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Improvementof Power Quality by using Active Power Filters in EV Charging Stations

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ABSTRACT

One of the primary reasons for the introduction of electric cars into the market is the concern over greenhouse gas emissions and their contribution to global warming. The purpose of creating electric cars that reduced or eliminated exhaust emissions was to help combat this issue. These EVby using Active Power Filters have a major impact on the power grid and distribution networks and due to the consequences of huge power demand to recharge their batteries. Large number of EVby using Active Power Filters charging station when integrates with the utility grid, it produces harmonics, affect the voltage profile, finally affects the power quality. In this paper, the impact of electric vehicleby using Active Power Filters charging station on distribution network is analyzed. The simulation model and the results are analyzed using MATLAB/Simulink.

KEYWORDS: Electrical Vehicles (EV), EV charging station, Distribution network

1. INTRODUCTION

Electric vehicles (EV) represent the most likely successor to conventional internal combustionengine vehicles. Over the past few years, sales have steadily increased, and this trend is expected tocontinue over the next few years [1]. To perform the battery charging process, EVs rely on a chargingstation, which can be found at home, at work, or at a public charging station. Typically, on-boardchargers are slow chargers, while off-board chargers are fast chargers. Both solutions come withadvantages and disadvantages [2]. On-board chargers have limited power ratings due to space, weight,and cost restrictions, while off-board chargers can be designed for high charging rates with fewerrestrictions. The different charging modes and their characteristics are summarized in Table 1 (fromIEC 61851-1 [3]). Current forecasts, driven by European Distribution System Operators (DSO), suggestthat, by 2030, AC power levels are expected to increase only slightly, since they will be constrained byexisting connection points. However, fast DC chargers will grow to more than 150 kW (even up to300 kW) [4].

Although most EV charging processes today take place at homes, it is clear that access to publicfast DC charging stations could help mitigate the so-called ‘range anxiety’, which is one of the reasonsconsidered for doubting buying an electric car. Therefore, the development of a charging infrastructureis a work in progress and likely the greatest long-term challenge for electric vehicles [5]. On theassumption that vehicles served by the gas stations will be replaced by EVs in the future, EV ChargingStation facilities (CS) will be progressively built to meet this energy demand.Considering that the network inside a CS is a three-phase four-wire Low Voltage (LV) network230/400 V, which is typical in EU and permits the connection of both AC single-phase (230 V) loads andalso AC three-phase (400 V) loads. As an illustrative case, suppose that there are 10 fast DC off-boardcharging piles, which are three-phase AC/DC voltage source converters (VSC), of about 100 kW perpile. There is also a parking zone equipped with 20 AC charging piles, both 1-phase and 3-phase, ofabout 30 kW on average, and a commercial facility (about 100 square meters) for shopping and anotherservices of about 10 kW of installed power (based on an estimation of about 100 W per square meter).

The global power will be about 1500 to 2000 kW, which is about the same as a residential building oroffice building [6].A load of this magnitude is expected to require a connection to the Medium Voltage (MV)distribution network. Therefore, distribution system operators need to be informed in order tocoordinate and facilitate the connection of these stations. However, the impact is not only in termsof the power demanded. Since the chargers are based on power electronic converters, the quality ofsupply will also be greatly affected. From the AC side, most battery chargers on the market behave asnon-linear loads, which causes harmonic distortion, reactive consumption, and imbalances. Theseimpacts on LV networks have been extensively documented and measured [7–9].In this paper, impact of EVs on the power distributionnetwork is analyzed by MATLAB simulation. This paperpresents harmonics and voltage profile along with the lossesof distribution transformer when overloading with EV with Active Power Filter chargers.

2. ELECTRIC VEHICLE CHARGING STATION

In World, Electric vehicle charging stations are not sufficient. There are two types of charging stations existsi.e. public and private charging stations. Government has established few charging stations in different cities of World but maximum charging stations are private. These private charging stations have taken a higher charging rate. Fig. 1 shows a block diagram of an EVCS which comprises transformer, rectifier and converter. Basically, rectifier and converter make a charger which used for EV charging. The specifications of EVs available in World are given in Table 1 below.

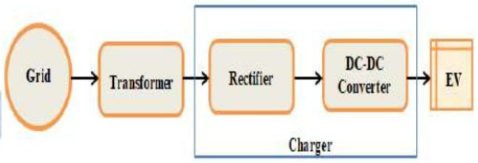

Fig.1: Block diagram of an Electric Vehicle Charging Station.

