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Impact of electric vehicle charging station on power quality

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ABSTRACT

Global warming has led to the widespread adoption of electric vehicles (EV). With the increasing use of electric vehicles, it is very important to understand the impact of electric vehicle charging. Electric vehicle charging station has a serious effect on the power quality of the local power distribution network, and it cannot be ignored. The electric vehicle charger is a type of non-linear load. This non-linearity introduces harmonics into the charging station. Therefore, a high-efficiency charger in the power grid is required. This research work aims to build a charging station model to analyze the effect of EV chargers on power quality and then shunt active power filter (SAPF) based on P-Q theory and synchronous reference frame (SRF). Theory is implemented in the system to suppress harmonics. The simulation will be carried out under two cases, without active power filter (APF) and with APF when number of chargers associated to the charging station. The simulation results of both the methods will be compared and verify the effectiveness of proposed method. The simulation will be done using the MATLAB/Simulink software.

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1. INTRODUCTION

Due to huge development in transportation sector by considering environment protection and depletion of fossil fuel, traditional vehicles shift to electric vehicle. Electric vehicles (EVs) are less environment pollution, cheaper mode of transportation and growth in battery technology it gaining much attention in the market. There are three main types of electric vehicles within the worldwide [1].

The continuous development of EVs can have adverse effect on distribution network. EV chargers contain electronic devices similar to non-linear load which causes harmonic problem and affecting power quality in the system [2], [3]. Huge EV charging load's impact on the three-phase power system is analyzed for different parameter on chargers, number of chargers. It is concluded in that APF+PI repetitive control can efficiently suppress the current harmonics and improve power quality [4], [5]. In the concept of vehicle-to-grid (V2G) is studied and analyzed parameters like frequency stability, voltage stability, and power quality are discussed for different penetration level of plug-in electric vehicles (PEV) [6], [7].

Fujun *et al.* [8] analyzed the influence of harmonic on load by fast charging station, where it is concluded that when the fast-charging station has a large capacity, harmonics have a greater impact on load. The researchers investigated the impact of harmonic distortion on EV charging station based on the measured data and actual test, result was simulated in MATLAB/Simulink software [9]–[11].

Woodman *et al.* [12] simulated the harmonic caused by non-linear load in IEEE 13 node test feeder that used to verify the VHDL-AMS model and their effects. In the switched filter compensator (SFC) are used to solve the problem of harmonic distortion network [13], [14]. It compensates reactive power to improve power factor, the results were analyzed and compared with and without SFC. This study examines how more EV charging stations affect power quality is examined using MATLAB/Simulink software. Active power filter (APF) based P-Q theory and synchronous reference frame (SRF) theory is adopted to reduce the harmonic in the system for different load conditions.

This paper is organized as: i) Section 1 provides introduction; ii) Section 2 detailed problem formulation for EV charging station is explained; iii) Section 3 presents proposed methodology and brief review of shunt active power filter (SAPF); iv) Further analysis of simulation results is discussed in section 4; and v) Followed by conclusion in section 5.

2. PROBLEM FORMULATION

With the higher penetration of electric vehicle day-by-day it has so many disadvantages. The EV charger is a non-linear load, that introduces harmonics into the system. This will influence the power quality of the framework. The research work evaluates the harmonic contamination in the electric system due to EV chargers. The charging station model connected to shunt active power filter [P-Q] theory and synchronous reference frame theory is implemented and simulated in MATLAB/Simulink software. Here the current harmonics are determined for different load conditions.

3. PROPOSED METHODOLOGY

The proposed work is carried out on shunt active power filter using two methods i) synchronous reference frame (D-Q) theory and ii) instantaneous reactive power (P-Q) theory, to suppress the harmonic distortion and improve the power quality in the distribution system. In the modelling phase following are the assumptions, three-phase source with the rating of 400 V 50 Hz AC and lithium-ion battery which is used in almost all the battery EVs.

