Effect of Electrical Vehicle Charging on Power Quality

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Abstract - Electric Vehicles (EVs) are a clean energy alternative to gas and energy powered vehicles. They form a crucial part of the present and future automotive. Electric vehicles being non-linear loads could affect the power quality of the grid. In this paper, we present a view of the fluctuations in power factor and Total Harmonic Distortion (THD) levels when varying number of electric vehicles (two wheeler and four wheeler) are connected to the power system .The system was simulated and studied in Simulink. Here, a captive power plant that is supplying power under base load and peak load conditions is considered.

***Key Words*:** Electric Vehicles, Charging Station, Captive Power Plant, Total Harmonic distortion, Power factor, Base load, Peak load

1.INTRODUCTION

Sustainable transport for the world is the need of the hour. Sustainability in transport can only be obtained when the transport system can rely only on sources of energy which last for a really long time like the energy from the sun and/or the wind. The best way of extracting energy from the sun and wind is by the electric way. In other words, sustainable transport system needs to have the electric energy source powering the vehicle. An Electric Vehicle (EV) is a vehicle that is powered at least partially by the electric force derived from the electric motors or the traction motors. A Charging System is a device used to deliver energy into a rechargeable battery by forcing electric current through it. The power input to the battery and the time through which it charges varies for different batteries. The nature, size, materials and electrochemistry of the battery system are to be considered for the type of charging system to be employed. The charging systems will have to keep constant monitoring on the parameters related to battery like the State of Charge(SOC), maximum voltage and temperature. The classification of charging power levels are done based on the output power that the charger can deliver to the battery. It also takes into consideration of power levels available at domestic and commercial utility as well as the industrial supply. The different levels of charging include:

Level 1 Charging: This is the most used and the slowest method of charging an Electric Vehicle. Level-1 uses a standard 110/220V 15A single-phase AC outlet that is common in most households. This type of charging is the most preferred one as this can be used at home for an overnight charging of the Electric Vehicle. The maximum power output in Level-1 charging is 3.5 kW.

Level 2 Charging: This type of charging is the most suitable for private and public places where the Electric Vehicles are parked outside the houses. Level-2 charging uses up to 240V and 80A AC outlet. As the power levels of this are very high, separate setup is necessary. The usage of this charging system is limited to cities and urban areas. The maximum power output for a specific charging system to be called Level-2 is 19.2kW.

Level-3 Charging: This charging system is only used for dedicated stations which can help charge the electric vehicle in a pretty quick time. It needs infrastructure used specific to electric vehicle charging. This is majorly used on highways and rest areas near them. These are synonymous to fuel stations that are in use. The voltage levels of these charger stations are above 480V (three-phase AC) and the power output is greater than 19.2 kW. This charger can have either AC or DC outputs.

Rapid Charging: Any electric vehicle that can be charged within 60 minutes is called a rapid charging. The different levels for charging an electric vehicle were discussed in the previous section. A Charging System can be called rapid charging at all the power levels.

The effect of charging of Electric vehicles (EVs) and Plug- in Hybrid Electric Vehicles (PHEVs) on the life of distribution transformers was discussed in [1].Charging of electric vehicles does not have a huge impact at the macro level as the power grid will have strong dispatching capacity. However, the uneven distribution of electric vehicles can lead to peak valley difference thus having a negative impact on the life of the utility grid [2]. The impact of large scale discharging of EVs on the daily load characteristics of China was analyzed in [3]. It was concluded that large scale discharging of EVs could make the load curve smoother if proper strategy is applied[3]. A general analysis of electric vehicles acting as energy storage units and power sources when connected to the grid was studied[4]. Charge controllers can sometimes exhibit high levels of total harmonic distortions which can degrade the magnetic devices present in the power system. Also, the total harmonic distortion of the current waveform changes as the vehicle is charging. The THD levels were found to be high during the high current period of the cycle [5]. A Synchronous Reference Frame Controller (SRFC) was proposed to eliminate the negative voltage distortion due to the EV charger system in [6]. Co-ordinated charging of electric vehicles at peak periods could reduce the impact o vehicle charging system on the grid [7].