Table 1: Specifications of Electric Vehicles

Easy Bike and Auto-rickshaw	Electric motor cycle
Power: 500 W-1000 W	Power: 1000 W
Voltage: 36/48/60 V	Voltage: 48/60 V
Battery: 120 Ah-130 Ah	Battery: 14-25 Ah
Charging time: 6-7 hours	Charging time: 6-8 hours
Max. speed: 30-40 km/h	Max. speed: 50-80 km/h
Driving distance: 60-100 km	Driving distance: 40-60 km

As the EV loads are increasing day by day in a rapid manner, thus the impacts of EVs should be analyzed. The impact of mass EV penetration on power system is expressed in Fig. 2 below. Although EV penetration has cheapest transportation system, lower GHG emission facility, smart grid facilities. But negative impacts on power system network are very much significant.

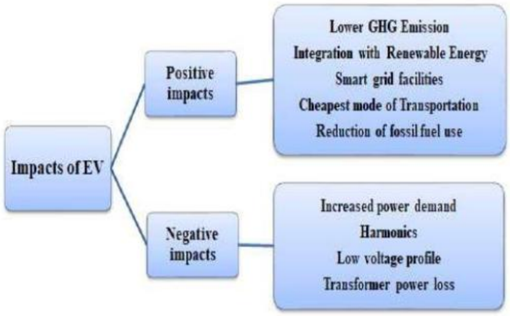

Fig. 2: Impacts of Electric Vehicle.

3. MATHEMATICAL MODELING

As a non-linear load, EV charger produces harmonics, low voltage profile and power loss in distribution transformer. In World, for EV charging level 2 type AC charging scheme is used where maximum current rating is 16 A and maximum power rating is 3.3 kW. Most of the electric vehicles have power ranges from 0.5 kW to 1 kW and all of them use single phase 240 V, 50 Hz supply system. In this section, we have developed mathematical modeling for harmonics, voltage profile and transformer overloading due to EV charging.

3.1 Power Demand

Electric Vehicle battery takes charge from the power distribution system. The increased power demand affects the stability of the system due to non-linearity. The power demand by an EV can be expressed as in Equation (1).

$$P_{EV} = \frac{C_{Batt} * (SOC_{max} - SOC_{min})}{T_D}; \quad (1)$$

Where CBatt is the battery capacity, TD is the duration of charging. Battery SOC is a factor whether the EV takes high or small power. The gross power demand of the EVs is the summation of individual power demand of all EVs which likely signifies as in Equation (2).

$$P_{Gross} = \sum_{N=1}^{N} P_{EV}; \quad (2)$$

3.2 Harmonics

The rise in high frequency components of voltage and current with compared to fundamental frequency is defined as harmonics. Harmonics distorts the voltage & current waveforms and thereby affecting power quality. It can be measured by total harmonic distortion (THD) of current & voltage.

$$THD_i = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_1} \times 100\%;$$
$$THD_v = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1} \times 100\%; \quad (3)$$

Equation 3 express the Total Harmonic Distortion (THD) for current and voltage respectively [6]. For slow charging THDi, THDv will be less than the fast charging. Thus, the EV with low SOC will have a great chance to produce harmonics.

3.3 Voltage profile

The low voltage profile becomes a threatening issue induced by EV charging. Voltage stability refers to the ability that the power network being stable after the sudden increase or decrease in the loads. EV loads take large amount of power at a very short duration. Thus, voltage profile will be degraded and grid will be unstable.

3.4 Transformer performance

Mass deployment of EVs creates an additional stress on distribution transformers and their life cycles. Another problem is that, the EV charging rate should be limited per day and charging stations should keep far away from transformer for reducing power loss. Harmonic current is responsible for occurring load losses in transformer whereas harmonic voltage incurs no load loss. Due to these harmonic losses, heating is increased relative to the pure sinusoidal wave. This harmonic withstand capability can be measured by a factor called k- factor.

$$K - factor = \sum_{n=1}^{N} n^2 [\frac{I_n}{I_R}]^2; \quad (4)$$

In is the current related to nth harmonic and IR is the rated load current. The presence of harmonics causes overheating in the transformer. Thus, the transformer should be selected according to the withstand capability at higher harmonic current for non-linear loading [7].

