International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622
International Conference On Emerging Trends in Mechanical and Electrical Engineering
(ICETMEE- 13th-14th March 2014)

RESEARCH ARTICLE OPEN ACCESS

Impact of Electric Vehicles on Energy Trading in an Electricity Market

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ABSTRACT
With the increase in number of Electric Vehicles (EVs) in the market, it is important to study their impact on electricity trading. The energy trading is highly dependent upon the charging and discharging schedule of EVs, hence both rigid and flexible charging strategies have been considered.Since these EVs can act as load as well as suppliers, they can participate in the market as a buyer as well as a seller. Thus, two modes of their participation in the market, viz. buyer mode and hybrid mode have been considered to analyze their impact. Considering these facts, four different cases have been studied with different penetration level of EVs to investigate their impact on energy trading.The study has been performed on a hypothetical market, comprising of six sellers and twenty buyers, having double-sided auction mechanism. The results showed that the hybrid mode with flexible charging has the potential to increase the trading of electricity in the market and would be beneficial for the customers.

Index Terms—Electricity markets, electric Vehicles, energy trading, rigid and flexible charging,

I. INTRODUCTION

Presently, automobile industry is shifting towards Electric Vehicles (EV), such as plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) in order to reduce the greenhouse gas emissions contributed by the transport sector. These electric vehicles use electricity as a fuel and include on board battery management systems (BMS), which allow their connection to the electric grid. The usage of EVs is expected to increase in coming decades due to fossil fuels scarcity. A large deployment of EVs will put an additional load demand on the power grid, which might provoke different impacts on power system operation. However, with the advent of Vehicle to Grid (V2G) technology, the power flow from vehicle to the grid has been enabled allowing grid integration of EVs. The usage of EVs for transport is limited to 4-8% in a day whereas they are parked for rest 92-96% of time. Thus, their integration into the power grid may offer solution to various problems such as supply of extra power to meet peak demand, increased spinning reserve and their high energy storage capacity can be utilized to avoid spillage of variable and intermittent renewable energy generation as well as operation of expensive generators during peak hours.

Recently, a lot of research has been carried out to develop mechanisms for integration of EVs into the power grid and analyzing their technical and economic impacts. A conceptual framework for integration of EVs into power system with the grid technical management and market operation has been presented in [1]. The impact of large scale charging and discharging of EVs on daily load of X city in China is analyzed in [2]. The effect of EVs on the operation of wholesale electricity market of Ireland has been investigated in [3] considering off-peak and peak charging scenarios. In [4], the maximum share of EVs, which can be integrated into the grid, has been determined using dumb charging and smart charging strategies. The effect of controlled and uncontrolled charging of EVs on locational marginal pricing has been analyzed in [5]. The impact of EV charge scheduling on the day-ahead electricity market price at various penetration levels of EVs has been studied in [6]. Further, an aggregator scheduling model and a joint scheduling model has been proposed for enabling participation of EVs in the electricity market. The joint scheduling model allows the individual EV owners to interact directly with the market to schedule EV charging assuming existence of advanced communication and control infrastructure. However, the aggregator-scheduling model requires an aggregator to manage and control the charge scheduling of a group of EV owners.

Literature survey reveals that the researchers have analyzed the impact of EVs on the market price, which would be affected by the mode of participation of EVs, their charging strategies and penetration level. However, only single sided auction has been considered for analysis. It is well recognized that the participation of buyers in the auction process can significantly affect the market price. In fact, EPEX SPOT of Germany, IEX of India and Nordpool of Nordic countries utilizes double auction mechanism of energy trading.

This paper analyzes the impact of high penetration of EVs on the trading of electricity considering double-sided auction mechanism. Participation of EVs in the market has been considered via two modes viz. buyer mode and hybrid mode. Since the energy trading is highly dependent upon the charging and discharging schedule of EVs, rigid and flexible charging schedule has been considered. The study has been performed on a hypothetical market, comprising of six sellers and twenty buyers, having double-sided auction mechanism. Four cases, viz. buyer mode with rigid charging, buyer mode with flexible charging, hybrid mode with rigid charging and hybrid mode with flexible charging has been analyzed with different penetration level of EVs to identify their impact on electricity trading.

II. MODELING OF ELECTRIC VEHICLES

The impact of EVs on electricity trading would be influenced by various factors such as the type and number of vehicles, the driving requirements of EV owners, charging and discharging characteristics of batteries, state of charge, time and location of charging etc. This section describes the EV characteristics considered in this paper.

