

Power Quality Improvement in EV Charging Stations Using DC-Link Voltage–Controlled Shunt Active Power Filter

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Abstract—The increased adoption rate of electric vehicles has created increased demand for the installation of reliable and efficient electric vehicle charging infrastructure. In order to operate EV chargers, it is necessary to utilize power electronic converters (e.g., rectifiers, DC-DC converters) which create nonlinear loads that introduce harmonic distortion into AC power systems, resulting in decreased power quality from the distribution network due to current waveform shape distortion, poor power factor, and increased losses throughout the distribution network. As such, this research provides an alternative control methodology for managing power quality from AC sources at EV charging stations via a shunt active power filter (SAPF) connected in parallel with the charger's source, where the SAPF uses a control method to inject compensating currents into the supply line to eliminate the harmonic components of the load currents drawn on the mains for charging EVs. The methodology to achieve this with the SAPF includes DC voltage regulation through reference current generation and simulation using MATLAB/Simulink. Simulation performance evaluations will also be conducted during non-linear loading conditions. Based on the results from the simulations, the proposed configuration will effectively reduce total harmonic distortion (THD), and improve both the shape of the source current waveform, and overall power quality delivered to loads connected to an AC source.

Index Terms—Shunt Active Power Filter [SAPF], Total Harmonics Distortions [THD], Electric Vehicle Charger, DC Link Capacitor.

Problem Statement: Due to the rapid growth of electric vehicle (EV) adoption, there is a large increase in EV charging stations connected to the electrical distribution system. Most EV chargers employ power electronics converters such as rectifiers and DC-DC converters. As such, EV chargers operate as nonlinear loads and also produce distorted current on the electrical distribution system (also referred to as the power grid), leading to several issues; including; 1) harmonic distortion; 2) poor power factor; 3) voltage

fluctuations. As a result of these issues, the efficiency of the entire electrical system will be negatively impacted, causing increased energy losses and resulting in poor performance of all other associated and sensitive electrical equipment connected to the same electrical distribution system. Historically, passive filters are used to reduce harmonic distortion. However, passive filters have limitations; such as; fixed compensation; large footprint; and possible resonance with the power distribution system. Therefore, there is a need for an alternative solution that is both efficient and flexible in mitigating harmonic distortion and improving power quality in EV charging systems. Active power filter technology can provide an effective solution to address the above-mentioned issues related to power quality.

I. INTRODUCTION

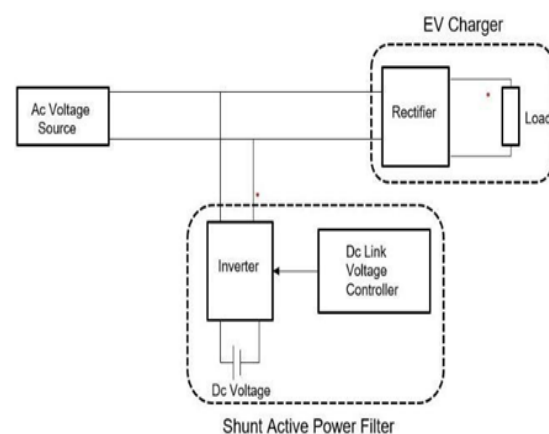
The rise in the popularity of electric vehicles (EVs) is changing the face of both transportation and energy on a global scale. EVs provide an excellent alternative to traditional methods of transportation for reducing greenhouse gas emissions and reliance on fossil fuels. As EV usage grows, so does the need for a robust network of available charging stations that can efficiently and reliably provide electricity to charge EV batteries. Electricity is supplied by EV chargers from the electrical grid and most EV chargers utilize power electronic converter devices such as rectifiers and DC-DC converters to convert AC power from the grid into a DC power source that will recharge an EV's batteries. However, because these converters function as nonlinear loads, they draw non-sinusoidal currents from the electrical supply grid, creating power quality problems such as harmonic distortion, poor power factor, and voltage fluctuations. The outcomes of these power quality problems will ultimately be detrimental to the performance of the entire power distribution system and the performance of any other electrically powered devices connected to the same distribution system network.

The use of power electronic devices and non-linear loads has increased the level of concern regarding power quality. EV charging facilities include rectifiers and converters that produce harmonic current and will contribute to the distortion of the current waveform of the source. Additional losses due to harmonic content in the system, overheating, malfunctioning of sensitive devices, and decreased efficiency of the power system can occur as a result of the presence of significant harmonic content in the power system. Passive harmonic mitigation methods, such as passive filters, have been used in many different applications for the purpose of reducing the effects of harmonics. Although passive filters are generally simple and low cost, there are a number of deficiencies (i.e., large size, fixed compensation characteristics, and potential resonance with the power system) associated with their use. Additionally, the use of passive filters in a EV charging facility will not be effective given the transient nature of the charging demand where loads

will continue to change.

