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Day Ahead Charging Coordination of Electric Vehicles to Improve Load Profile

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ABSTRACT: The growing concern about global climatic changes and fossil fuel depletion calls for a shift from conventional modes of transportation to electric vehicles (EV). The idea of bidirectional interaction between grid and Electric vehicle has brought the V2G ,V2H etc. technologies . Bi- directional chargers adds the benefit of EVs by enabling energy transfer from vehicle to grid (V2G) or vehicle to home (V2H) in addition to charging from grid to vehicle(G2V). The adoption and diffusion of EV's to the power grid is beneficiary from the environmental perspective but they pose a serious impact on the power system. The major issues includes: The peak demand for the electrical grid will increase, the distribution transformer would be overloaded, and the power quality and the reliability of the whole system would be degraded. A possible panacea for mitigating these impacts is to make use of smart charging/discharging capability of EV's. This paper proposes a day ahead charging algorithm for load leveling and load shifting thus improving the load curve ,giving due importance to providing cost benefits to the consumer. The algorithm depends only on the relative shape of the forecasted load curve and hence flexible. The charging/discharging schedules of EV's are developed using Lingo optimization software.

KEYWORDS: Electric Vehicle, peak load, charging optimization, load profile, load shifting, loadleveling.

I.INTRODUCTION

Electric vehicles (EVs) are currently emerging in the market and are viewed as a promising option towards road transport that is less carbon intensive, less polluting and less oil dependent. The adoption and diffusion of EVs does not only depend on demand for such vehicles but is also subject to supply side restrictions which include battery performance and cost, and the level of access to charging infrastructure. Deployment of Battery EVs (BEV's) is expected to remain limited until at least 2025. Access to charging infrastructures at home, work and in urban public areas forms the main barrier to large scale market development, both in the short and longer term. For Plugged in Electric Vehicles(PEV's) more rapid market penetration is expected once they will be widely commercialized. A voluntary development of standards on charging technology and infrastructure would contribute to achieve a substantial market penetration of both BEVs and PHEVs.

A major issue with the growing interest in electrical vehicles is preparing the power system to accommodate the EV battery charger loads [3]. Plug-in Hybrid electric vehicles (PHEVs) can store energy from the grid in rechargeable battery packs, which vary in size depending on vehicle type. Charging of these batteries at homes and parking lots represents a load in significant numbers not seen earlier in power systems. Most of the consumers plug in thier EV's to the power supply once they reach their home or parking lots . However, if all batteries start charging at the same time, assuming that they are at fully discharged state, the peak demand for the electrical grid will increase, the distribution transformer would be overloaded, the power quality and the reliability of the whole system would be degraded [8][9].
The increasing penetration of the electric vehicles, pose a serious threat on the power system in terms of superimposition of the battery charging peak loads on the existing peak load and also increased penetration in the distribution network. Hence proper charging coordination of electric vehicles is required .The unique charging/discharging method proposed completely mitigates this problem by the optimized selection of time intervals

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for the overall load leveling and load shifting and reduces the congestion in the distribution network, by reducing the overall cost of charging and maximizing the incentive on the overall discharging. The addition of electric vehicles into the distribution network brings an opportunity for the consumers to actively participate in energy management and marketing.

To overcome the issues and make use of the opportunities of EV penetration to the power grid , utilities need to reinforce their generation, transmission, and distribution infrastructure. Another recommended solution is that the utilities would either apply financial incentives for off-peak charging or utilize EVs' smart charging that enables communication between utilities and vehicles to control charging pattern. The next-generation EVs have the capability of performing vehicle-to-grid (V2G) or vehicle to building (V2B) operation. V2G technology is regarded as an important application of smart grid technology. An EV may be used as energy storage which allows the bi-directional electricity flow between the vehicle's battery and the electric power grid. V2G can efficiently improve the load profile of the electric system with optimal scheduling of charging (grid-to vehicle, G2V) and discharging (V2G) behaviour [1].This paper presents a similar idea.