A. EV-Battery

Three types of EVs namely BEV, City-BEV and PHEV90 comprising 37%, 10% and 53% respectively, has been considered in this paper [7]. The average battery capacity and average energy consumption of the EVs has been taken from and listed in Table I. It has been assumed that the battery will take 6 hours to charge fully from 0% State of Charge (SOC). The charging power/discharging power required/delivered by the battery can be calculated by dividing the required energy by the duration of charge/discharge. Thus, the charging and the discharging power are assumed to be constant and equal to 4.017 kW.

TABLE I
BATTERY DATA [7]

Battery Capacity	24.1 KW/Hr
Consumption	0.192 KWh/Km
Max. Distance	125.25 Km

B. EV Data

The information of availability hours of EV is important to analyze their impact on the power grid as well as market. The EV availability data extracted from the driving data of National Transport Survey Data (TU data) in [8] has been used in this paper. The hourly EV availability data for a day, shown in Fig.1, has been used to determine the charging and discharging hours of EVs. The average driving distance is assumed to be 30 km [8]. The total number of EVs are assumed to be 0.2 million. Few more assumptions are made as mentioned below.

1) The vehicle travels equal distance from home to work and back from work to home.
2) The vehicle is fully charged while leaving from home and there is enough power left for the return trip while leaving work place.

C. Charging Strategies

It has been assumed that the charging infrastructure is available at home as well as at work. EVs are assumed to be unavailable for charging/discharging during driving time only. It can be seen from Fig. 1 that the vehicles start arriving at home around 18.00 hours and most of the vehicles return by 21.00 hours. Following two types of charging strategies have been considered in this paper as explained below.

1) Rigid Charging

In this type of charging, customers are assumed to charge their vehicles as soon as they reach home irrespective of electricity price and discharge in afternoon hours. Charging hours are taken as 18.00 hours to 06.00 hours while the discharging hours are taken as 10.00 to 14.00 hrs. EVs are neither charging nor discharging during time interval 06.00 to 10.00 hours and 14.00 to 18.00 hours. The number of vehicles

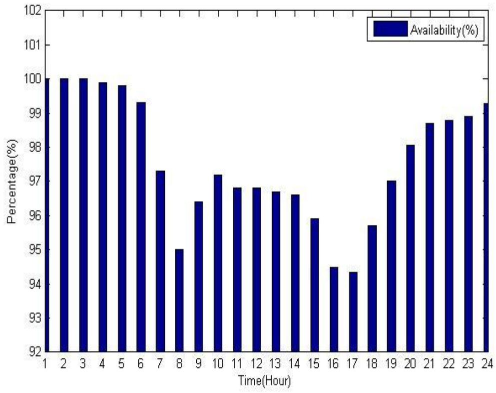

Fig.1.Percentage of EV Available per hour [8]

charging during a particular hour is obtained from the availability curve of vehicles shown in Fig. 1.

2) Flexible Charging

This type of charging assumes customers to be price responsive and will charge their vehicles during low price periods while discharge them during high price periods. In the coming years, the customers would be able to see the electricity prices at their home/work place with the help of advanced metering infrastructure. However, in this paper, the electricity market price has been obtained by simulating the market clearing process considering double sided auction mechanism.Market participants are assumed to comprise of six sellers and twenty buyers. The bidding prices and quantities of the participants have been taken from [9]. The Market Clearing Volume (MCV) and the Market Clearing Price (MCP), shown in Figs. 2 and 3 respectively, are obtained without participation of EVs and has been considered as the base case trading of energy.

From Fig. 3, it can be seen that the price is low during 18.00 hours to 8.00 hours and high in the rest time period. Assuming that the EV users may start leaving for office in the morning hours, charging period is assumed from18.00 hours to 6.00 hours while the discharging period is assumed from 9.00 hours to 17.00 hours. Half of the vehicles are assumed to charge during 18.00 hours to 00.00 hours and the other half during 0.00 hours to 6.00 hours.