5. ACTIVE POWER FILTER

The increasing use of power electronics-based loads (adjustable speed drives, switch mode power supplies, etc.) to improve system efficiency and controllability is increasing the concern for harmonic distortion levels in end use facilities and on the overall power system. The application of passive tuned filters creates new system resonances which are dependent on specific system conditions. In addition, passive filters often need to be significantly overrated to account for possible harmonic absorption from the power system. Passive filter ratings must be coordinated with reactive power requirements of the loads and it is often difficult to design the filters to avoid leading power factor operation for some load conditions. Active filters have the advantage of being able to compensate for harmonics without fundamental frequency reactive power concerns. This means that the rating of the active power can be less than a comparable passive filter for the same nonlinear load and the active filter will not introduce system resonances that can move a harmonic problem from one frequency to another.

The other solution is to install line-conditioning systems that suppress or counteracts the power system disturbances. Active power filters offer a flexible and versatile solution to voltage quality problems. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. Active power filters can perform one or more of the functions required to compensate power systems and improving power quality. As it will be illustrated in this paper, their performance depends on the power rating and the speed of response. The selection of the type of active power filter to improve power quality depends on the source of the problem.

Active filtering technique senses the non-linear load harmo voltages or current use either

1) Inject harmonic current at 180 degrees out of phase with the load harmonics.
2) Inject or absorb current bursts to hold the voltage waveform within an acceptable tolerance.

These approaches provide effective filtering of harmonics and eliminate some adverse effects of passive filters such as component aging and resonance problems. The active filter is a generic name and is applied to a group of power electronics circuits incorporating power semiconductor device and passive energy storage circuit elements, such as an inducto and capacitors. The function of these circuits varies, depending on the applications. They are generally used for controlling current/voltage harmonics in supply voltage. They are also used for the reactive power generation and load balancing.

The active power filters are classified into different sections based on,

- The power circuit configuration and connection,
- Technique used for estimating reference current/voltage,
- Control strategies.

Classification based on the power circuit configuration and connectionIn this class of filters, the power circuit configurations are,

a) Shunt Active Power Filters

b) Series Active Power Filters

c) Combination of Series-Shunt Active Power Filters

5. SIMULATION RESULTS

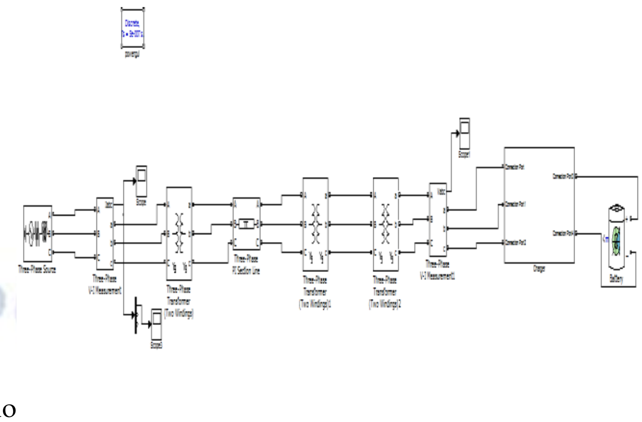

Fig 3 Simulink diagram of Proposed System is when single EV is connected at a charging station

Harmonics are the disturbances of a power system. EV charger is non-linear load and when it connected in the power system then it generates harmonics. As the EV charger normally connected at the power distribution network for charging, the aggregated effects of harmonics can be threat for the whole power system. In the MATLAB Simulink modeling, the harmonics generated at the different ratio of EV charging is shown in below Fig. 4, 5, 6.

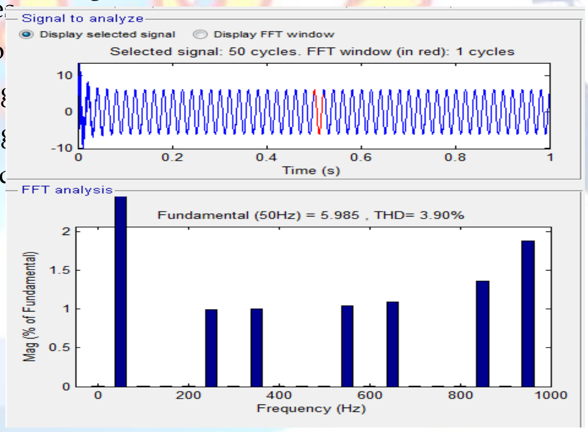

Fig. 4 Harmonics, when single EV is connected at a charging station

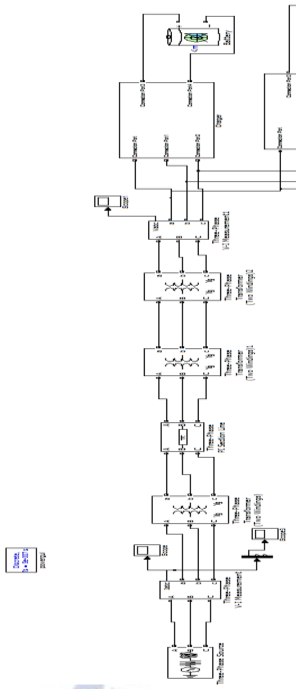

Fig 5 Simulink diagram of Proposed System is when three EV is connected at a charging station