The use of active power filters has been increasing steadily to provide solutions that address the problems associated with poor power quality in today's power grids. One of the more recent types of active power filters is called shunt active power filter or SAPF, which has the ability to dynamically compensate for harmonic currents and help improve the overall quality of the supplied electric power. The SAPF is connected in parallel to a nonlinear load and injects compensating current into the electrical system in order to cancel out any harmonic components produced by the nonlinear load. The result is that the source current is nearly sinusoidal and the power factor is improved. In this study, a single-phase SAPF will be proposed as an alternative method for improving power quality in electric vehicle (EV) charging stations. A model of the SAPF will be built and simulated using MATLAB/Simulink, and will allow the performance of the device to be evaluated under nonlinear loading conditions. Simulation results showed that the proposed device was effective at minimizing harmonic distortion and increasing dependability of the utility's power distribution system.

Block Diagram



1) AC Voltage Source:

The AC voltage source represents the electricity supplied by the utility company and provides single-phase AC Power to an EV Charger System. Although utility grids normally supply sinusoidal voltages, the connection of non-linear loads (i.e. EV Chargers) results in distorted currents being drawn from the

utility grid. The distorted current results in the introduction of Harmonics into the Power System which reduces both Power Quality and the Efficiency of the Electric Power Distribution Network.

2) EV Charger (Rectifier + Load):

The EV charger block consist mainly of a rectifier and load, the rectifier converts AC power from the grid into DC power. This DC power is used to charge the electric vehicle battery. The load represents the EV battery charging system. the rectifier behave like a nonlinear load,so they draw non-sinusoidal current from the grid and produced harmonics and to many problems such as:

- poor power distortion
- current distortion
- increased heating in equipment

3) Shunt Active Power Filter (SAPF):

The Shunt Active Power Filter is connected across the EV charge. It's mainly used for compensated the harmonic current by generating opposite sin wave. The SAPF mainly consists of Voltage Source Inverter (VSI), DC link capacitor, Control system

Grid current = load current-Harmonic current as a

Result :

- Harmonics are cancelled
- Source current becomes sinusoidal
- Power factor improves

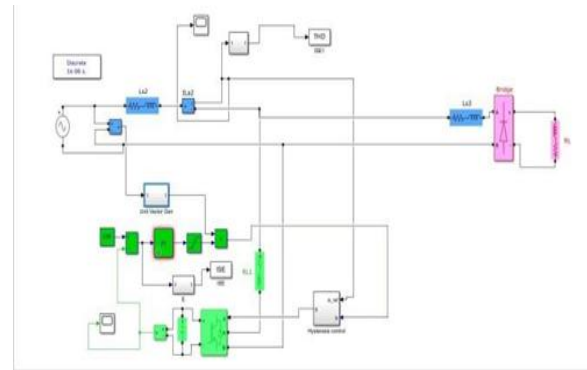
4) DC Voltage Controller :

The DC Link voltage controller maintain constant voltage across the DC Link capacitor used for control the amplitude of reference current, Maintain stable inverter operation, Control the amplitude of reference current.

5) Inverter

The inverter converts DC voltage into AC Compensating from the DC link capacitor. (IGBT) is Used as Switching devices, The inverter generates and injects the required current waveform into the power line. these current cancels the harmonic of the EV charger.

II. SIMULATION



1) AC Source : It provide the supply voltage to the system act as a AC grid

Typical value used :

Peak amplitude :141.4214 (V) Frequency :50(Hz)

2) Source Inductor (Ls2): Represent line impedance, used to Limits current and represents practical transmission line impedance.

Typical value used :

after compensation

$$i_s = i_L - i_f$$

Inductance :1 mH

Resistance :0.1 Ohms

3) Rectifier+Laod(EV charger):

Rectifier: It's a two-arm diode bridge used to convert AC to DC for EV battery charging. However, this diode Rectifier draws non-sinusoidal current, which produces harmonics.

$$i_s = i_f + i_L$$

where

i_s =source current i_f =filter current i_L =load current

4) Unit Vector Generator: this block generate a sinusoidal reference signal synchronized with the supply voltage

$$u = \sin(\omega t)$$

Where,

$$\omega = 2\pi f$$

5) DC Link Voltage Control: DC link capacitor connected to the inverter in the (SAPF), this capacitor

maintains the DC link voltage as reference voltage

$V_{dref}=200V$

the actual DC voltage is measured and compared with the reference and calculated as Error $e(t)$. this Error Signal is sent to the PI controller

$e(t)=V_{dref}-V_{dc}$

6) PI Controller Operation: the PI controller is used to maintain and regulate the DC-link voltage of the inverter. Maintaining a constant DC-link voltage in inverter requires stable DC power to inject the compensating current that cancels harmonics produced by the EV charger.