In this paper we have studied the impact of electric vehicle charging stations on the power quality of the grid considering a captive power plant..

2. TEST SYSTEM CONSIDERED

To understand the impact of charging electric vehicles on the quality of power at the grid, a captive power plant unit was considered. Captive power plant is a facility that is dedicated to providing a localized source of power to an energy user. The plants may operate in grid parallel mode with the ability to export surplus power to the local electricity distribution network. Alternatively they may have the ability to operate in island mode; i.e. independently of the local electricity distribution system.

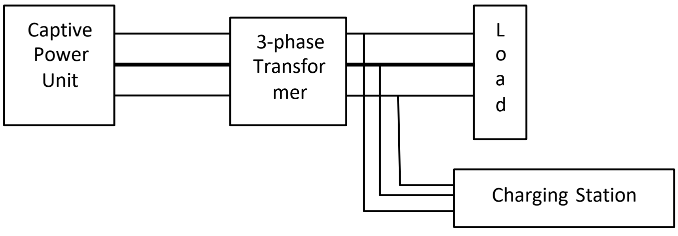
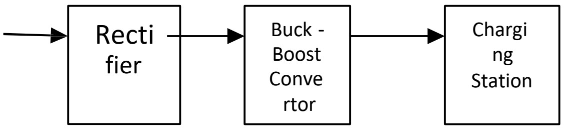


Figure A: Simulink Model

The power system model consisting of captive power plant, three phase transformer, load and charging stations was modelled and simulated in Simulink (MATLAB).

1) Captive power plant model: A three-phase generator rated 200 MVA, 13.8 kV, 50 Hz is connected to the network through a 200 MVA, 13.8/230 kV Delta-Wye transformer. The model consists of a hydraulic turbine, governor and excitation system that is connected to a salient pole synchronous machine.

2) Charging station: The charging unit model consists of
a) Three phase AC-DC rectifier model
b) Buck-boost convertor unit
c) Battery unit.



The three phase diode rectifier unit converts the 3-phase AC voltage at the input to a DC voltage at the output. The DC voltage at the output of the rectifier is fed to a buck boost convertor unit to supply the necessary voltage required to charge the batteries. The buck boost convertor unit was modelled with PWM switching.

3) The battery unit consists of Lithium ion(Li-ion) battery models that are designed for two wheeler and four wheeler applications.
The two wheeler Li-ion battery model is rated 48V, 24Ah, 80%SOC.Each two wheeler battery model has a maximum capacity of 24Ah, fully charged voltage of 55.81V and a nominal discharge current of 10.4348A.The capacity of the battery at nominal voltage is 21.7Ah.
The four wheeler Li-ion battery model is rated 72V, 100Ah, 80%SOC.Each four wheeler battery model has a maximum capacity of 100Ah, fully charged voltage of 83.8V and a
nominal discharge current of 43.478A.The capacity of the battery at nominal voltage is 90.434Ah.
Around 18 electric vehicles were connected at each charging station for this study. The vehicles are assumed to be charged under intermediate mode of charging. The charging was done under off-peak and peak hours and the results were analyzed.

3. CASE STUDY

To the system, varying number of two wheeler and four wheeler charging stations were connected. The charging model was simulated in Simulink for a time period of four cycles (0.08 seconds).

(a) Case Study 1: The Simulink model was simulated without any EVs connected.

(b) Case Study 2: The EV charging model was simulated under base loads(5MW) with two wheeler and four wheeler electric vehicles connected exclusively.

(c) Case Study 3: The EV charging model was simulated under peak loads (70MW) with two wheeler and four wheeler electric vehicles connected exclusively. THD and input power factor levels were calculated for the aforementioned case studies.

