golf carts, as expected. However, the ratio of THDv distortions in modern EVs is higher. When multiple EVs are charging concurrently, the total harmonics (THD) of the voltage and current does not add to that of a single vehicle. These findings provide significant new insights into the harmonic distortion brought on by EVs connected to the electrical grid for charging.

REFERENCES

1. Maren Kuschke, Kai Strunz, "Decentralized Energy Systems in Germany: Development and Research", 2011 APEC Workkshop on Addressing Challenges in AMI Deployment and Smart-Grid in APEC, Taipei, August 2011
2. Larry Dickerman, Jessica Harrison, "A New Car, a New Grid", IEEE power & energy magazine, March/April 2010.
3. Laurent J. Masson, "Fast Charging an EV: AC/DC Questions and Renault's Answers", November 21, 2012, website Plugincars

4. Anders Holm Foosnas, Allan Norsk Jensen, Niels Chr. Nordentoft, "REPORT: CASE STUDIES OF GRID IMPACTS OF FAST CHARGING", EDISON Deliverable WP 4.4 ; September 19th, 2011.
5. Quoc-Tuan. TRAN, LP. Xavier, M. Saheli, "Stochastic Approach to Assess Impacts of Electric Vehicles on the Distribution Network", 2012 IEEE/PES 3rd Innovative Smart Grid Technologies EUROPE (ISGT) - Berlin Germany
6. P. T. Staats, W. M. Grady, A. Arapostathis, and R. S. Thallam, "A statistical method for predicting the net harmonic currents generated by a concentration of electric vehicle battery chargers", IEEE Transactions on Power Delivery, vol. 12, no. 3, p. 1258 -1266, juill. 1997.
7. L. Yanxia and J. Jiuchun, "Harmonic-study of electric vehicle chargers ", in Proceedings of the Eighth International Conference on Electrical Machines and Systems, 2005. ICEMS 2005, 2005, vol. 3, p. 2404 - 2407 Vol. 3.
8. M. A. S. Masoum, P. S. Moses, and S. Deilami, "Load management in smart grids considering harmonic distortion and transformer derating ", in Innovative Smart Grid Technologies (ISGT), 2010, 2010, p. 1 -7.
9. M. A. S. Masoum, S. Deilami, and S. Islam, " Mitigation of harmonics in smart grids with high penetration of plug-in electric vehicles ", in 2010 IEEE Power and Energy Society General Meeting, 2010, p. 1 -6.
10. E. C. Bentley, P. Suwanapingkarl, S. Weerasinghe, T. Jiang, G. A. Putrus, and D. Johnston, " The interactive effects of multiple EV chargers within a distribution network ", in 2010 IEEE Vehicle Power and Propulsion Conference (VPPC), 2010, p. 1 -6.
11. S. Deilami, A. S. Masoum, P. S. Moses, and M. A. S. Masoum, " Voltage profile and THD distortion of residential network with high penetration of Plug-in Electrical Vehicles ", in Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES, 2010, p. 1 -6
12. S. Lacroix, E. Laboure, and M. Hilairet, " An integrated fast battery charger for Electric Vehicle ", in 2010 IEEE Vehicle Power and Propulsion Conference (VPPC), 2010, p. 1 -6.
13. V.L.Nguyen, T.Tran-Quoc, S.Bacha, « Improved DC/DC Link Control for Fault-Ride-through Capability of Photovoltaic Inverter », Proceedings European Photovoltaic Solar Energy Conference and Exhibition, 2012, p. 4064 - 4067.
14. L. De Sousa, B. Bouchez, "Dispositif électrique combiné d'alimentation et de charge", French Patent WO 2010/057892 A1, Valeo Systèmes de Contrôle Moteur, May 2010.
15. [15] L. De Sousa, B. Bouchez, "Procédé et dispositif électrique combine d'alimentation et de charge à moyens de compensation", French Patent WO 2010/057893 A1, Valeo Systèmes de Contrôle Moteur, May 2010
16. I. Etxeberria-Otadui, A. L. de Heredia, H. Gaztanaga, S. Bacha, et M. R. Reyero, « A Single Synchronous Frame Hybrid (SSFH) Multifrequency Controller for Power Active Filters », IEEE Transactions on Industrial Electronics, vol. 53, no 5, p. 1640 -1648, oct. 2006.
17. N. Melo, F. Mira, A. de Almeida, and J. Delgado, " Integration of PEV in Portuguese distribution grid: Analysis of harmonic current emissions in charging points ", in 2011 11th International Conference on Electrical Power Quality and Utilisation (EPQU), 2011, p. 1-6.
18. R. L. de Araujo Ribeiro, C. C. de Azevedo, and R. M. de Sousa, " A

- Robust Adaptive Control Strategy of Active Power Filters for Power- Factor Correction, Harmonic Compensation, and Balancing of Nonlinear Loads “, IEEE Transactions on Power Electronics, vol. 27, no 2, p. 718 -730, févr. 2012.
19. Mojtaba Yousefi; Amin Hajizadeh; Mohsen N. Soltani; Branislav Hredzak “Predictive Home Energy Management System with Photovoltaic Array, Heat Pump, and Plug-In Electric Vehicle” IEEE Transactions on Industrial Informatics, 2021, Volume: 17, Issue: 1.
 20. Rania A. Swief; Noha H. El-Amary; Mohamed Z. Kamh “Optimal Energy Management Integrating Plug in Hybrid Vehicle Under Load and Renewable Uncertainties” IEEE Access, 2020, Volume: 8.
 21. Sara Deilami “Online Coordination of Plugged-In Electric Vehicles and Optimal Rescheduling of Switched Shunt Capacitors in Smart Grid Considering Battery Charger Harmonics” IEEE Power and Energy Technology Systems Journal, 2018, Volume: 5, Issue: 4.
 22. Rui Wang; Qiuye Sun; Dehao Qin; Yushuai Li; Xiangke Li; Peng Wang “Steady-state Stability Assessment of AC-busbar Plug-in Electric Vehicle Charging Station with Photovoltaic” Journal of Modern Power Systems and Clean Energy, 2020, Volume: 8, Issue: 5.
 23. Siyang Sun; Qiang Yang; Wenjun Yan “Hierarchical optimal planning approach for plug-in electric vehicle fast charging stations based on temporal-SoC charging demand characterisation” IET Generation, Transmission & Distribution, 2018, Volume: 12, Issue: 20.
 24. A. Lucas, F. Bonavitacola, E. Kotsakis, and G. Fulli, “Grid harmonic impact of multiple electric vehicle fast charging,” Electric Power Systems Research, vol. 127, pp. 13–21, 2015.
 25. Wei Yuan; Jianwei Huang; Ying Jun Angela Zhang “Competitive Charging Station Pricing for Plug-In Electric Vehicles” IEEE Transactions on Smart Grid, 2017, Volume: 8, Issue: 2.