3.1. Charging station using P-Q theory-based shunt active power filter

The most reason of the shunt active power filter is to generate compensation currents of the same magnitude but in opposite phases to suppress current harmonics [15]. In this research work P-Q theory method is implemented, also known as instantaneous reactive power theory, and creates a simulation model using MATLAB/Simulink. Figure 1 shows a block diagram of an electric vehicle charging station connected to SAPF. To generate compensating reference current, Clarke transformation is used to convert the, source voltage and current from a-b-c coordinates to alpha-beta coordinates, as shown in [16]–[18].

$$\begin{bmatrix} v0 \\ v\alpha \\ v\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \tag{2}$$

Here zero sequence component is absent as α and β axes make no contribution to zero component. Hence it can be easily eliminated from the system.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \tag{3}$$

To generate harmonic reference current active power component ($\bar{p}_{ac}$), total reactive component (q) and real power ($\bar{p}_{loss}$) from 3ϕ AC source is required given as (4).

$$\tilde{p} = P - \bar{p}_{ac} + \bar{p}_{loss} \tag{4}$$

Generated compensating current are then transformed from α-β-0 to 3ϕ a-b-c frame by inverse Clarke transformation as shown in (5).

$$\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i0 \\ i\alpha \\ i\beta \end{bmatrix} \tag{5}$$

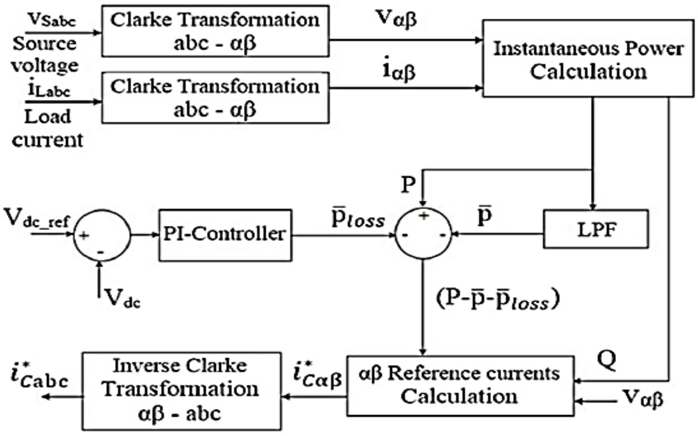


Figure 1. Block diagram of P-Q theory

3.2. Charging station using synchronous reference frame theory-based active power filter

A rotating coordinate system's ability to cause harmonics to change frequency is the foundation of the synchronous reference approach. The reference current has nothing to do with the supply voltage and it is directly derived from the actual load current [19], [20]. An electric vehicle charging station connected to an SRF-based active power filter is shown in block diagram from Figure 2.

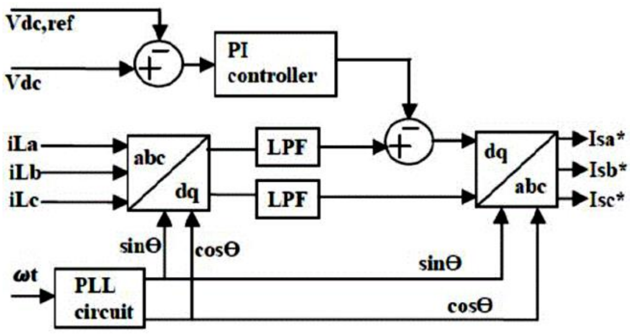


Figure 2. Block diagram of SRF theory

To generate the compensating reference current, the 3-phase supply current i_a, i_b, and i_c are transformed into 2ϕ (α-β) current in the stationary frame [21]–[25].

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \begin{bmatrix} 1 & -1 & 1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \tag{6}$$

Next the α-β plane converted into D-Q rotating frame, the phase locked loop (PLL) circuit is applied to generate sine and cosine signals to properly synchronize the current with the voltage. The current expression is given by (7).