4. RESULTS

A. Fundamental voltage and current waveforms were obtained for all the case studies at the generator end.

(a) Case Study 1:

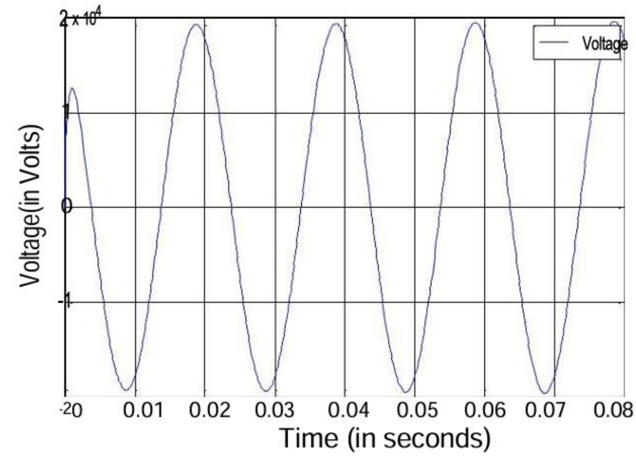


Figure 1: Voltage Profile.

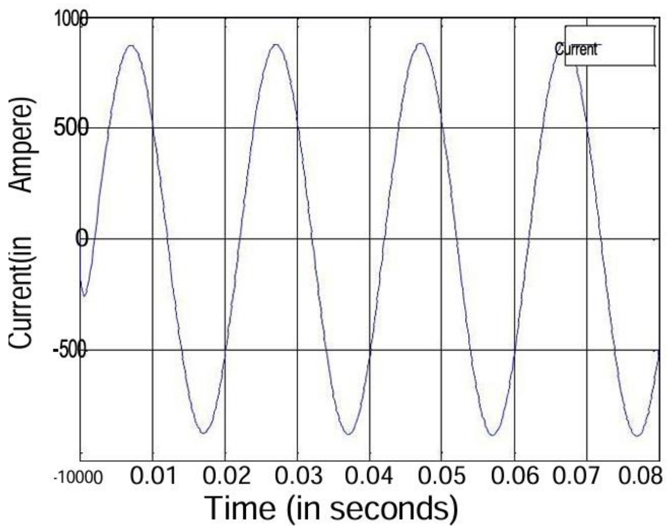


Figure 2: Current profile.

Figure 1 and Figure 2 represent the voltage and current profiles at the generator end respectively when no EVs were connected. The voltage and current waveforms were found to be sinusoidal with least distortion level. The little distortion present in the waveforms is due to the inherent load in the system.

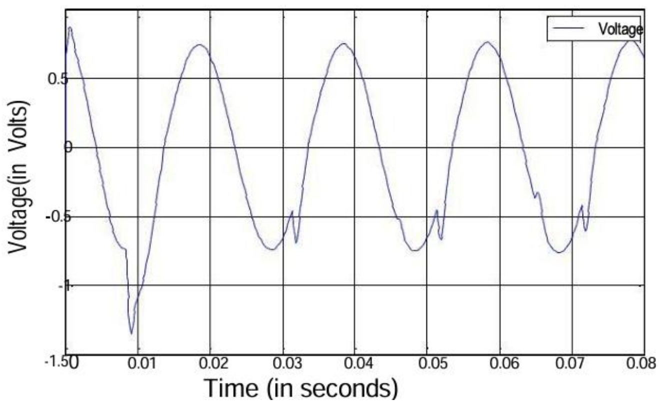


Figure 3: Voltage waveform with two wheelers connected.

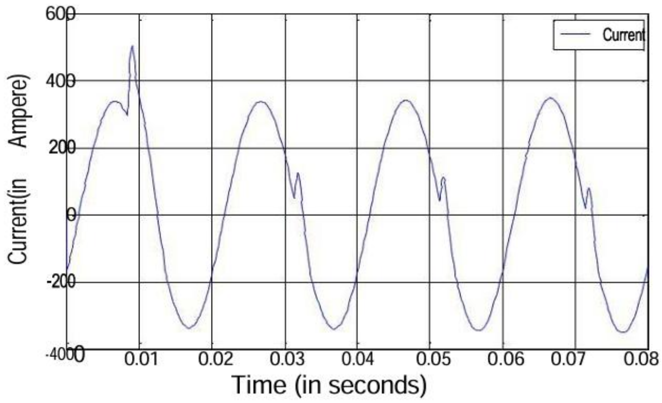


Figure 4: Current waveform with two wheelers connected.