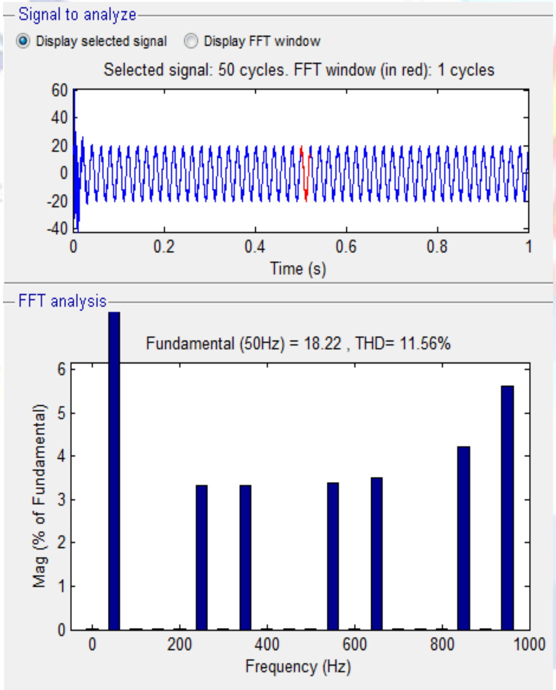

Fig. 6 Harmonics, when 3 EV chargers are connected at a charging station

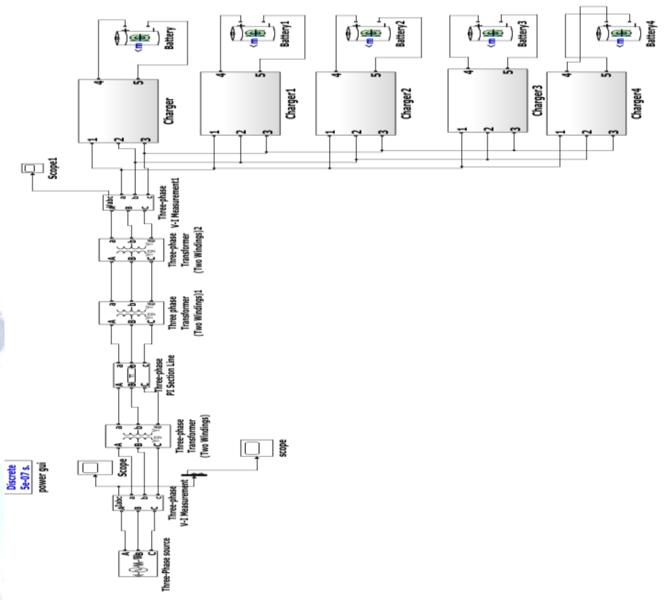

Fig 7 Simulink diagram of Proposed System is when five EV is connected at a charging station

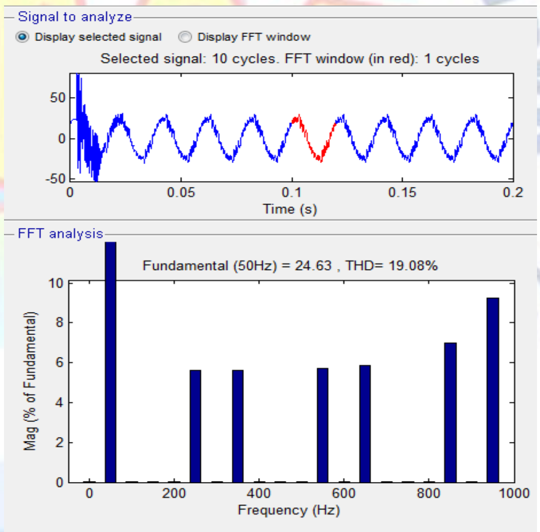

Fig. 8 Harmonics, when 5 EV chargers are connected at a charging station

Voltage at the distribution end also reduces when multiple EV chargers are connected. The overloading due to large number of EVs causes this problem. The voltage profile variation before connecting EV charger and after connecting EV charger is shown in Fig. 10 & 11. Fig. 11 shows that, the voltage is affected by harmonics disturbanec compared to the voltage without connection of EV chargers in Fig. 10. In the Fig. 11, it is seen that voltage sag and swelling occurs with harmonic disturbances.