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \tag{7}$$

Here the produced d-axis and q-axis component consist of both dc and ac component. The AC component goes through the low pass filter to remove the harmonic component, and the PI controller is used to reduce each harmonic component's steady state error.

$$id = iddc + idac \tag{8}$$

$$iq = iqdc + iqac \tag{9}$$

Once the desired harmonic elements are removed from the distorted load current, the D-Q rotating frame is converts back to the a-b-c stationary frame.

$$\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ 1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \tag{10}$$

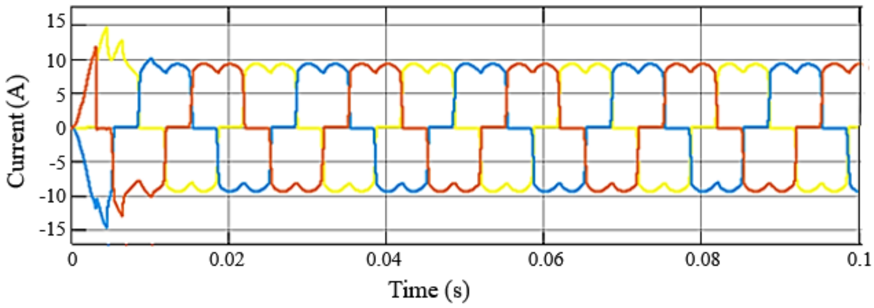
The extracted reference current is transferred for generation of switching pulses for the inverter.

4. RESULTS OF THE SIMULATION

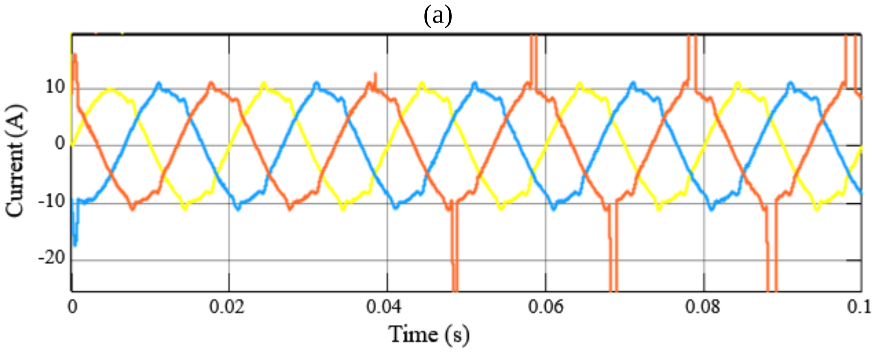
In this study, a simulation model is created in the simulation toolbox MATLAB2018b to analyze the harmonics produced during the charger's charging stage. The simulation parameters utilized in this model are displayed in Table 1. By analyzing the total harmonic distortion (THD) content of the two charging stations, comparing the THD values of the two charging stations and analyze which charging station has the lowest THD content. According to the simulation results, the current control approach can deliver the optimum results. Figure 3(a) displays the source side current waveforms before the current is compensated and Figure 3(b) displays the source side current waveforms after the current is compensated.

Table 1. Simulation parameters used for design

System-parameter	Values
Supply voltage	400 V
Frequency	50 Hz
Filter inductance	10 mH
Load line inductance	1 mH



(a)



(b)

Figure 3. Source current I_s (a) before compensation and (b) after compensation

4.1. Charging station using SAPF

Figure 4 shows the generated compensation currents required for elimination of harmonic distortion present in the system. The algorithm is carried out MATLAB/Simulink software. The fast Fourier transform analysis in Figure 5 fast Fourier transform (FFT) analysis of source current $I_{s,}$ Figures 5(a) and 5(b) shows the source current I_s is before compensation, after compensation and total harmonic distortion reduced from 28.24% to 6.23% using APF based on P-Q theory.