In this paper the first step is to obtain the suitable daily load forecast with half-hour interval. The regional load forecast is to be obtained or developed beforehand. For developing the load demand for a particular day, data like the load demand curve of the same day during the previous week, the temperature and humidity conditions of the previous week as well as on the day to be forecasted are required. The load forecast is done using neural networks in MATLAB. Once the load profile is obtained, the next stage is development of charging/discharging algorithm for obtaining the best possible time slots for the charging and discharging process. The decision variable width intended in this project is of half hour each, throughout the entire planning horizon i.e. 48 intervals. 1, 0, -1 will be the grading on each of the decision variable. One for charging and zero for no action and negative one for discharging. The charging algorithm is implemented using Lingo optimization software. Once the charging and discharging intervals are obtained they can be used as control signals for the onboard charger. An efficient charger system is a key component for electric vehicle.

II.UTILIZING EV'S FOR LOAD SHIFTING AND LOAD LEVELING

The vehicle to grid facility can be utilized effectively to achieve load leveling and load shifting. With proper scheduling of the charging and discharging intervals, electric vehicles can be used for eliminating the effect of high penetration of charging loads into the existing system during peak hours [2]. Most of the EV's reach home by 6 p.m. and leave by 8 in the morning. This can be seen as an opportunity to utilize the availability of electric vehicles at home for the load profile improvement of the grid. A certain number of EV's are also considered to be charged in the parking lots to incorporate the effect of smart parking lots. In order to achieve such a goal, the charging has to be distributed rather than continuously charging the battery [6]. The discharging of the battery must be done during the peak demand hours keeping in mind that the state of charge of EV battery should not go down beyond a threshold value. In the proposed algorithm the maximum energy to be discharged from EVs is to be determined by the consumer but the threshold limit is preset.

A. TYPES OF ELECTRIC VEHICLECHARGING POWER LEVELS

The power output of the electric vehicle charger determines the rate at which the battery is charged. Based on their power usage the charging methods can be divided into three levels – Level 1, Level 2 and Level 3[4].

 Level 1: It is a low power charging method which works at a supply voltage of 120 V and current of 15 A. It is the slowest charging scheme. For a pure electric vehicle like Nissan Leaf the Level 1 charger will take almost 22 hours to fully charge an empty battery which is not acceptable.

 Level 2: It is the most popular and widely used house hold charging unit at present. It works at a supply voltage of 240 V. The current rating can be either 15 A or 30 A. The 15 A charger has a power capacity of 3.3 kW and is the best choice for household charging units. The 30 A charger has a power capacity of 6.6 KW and is the best choice for parking lot charging units.

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 Level 3: These are mainly equipped at fast charging stations which are analogous to gas filling stations. They operate at 480 V or three phase AC supply. Additional off board ac-dc converter is needed. Frequent use of Level 3 charging is not recommended as it shortens the lifespan of EV battery.

Here in this paper a total number of 350 EV's are considered-250 of which are being charged at home during night time and 100 of them are being charged at parking lots during morning time. Level 2 charging is considered to be the primary means of EV charging. Based on it, for the EV's that are being charged from Home are assigned a charging rate of 3 kWh for the development of the charging algorithm in this paper so that the EV battery can be fully charged during night hours .In case of vehicles charged at parking lots the charging rate is fixed at 5 KWh. This ensures that the electric vehicle will be ready for commutation by morning and the peak load due to charging loads are distributed during night time rather than in peak hours. Fig.1. shows the effect of uncoordinated charging on the load profile. A day is divided into 48 equal intervals : time from 0:00 AM to 0:30 AM is taken as 1st interval and so on , thus 11:30 PM to 12:00 AM makes up the 48th interval.

The discharging rate is fixed keeping in mind the battery performance alone. The best operational range of a battery is when the SOC is between 30 – 80%. Most of the electric cars will be used for a daily commutation of 40 to 50 km. The Nissan Leaf has a range of nearly 130 km when it is fully charged. Thus for a normal user only half the capacity of the EV battery would be drained out during daily commutation. The discharging limit is set at 5kWh so that the battery SOC will be maintained above 30 % as the EV returns home after commutation. Also the discharging rate is limited to 1 kWh so that the battery will be drained at a slow pace.