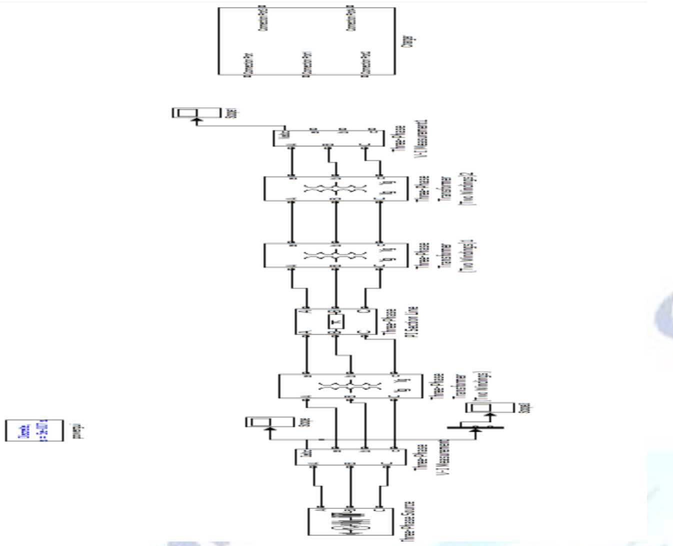

figure 9 Simulink diagram of proposed system before connecting Charger.

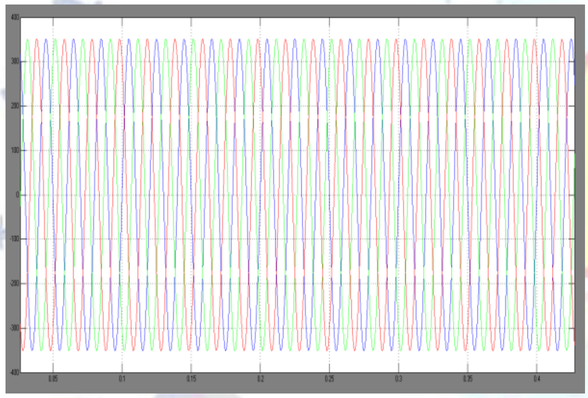

Figure10 Input Voltage, before connecting Charger.

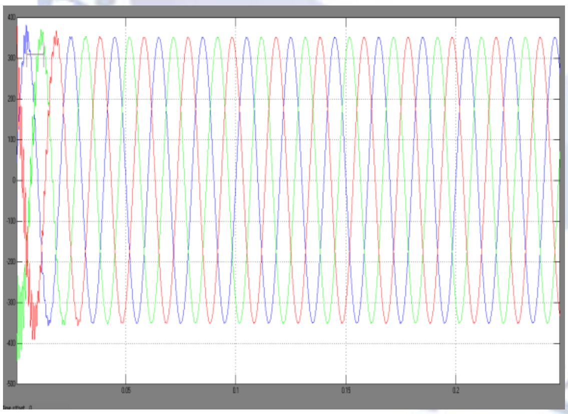

Fig. 11 Input Voltage, after connecting Charger.

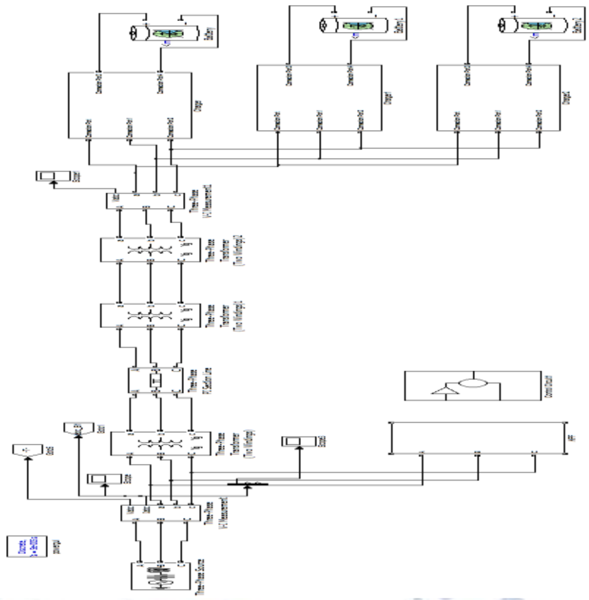

Figure12 Simulink diagram of proposed system(3 EV chargers are connected at a charging station) with Active Power Filter.