7) Shunt Active Power Filter (Inverter): the (SAPF) is connected across the grid and EV charger load and it's consist IGBT inverter, DC link capacitor and Filter inductor (RL1). (SAPF) is used to injects a

compensating current into the line.

8) Harmonic Compensation:

Before Compensation

$i_s=i_L$

III. SIMULATION RESULTS AND DISCUSSIONS

The proposed solution to improve power quality at EV charging stations was created in a MATLAB/Simulink model. The EV charger in this simulation was represented by a single-phase diode bridge rectifier connected to an RL load, which operates as a non-linear load. The current drawn from the AC source is made non-sinusoidal due to the operation of the rectifier and has significant harmonics present in this non-sinusoidal current waveform. These harmonics distort the source current waveform and therefore reduce the overall electrical power quality of the entire electrical system.

To solve this problem, the system integrates a single-phase Shunt Active Power Filter (SAPF), uses a DC-link voltage PI controller, and uses a hysteresis controller for the switching pulse signals for the

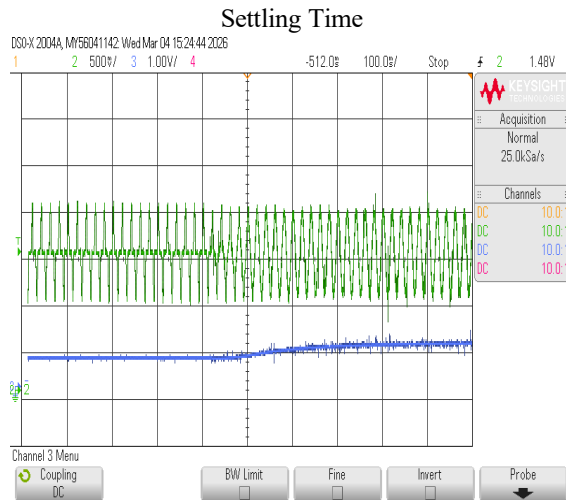
inverter switches. The PI controller maintains constant DC link voltage to the inverter; while the hysteresis controller generates the switching pulse signals to the inverter switches. The inverter injects compensating current into the system to eliminate harmonics based on the difference between reference current and actual source current.

In the simulation before compensation, the source current is very distorted, and has a very high percentage of THD, while its compensated current achieves near sinusoidal waveform and significantly reduces THD, significantly improving the power quality of the EV charging system. When the SAPF is activated and a compensatory current is injected, it cancels out the harmonics produced by the EV charger.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

An experiment was done to validate the effectiveness of the Shunt Active Power Filter in improving power quality at charging systems for electric vehicles (EVs) using hardware. The test setup consists of an AC supply, an autotransformer, an inverter-based Active Power Filter, a control circuit, and a nonlinear load that simulates an EV charger. A digital storage oscilloscope was used to monitor the operation of the equipment. The first measurement was taken when the test load of 3 kW was connected to the supply without any compensation. There was significant distortion in the current flowing back to the supply due to the non-linearity of the EV charging circuit. This distortion produced harmonic currents that are common to all electrical power systems. When the Active Power Filter was switched on, the control circuit produced switching pulses to the inverter using hysteresis current control.

The inverter supplied compensating current back to the line that cancelled out the harmonic current produced by the load. Therefore, the current returned to the supply improved significantly toward a sinusoidal shape. Based on the results of the experiment, the proposed system was very effective in reducing the amount of harmonic distortion and, overall, improving the quality of the electrical power.

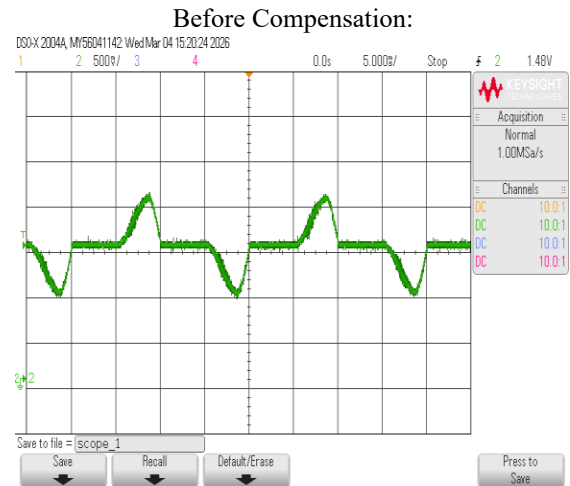


Settling Time refers to the amount of time it takes for the output of a given system to settle back to its normal operating condition (steady state), and will remain within an acceptable range following a disturbance/transition.