Figure 3 and Figure 4 represent the voltage and current profiles when two wheeler charging stations were connected to the power system respectively under base loads.

(b) Case Study 2:

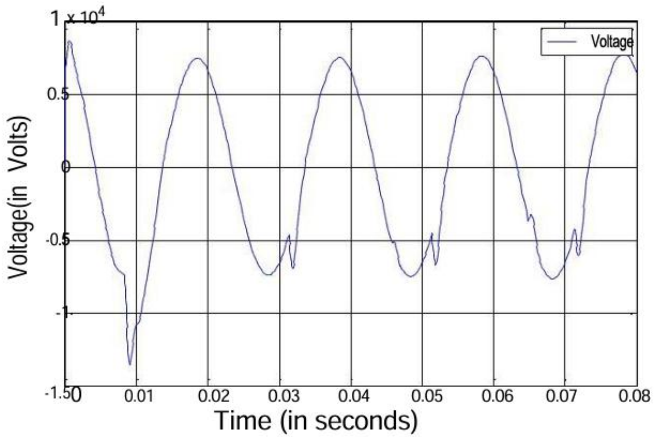


Figure 5: Voltage waveform with four wheelers connected.

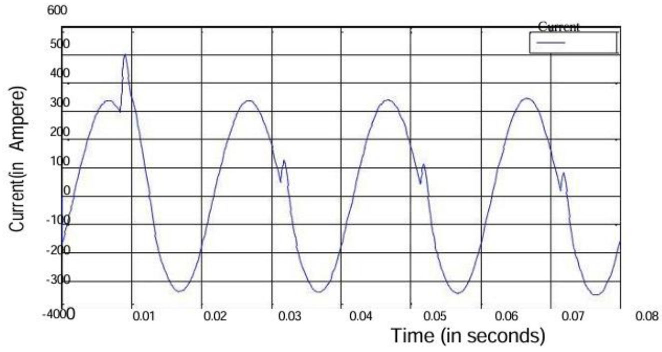


Figure 6: Current waveform with four wheelers connected.

Figure 5 and Figure 6 represent the voltage and current profiles when four wheeler charging stations were connected to the power system respectively under base loads. When two wheeler or four wheeler charging stations were connected to the power system under base load, some amount of distortion was found in the fundamental voltage and current waveforms.

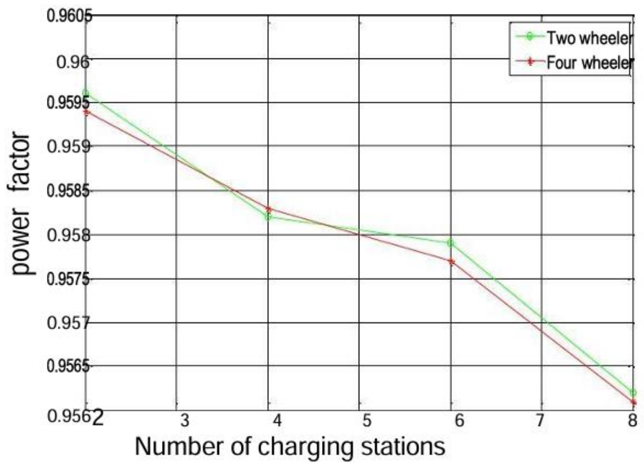


Figure 7: Power factor profile under base load

Figure 7 shows the input power factor profiles when two wheeler and four wheeler charging stations are connected to the power system respectively under base load conditions.

It is seen that in both the cases the input power factor levels gradually decrease as the number of charging stations connected to the power system increases. The maximum input power factor was obtained when no EVs were connected. Figure 8 depicts the change in total harmonic distortion levels when varying number of two wheeler and four wheeler charging stations are connected to the power system under base load.