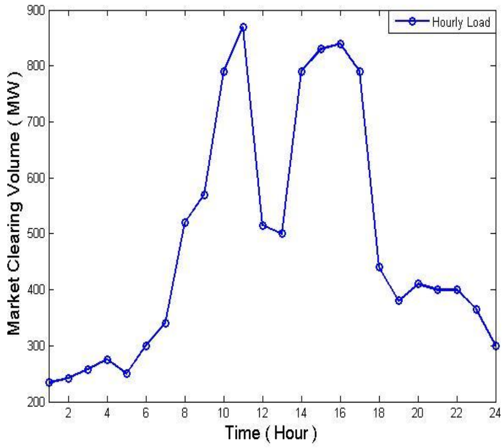

Fig.2 Base Case Market Clearing Volume

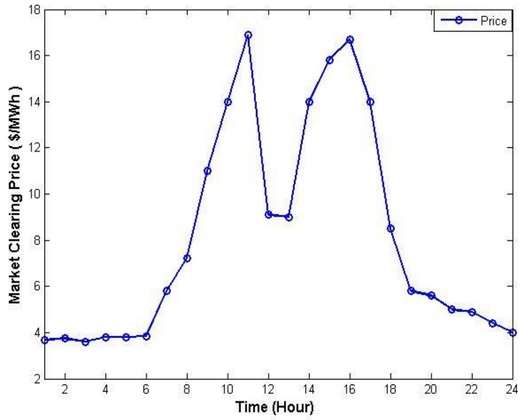

Fig.3 Base Case Market Clearing Price

D. Participation in the Market

Since EVs can absorb the energy from the grid as well as deliver it to the grid, they can participate in the market as a buyer as well as a seller. Based on this, following two modes of their participation has been analyzed.

1) Buyer Mode

In this mode, EVs are assumed to participate in the market as a buyer during charging as well as discharging. While discharging the vehicle, it is assumed that they are utilizing the energy delivered by the vehicle for their own use instead of selling it in the market. Thus, during discharging the load decreases below the base value while it increases above the base value during charging. The load due to EVs is distributed in weighted ratio of the base load among different existing buyers. Buyers estimate the total load for a particular hour and then bid the price and quantity into the market. The bid price of buyers is assumed to be the same as that for the base load.

2) Hybrid Mode

This mode assumes EV participation as a seller during discharging and as a buyer during charging. EVs are expected to replace the conventional vehicles in future and a large number of EVs would require a separate entity, an aggregator, for their management and control. The aggregator would participate in the bidding process in the market. It would collect information from the EV users regarding the expected supply as well as consumption of energy for EV loads to decide the bidding quantity. However, the bidding price needs to be decided strategically to gain maximum profit. In this work, it has been assumed that the aggregator's aim is to get selected in the market. Thus, to minimize the risk of selection in a uniform price market, the selling bid price is kept as 0 $/MWh whereas the buying bid price for each hour is assumed to be 10% higher than the corresponding base case MCP.

III. CASE STUDY

In order to analyze the impact of high penetration of EVs on the trading of electricity, the study has been performed on a hypothetical market having double-sided auction mechanism. The market participants comprises of six sellers and twenty buyers. The bidding prices and quantities of the participants have been taken from [9]. Figs. 2 and 3 show the trading of electricity at the base case.The hourly load profile of EVs at 10% penetration level, in accordance with their availability shown in Fig. 1, is depictedin Fig. 4 for rigid as well as flexible charging. The simulation has been performed using Symbolic and Optimization Toolbox of MATLAB. Following four cases have been analyzed with different penetration level of EVs to identify their impact on electricity trading.

Case 1: Buyer mode with rigid charging
Case 2: Buyer mode with flexible charging
Case 3: Hybrid mode with rigid charging
Case 4: Hybrid mode with flexible charging