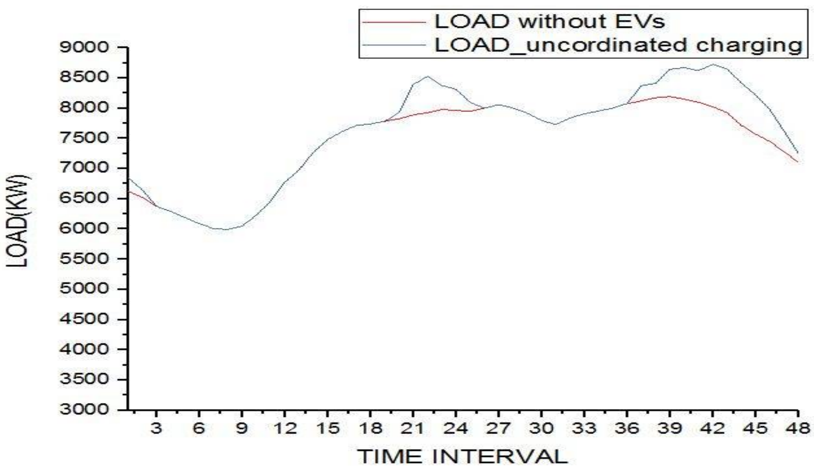

Fig 1. Effect of Uncoordinated charging on Load Curve

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B. PROPOSED METHODOLOGY

A new cost effective charging algorithm is proposed in this paper. Initially the day ahead load demand curve of the distribution area is to be obtained. It requires data like load and temperature data of previous day and previous week. Once the data is obtained they need to be sorted to eliminate erroneous data [6]. The neural network tool of MATLAB is used to train and develop a model for load forecasting. The accuracy of load forecast is being checked and the model is retrained to obtain a neural network model with minimum error. The forecasted demand curve is then obtained .Next step is to develop the cost matrix based on demand. Thus the cost function will be linearly dependent on the demand curve and makes the algorithm more flexible. The charging and discharging schedules are obtained using lingo optimization software with the cost minimizing function. Since the cost and demand are correlated the algorithm will be minimizing the demand curve indirectly. The complete optimization process is as shown in Fig.2.

C. MODELING OF OBJECTIVE FUNCTIONS AND CONSTRAINTS

The optimization process begins with grading of cost matrix based on forecasted demand curve. Once the cost matrix is obtained the availability of electric vehicle is checked. The availability matrix will be same for both charging and discharging purpose.But the cost matrix will be different since for charging the aim is to minimize the cost where as in the development of discharging intervals the ultimate goal is to maximize the cost. For discharging intervals, the cost matrix is developed in such a manner that the consumers will gain more profit if they discharge the EV batteries during the peak demand hours. The objective function is developed using the cost matrix and availability matrix.