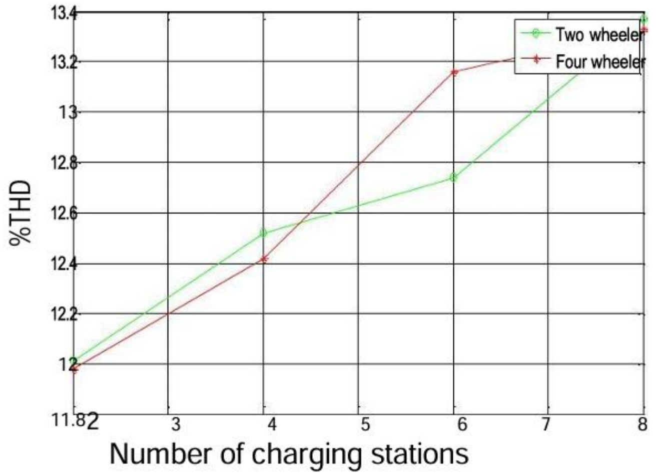


Figure 8: %THD profile under base load

It is seen that the harmonic distortion is slightly greater when four wheeler charging stations are connected compared to two wheeler charging stations.The THD levels increase as the number of charging stations increases.

(c) Case Study 3:

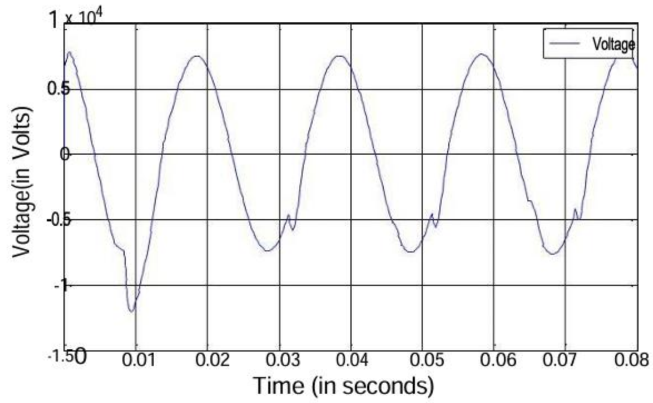


Figure 9: Voltage waveform with two wheelers connected.

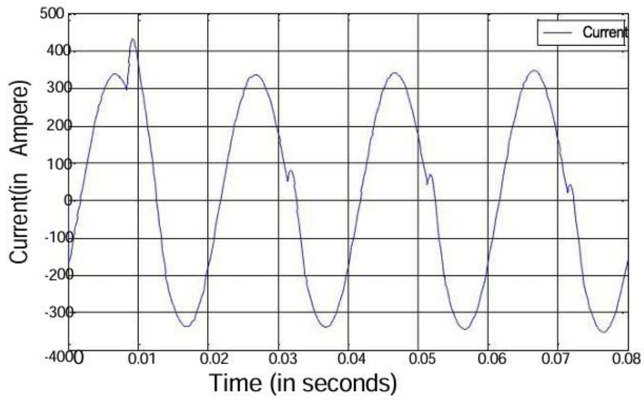


Figure 10: Current waveform with two wheelers connected.

Figure 9 and Figure 10 represent the voltage and current profiles when two wheeler charging stations were connected to the power system respectively under peak loads.

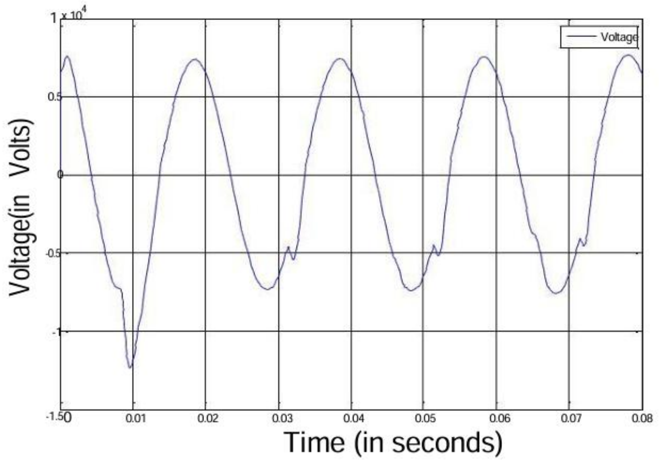


Figure 11: Voltage waveform with two wheelers connected.