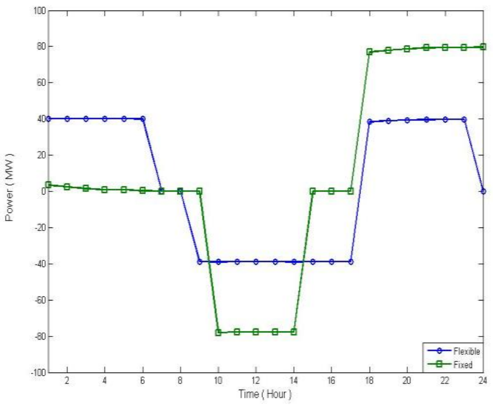

Fig.4 Hourly Load profile of EVs at 10% penetration level

Case 1:Buyer mode with rigid charging

The change in Market Clearing Volume (MCV) and Market Clearing Price (MCP) in each hour is depicted in Figs 5 and 6 respectively, for different penetration level of EVs. It can be seen that the trading of electricity increases above the base value during the initial charging hours leading to significant rise in price. However, the trading is almost same as the base case after 24.00 hours, while it decreases during the discharging hours due to the reduction in the load requirement. It can be observed that the increase in MCV during charging hours is balanced by decrease in MCV during discharging hours at penetration level of 10% and 25%. However, the decrease in MCV during discharging hours is higher than the increase in MCV during charging hours at penetration level of 50%. This shows that the participation of EVs as a buyer can reduce the trading of electricity in the market by about 35%. The highest increase in MCP is around 6$/MWh even at smaller penetration level of 10% whereas at higher penetration level, the MCP increases significantly. This may be due to the commission of expensive generators to meet the increased demand. During discharging hours, due to the minor decrease in MCV at smaller penetration level, MCPs almost remained same as at base case whereas at higher penetration level, the highest decrease in MCP is around 6$/MWh due to the availability of low priced V2G power.

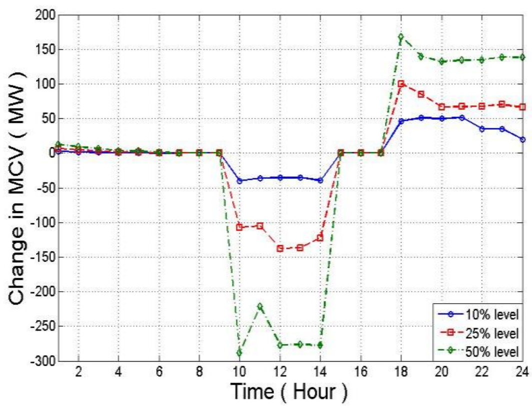

Fig. 5 Change in MCV for Buyer Mode with Rigid Charging

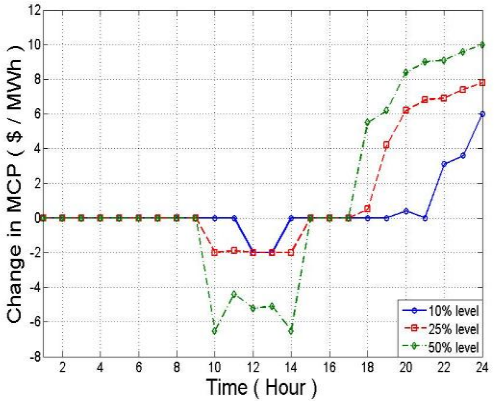

Fig. 6 Change in MCP for Buyer Mode with Rigid Charging

Case 2: Buyer mode with flexible charging

In this case, half of the vehicles are assumed to charge from 18.00 hours to 0.00 hours and the other half from 0.00 hours to 6.00 hours.Thus, dividing the charging load equally into these two periods. The change in MCV and MCP obtained in this case has been shown in Figs. 7 and 8 respectively. It can be seen that the MCV has increased in both the periods resulting in increase in MCP during these periods. For smaller penetration of EVs up to 25%, MCP has been increased by 2 $/MWh in early hours of the day, whereas in late hours, only 10% of EVs can be accommodated in the market without a significant increase in MCP. The increase in MCP is significant during early hours as well as late hours at higher penetration level.