In the case of an Electric Vehicle Charger (EVC) system paired with a Shunt Active Power Filter (SAPF), settling time reflects how quickly the DC Link Voltage and compensation current (from the SAPF) stabilizes, either after an initial system startup or due to a change of load on the EVC.

Oscilloscope waveforms of the EVC system demonstrate the transient voltage and current fluctuations that occur during the startup of the circuit. During these fluctuations, the controller is working to adjust the inverter switching to provide the proper level of compensation current; thus, the PI controller is providing the appropriate Voltage to the DC Link and the Hysteresis Current Controller ensures that the actual current is following the reference current. Eventually the circuit oscillates less and the waveforms stabilize.

The waiting period for these waveforms to stabilize is referred to as the settling time. A shorter settling time represents a faster and more effective response from the control system, thereby providing greater stability of operation and improved power quality on the EVC system.

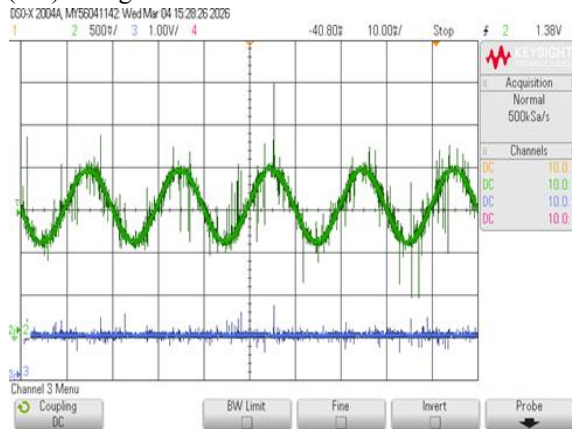


The electric vehicle (EV) charger functions as a nonlinear load due to the presence of a diode bridge rectifier before compensation is applied. Non-sinusoidal current is drawn from the AC supply, which leads to high levels of harmonic distortion. When viewing an oscilloscope waveform, one can see that the current waveforms are distorted and irregular, with sharp peaks and uneven shapes. The distortion from these non-sinusoidal currents increases the overall Total Harmonic Distortion (THD) of the power system and decreases the overall power quality. These non-sinusoidal harmonic currents can also create additional losses, heat up electrical equipment, and interfere with other sensitive devices on the same power system. Therefore, harmonic mitigation techniques should be applied in order to improve the shape of the current waveform and provide stable power quality.

After Compensation:

The Shunt Active Power Filter, which reduces Harmonic Distortion in the power system after compensation, is switched on. The Hysteresis Current Controller then creates switching pulses for the inverter, thus allowing compensating current to flow via the supply line into the nonlinear EV charger load and cancelling out any Harmonic components created by this load. The result is a Source Current waveform that resembles a smooth and sinusoidal waveform as measured by the Oscilloscope. As a result, there is a significant reduction in the Total Harmonic Distortion levels, along with a major enhancement of overall power quality for the entire system and continued stable/effective operation of the Electric Vehicle

(EV) Charger Station.



V. CONCLUSION

This paper proposed the design and simulation of an electric vehicle (EV) charger with a shunt active power filter (SAPF) to enhance the power quality of the electrical system. Electric vehicle chargers are regarded as nonlinear loads since they utilize power electronic converters (diode bridge rectifiers), which cause them to draw non-sinusoidal current from the grid therefore producing harmonic distortion and causing issues of low power factor and overall poor quality of electric power supply.

The addition of a SAPF to the system using a PI controller and hysteresis current controller will eliminate these problems.

The entire system was modeled and simulated in MATLAB/Simulink for analysis of the performance of the developed harmonic compensation technique and the behaviour of the EV charger. The performance of the PI controller will produce a consistent DC-link voltage to the inverter, while the hysteresis current controller will produce switching pulses necessary to produce the compensating current, which will be injected into the system to cancel out the harmonic components created by the nonlinear load.

The simulation results of this work show a highly distorted source current signal prior to compensation and that the use of an SAPF resulted in a substantial reduction of harmonic components in the source current and an improved sinusoidal-shaped source current. Therefore, the proposed system improves power quality and decreases Total Harmonic Distortion (THD) in EV charging systems.

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