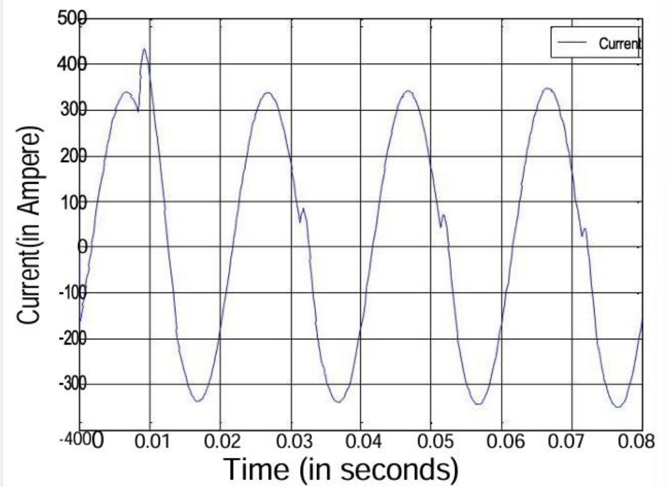


Figure 12: Current waveform with four wheelers connected

Figure 11 and Figure 12 represent the voltage and current profiles when four wheeler charging stations were connected to the power system respectively under peak loads. It can be observed that the voltage and current waveforms are distorted when either two wheeler or four wheeler charging stations were connected under peak load conditions. The variations in power factor and THD levels were observed.

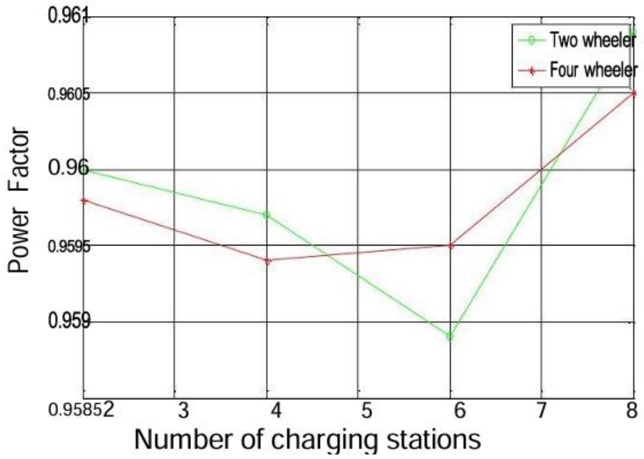


Figure 13: Power factor profile under base load

With an increase in the number of charging stations connected to the power system, the power factor levels decreased gradually as shown in figure 13. However, when many charging stations were connected to the grid there was a slight increase in the power factor level.

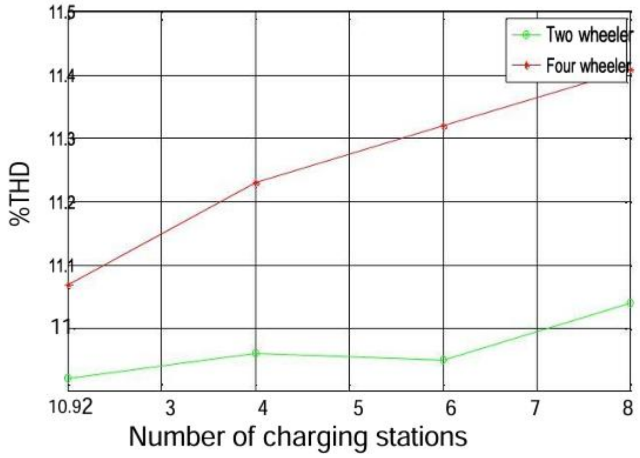


Figure 14: %THD profile under peak load.

The %THD level was found to increase gradually with an increase in the number of charging stations connected to the power system as depicted in figure 14. Also, the THD levels under peak load conditions was found to be less significant than that under base load conditions.

5. CONCLUSION

When electric vehicles were charging under base load and peak load conditions, it is observed that the input power factor levels dropped gradually as increasing number of charging stations were connected to the power system. Total harmonic distortions were found to increase with inclusion of charging stations during base loads. The THD levels do not vary significantly during peak loads.

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