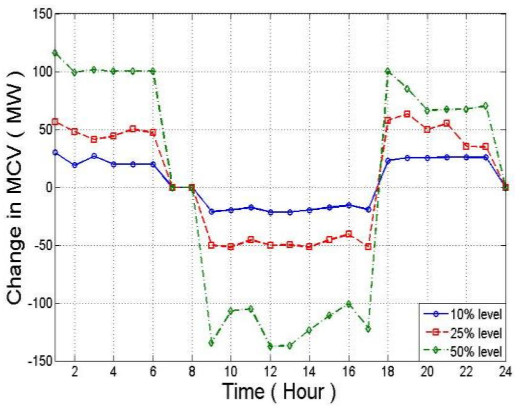

Fig. 7 Change in MCV Buyer Mode with Flexible Charging

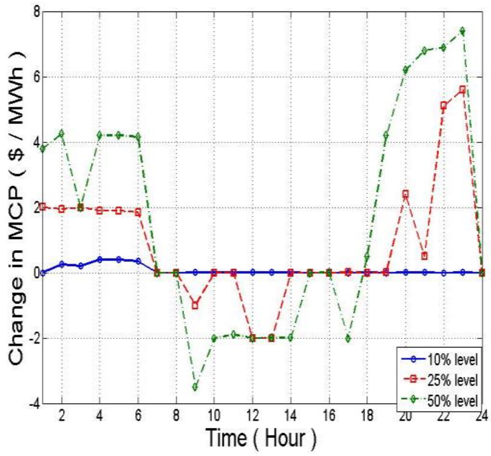

Fig. 8 Change in MCP for Buyer Mode with Flexible Charging

Case 3: Hybrid mode with rigid charging

In this case, EVs are assumed to participate in the market for selling and buying electricity through an aggregator. The aggregator submits the selling and buying bids in the market. Figs. 9 and 10 depict the variation obtained in MCV and MCP respectively, in this case. It can be seen that during the charging hours, even at higher penetration levels, electricity trading has been reduced as compared to case 1. This is due to the fact that the aggregator price bid is not sufficient to trigger the next expensive generator resulting in reduced change in the MCV and the MCP. The unfulfilled EV demand has been assumed to be meet by some other sources. Thus, to analyze the impact during discharging hours, the EVs are assumed to be completely charge. Since the aggregator is assumed to submit the selling bid price of 0 $/MWh to qualify in the market, he is able to sell his full available electric power. The highest decrease in MCP obtained at higher penetration level is around 9 $/MWh. Figs. 11 and 12 show the deviations obtained in the MCV and the MCP, respectively, when the aggregator is submitting the buy bid equal to thrice of the base case MCP in order to get selected in the market. It can be seen that both the MCV and the MCP has increased significantly during the charging hours as compared to case 1.

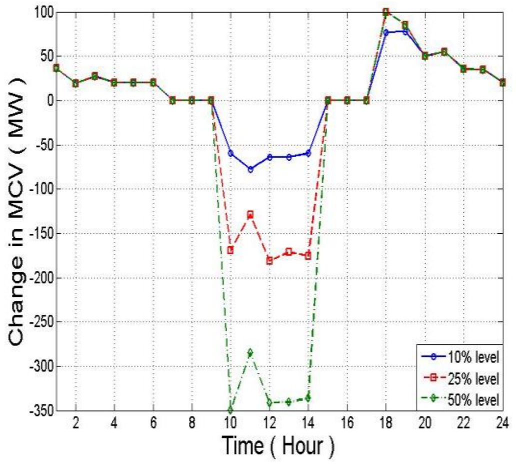

Fig. 9 Change in MCV for Hybrid Mode with Rigid Charging

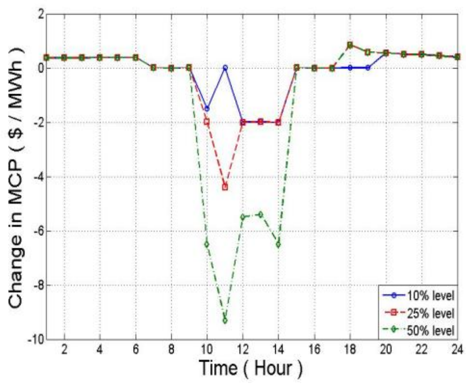

Fig.10 Change in MCP for Hybrid Mode with Rigid Charging

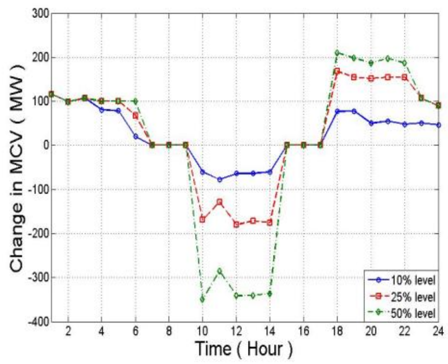

Fig.11 Change in MCV for Hybrid Mode with Rigid charging at the bid price of three times the base case MCP.

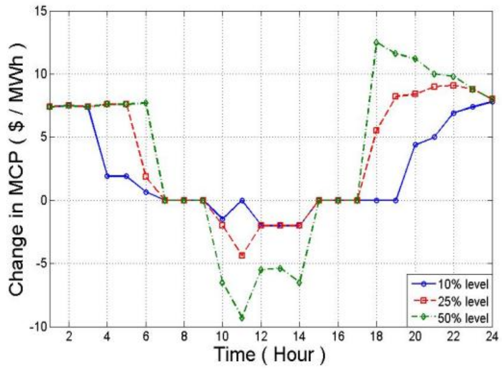

Fig.12 Change in MCP for Hybrid Mode with Rigid Charging at the bid price of three times the base case MCP.