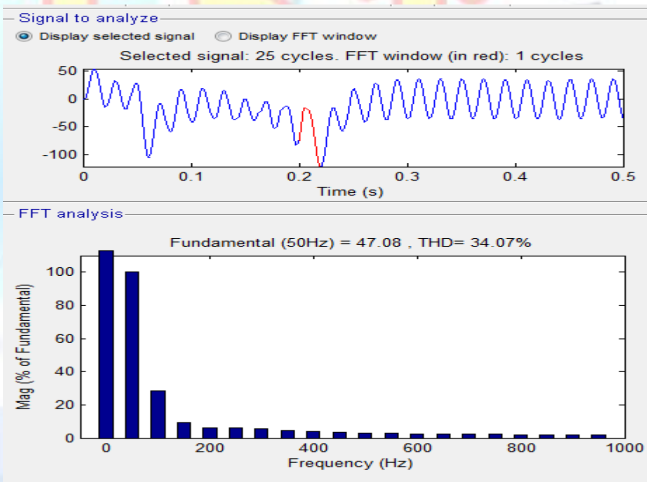

Fig. 13 Harmonics, when 3 EV chargers are connected at a charging station with charging Station with Active Power Filter.

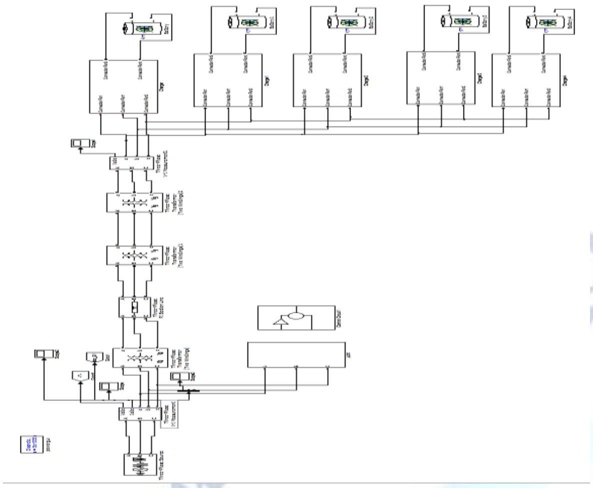

Figure 14 Simulink diagram of proposed system (5 EV chargers are connected at a charging station) with Active Power Filter.

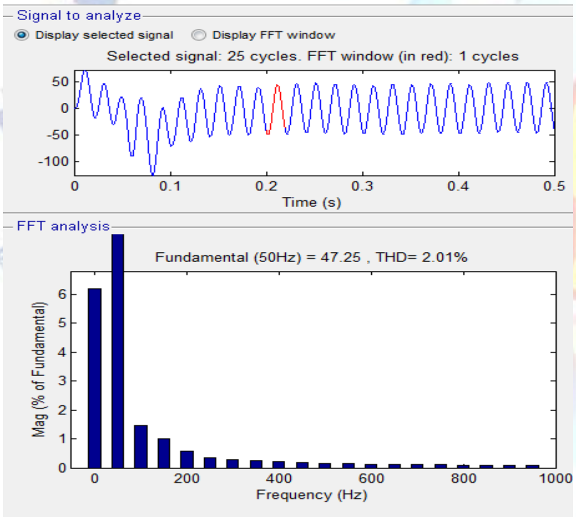

Figure 15 Harmonics, when 5 EV chargers are connected at a charging station with charging Station with Active Power Filter.

6. CONCLUSION

Prominent features of less environmental pollution & cheapest mode of transportation makes EV market more attractive to the consumers. As maximum EVs are charged at residential connection due to the lack of charging stations with filters in World, the power sector has been failed to earn the profit from this sector. However, due to some reasons EVs with filters penetration makes power system more vulnerable and hampers power quality. In this paper, the power quality issues like harmonics, voltage fluctuation, transformer power losses are analyzed using MATLAB Simulink in the context of World power sector. In addition to this, the mitigation technique with filters using available renewable resources is also discussed in this paper. Although the EVs with filters have several benefits as like stabilizing the grid at under loaded condition, lower GHG emission but the power quality issues should regulate properly for sustainable development in the power sector

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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