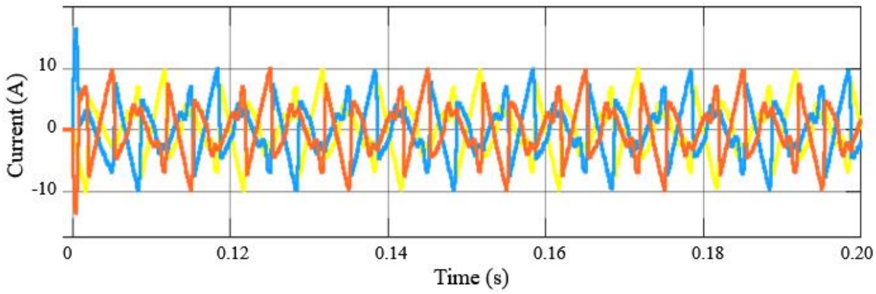
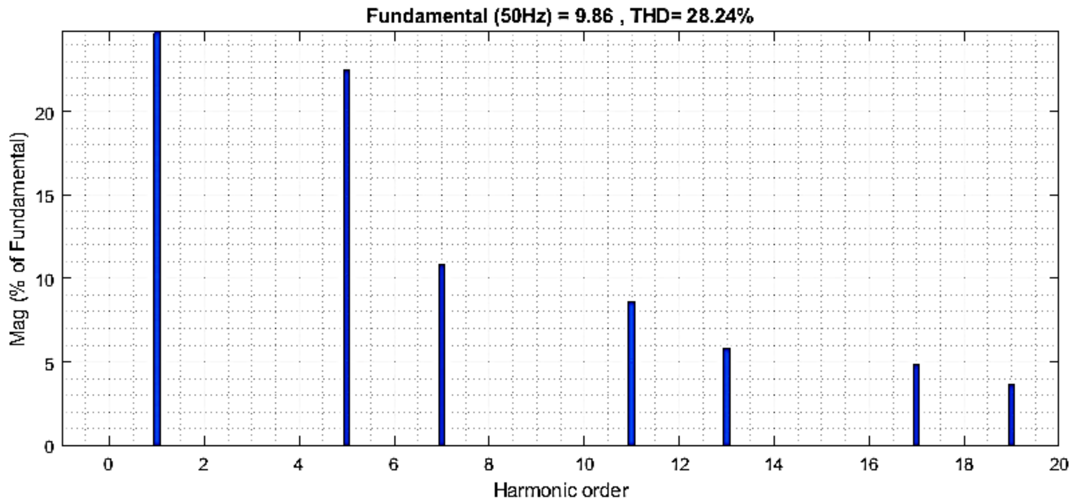
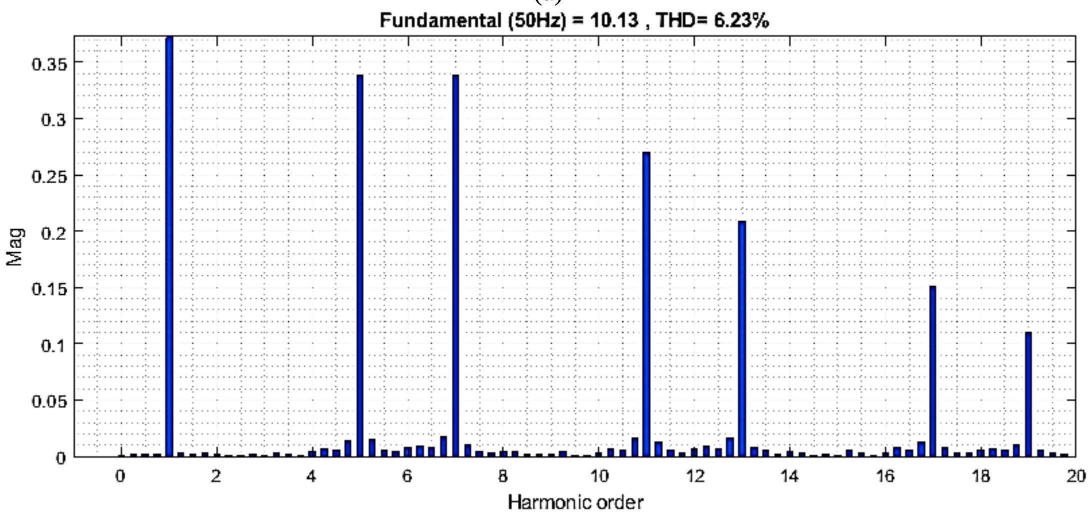


Figure 4. Waveform of the compensation current



(a)



(b)

Figure 5. FFT analysis of source current I_s (a) before compensation and (b) after compensation

4.2. Charging station using SRF theory

Figure 6 shows the output waveform of the sine and cosine signals used for synchronization and generate the required reference current signal. Figure 7 shows that the total harmonic distortion is only 2.92%, which is an acceptable value compared to the IEEE standard of 5% limit. Table 2 shows the comparison based on the connection of filter under different load condition.