Case 4:Hybrid mode with flexible charging

The variation in the MCV and the MCP obtained in this case is shown in Figs. 13 and 14, respectively. It can be observed that due to the insufficient buy bid, less amount of electricity has been traded during the charging hours resulting in less increase in the MCP. However, during the discharging hours, there is no significant decrease in MCP as compared to case 2. In order to analyze the impact of EVs on MCP during the charging hours, when participating through an aggregator, the buy bid price of the aggregator is assumed to be thrice of the base case MCP. This enables the aggregator to be selected in the market. The deviation obtained in the MCV and the MCP is shown in Figs. 15 and 16, respectively. During both the charging hours, the MCP is increased significantly athigher penetration level as compared to case 2.

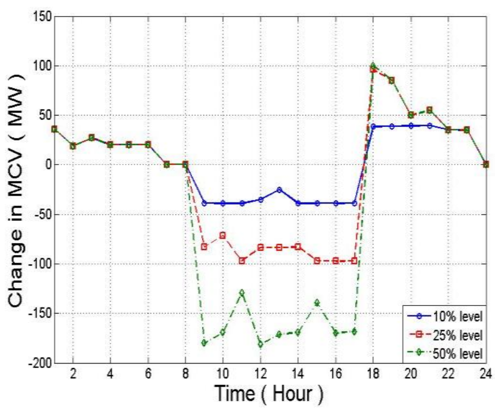

Fig. 13 Change in MCV for Hybrid Mode with Flexible Charging

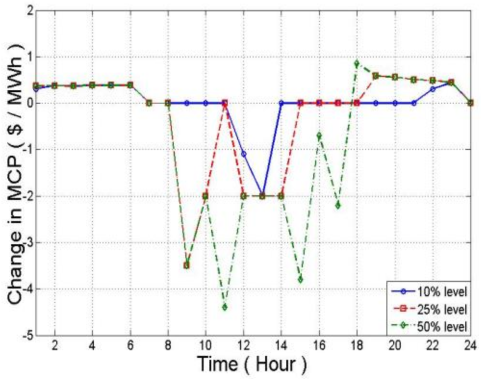

Fig. 14 Change in MCP for Hybrid Mode with Flexible Charging

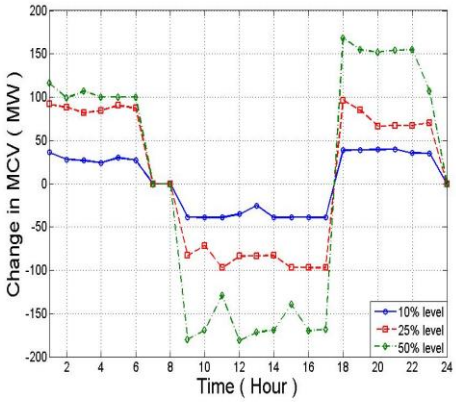

Fig. 15 Change in MCV for Hybrid Mode with Flexible Charging at the bid price of three times the base case
MCP.

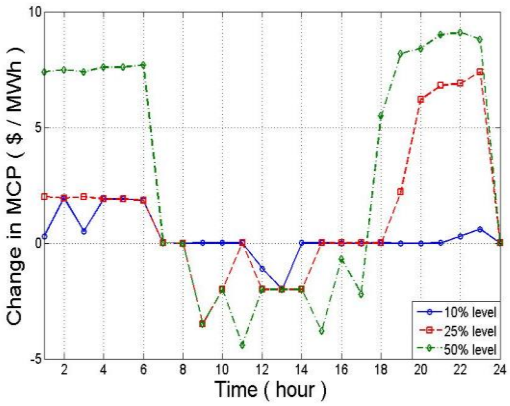

Fig. 16 Change in MCP for Hybrid Mode with Flexible Charging at the bid price of three times the base case MCP.

IV. CONCLUSION

The impact of EVs on energy trading has been analyzed in this paper considering different charging strategies and different modes of participation of EVs. The EVs are assumed to participate in the market via buyer mode and hybrid mode. In the buyer mode, EVs are assumed to participate as a buyer only whereas in the hybrid mode, they are participating as a buyer as well as a seller through an aggregator. Further, rigid and flexible charging strategies have been considered to analyze the impact. Thus, four different cases, viz. buyer mode with rigid charging, buyer mode with flexible charging, hybrid mode with rigid charging and hybrid mode with flexible charging, have been analyzed with different penetration level of EVs. The results showed that the hybrid mode with flexible charging has the potential to increase the trading of electricity in the market and would be beneficial for the customers. It might help in reducing the usage of expensive generators during peak power demand.

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V. BIOGRAPHIES

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