Table 2. Percentage THD comparison

Filter	25 Chargers THD %	50 Chargers THD %
Without filter	28.24	41.59
Active power filter	6.23	10.58
SRF based active filter	2.92	5.14

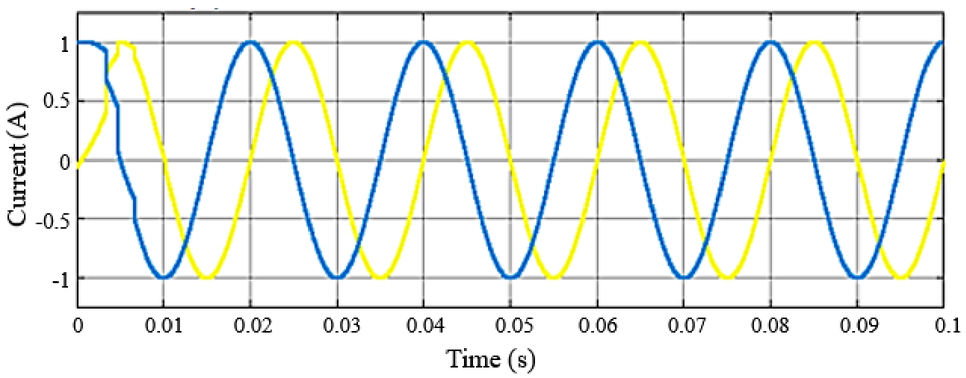


Figure 6. Sine and cosine function from the PLL circuit

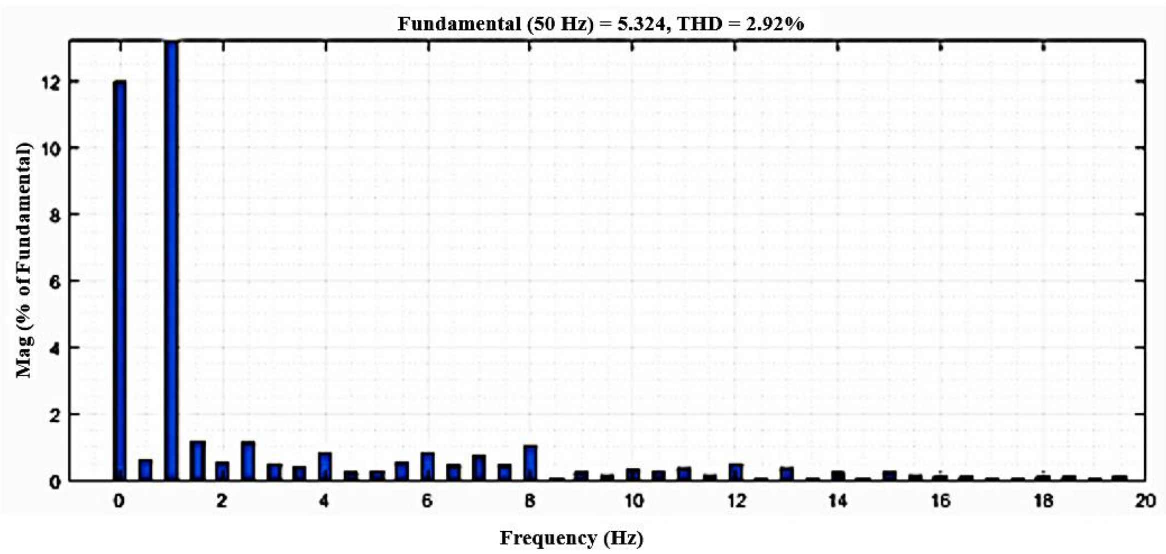


Figure 7. FFT analysis of SRF theory

5. CONCLUSION

This work proposes a solution to mitigate the effect of the increase in EV charging stations on power quality. The simulation model of the electric vehicle charging station is created in the MATLAB/Simulink software. To analyze the harmonic contamination, charging station with P-Q theory-based shunt active power filter and SRF theory-based active power filter was simulated. Both the charging station with the same parameters and the batteries are used as a load during charging. The charging station with SRF theory has a lower THD value than the charging station with a P-Q theory-based power filter and without a filter. Synchronous reference theory model can viably relieve the harmonic distortion. The generated reference signal is not distorted in the SRF approach, which improves performance and it has good compensation result for harmonic currents.

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