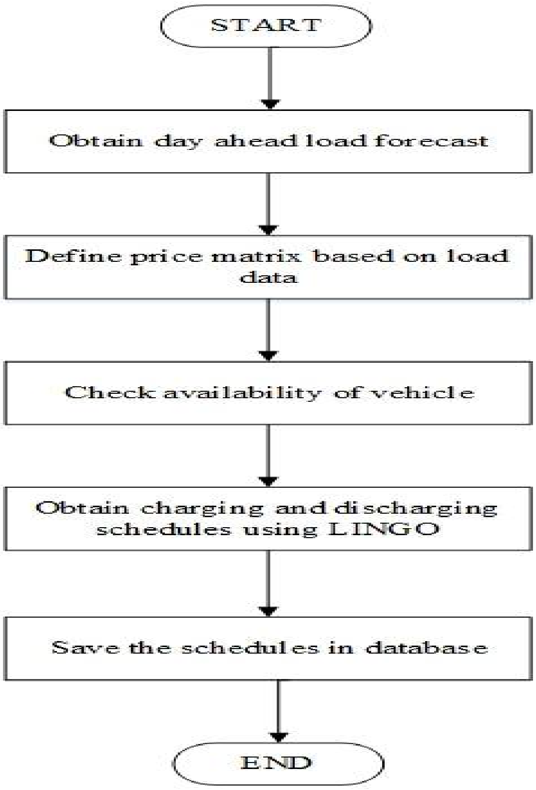

Fig. 2. Optimization process

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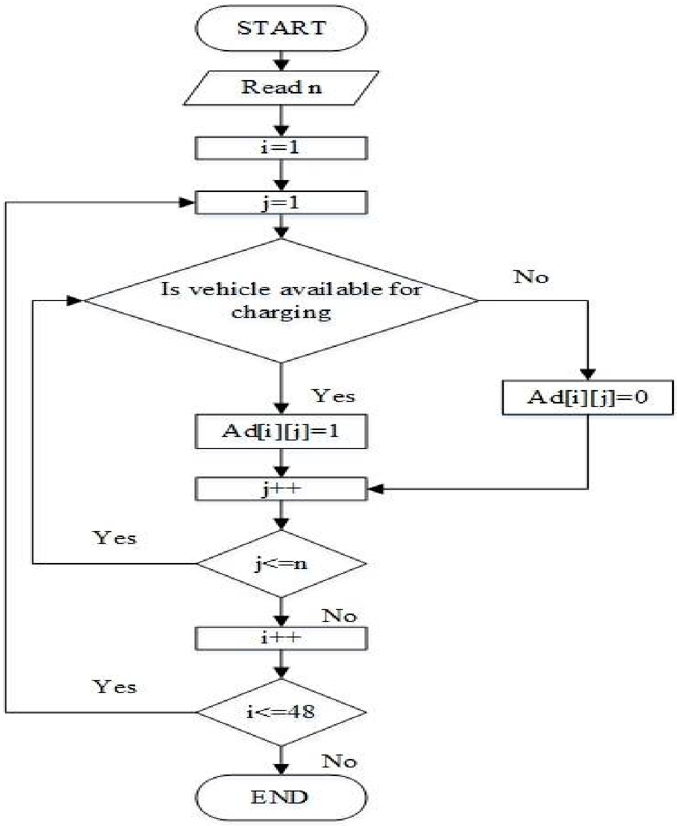

Fig. 3. Availability matrix

The objective function for charging is given by the following equation:

$$C_c(i)_{(1*n)} = \text{Min}\,(\textstyle\sum_1^{48}(E_{c_{(1*48)}} * A_{c_{(48*n)}}) \qquad (1)$$

$_{(1*48)}$ is the half hourly cost matrix that contains the graded cost based on load demand. The charging intervals are divided into 48 intervals so that a deeper control can be obtained during the distribution of charging intervals. $_{(48*n)}$ is the availability matrix that defines the availability of EVs for charging during each interval. Integer 1 will be allocated if the vehicle is available and 0 for those unavailable vehicles. N represents the total number of vehicles. $C_c(i)$is the scheduled charging matrix for each time interval.

The objective function for discharging intervals is given by the equation:

$$D_d(i)_{(1*n)} = \text{Max}\,(\textstyle\sum_1^{48}(E_{d_{(1*48)}} * A_{d_{(48*n)}}) \qquad (2)$$

$D_d(i)$ represents the scheduled discharging matrix. E_d and A_d represents the cost matrix and availability matrix respectively corresponding to discharge intervals. The availability matrix will be common for both charging and discharging. The flow diagram for obtaining availability matrix is as shown in Fig 3.

The major constraint of the optimization algorithm is to maintain minimum energy level in the EV battery for commutation purpose and to maintain the SOC between 30 – 80 %. In the proposed algorithm the discharge energy can either be prefixed or be determined by the consumers, the algorithm have set the maximum limit to be 5 kWh based on the daily commutation needs of consumers. The discharge rate is fixed at 1 kW in order to avoid deep discharging of the battery and thus improve the battery performance.

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III.SIMULATION RESULTS

The load forecasting is done using the neural network tool in MATLAB and its accuracy is checked. Once the load curve is obtained the graded price matrix and other constraints are given as inputs o lingo optimization software. After the optimized schedules are obtained its effect on load profile is also studied.

A. Load forecast

The load forecast process starts with data collection. The data required for short term load forecasting include load demand, weather data – dry bulb, wet bulb and humidity [5][7]. The historical data must be sorted to form a predictor matrix that contains the temperature and load data of previous day previous week. Data like day of week and a flag to indicate holiday is also needed for accurate prediction. The neural network model uses Levenberg–Marquardt back propagation algorithm to train the model. It is one of the fastest neural network algorithms in MATLAB. The error checking gave an MAPE of 2.99 %. The output of load forecast is shown in Fig.4.

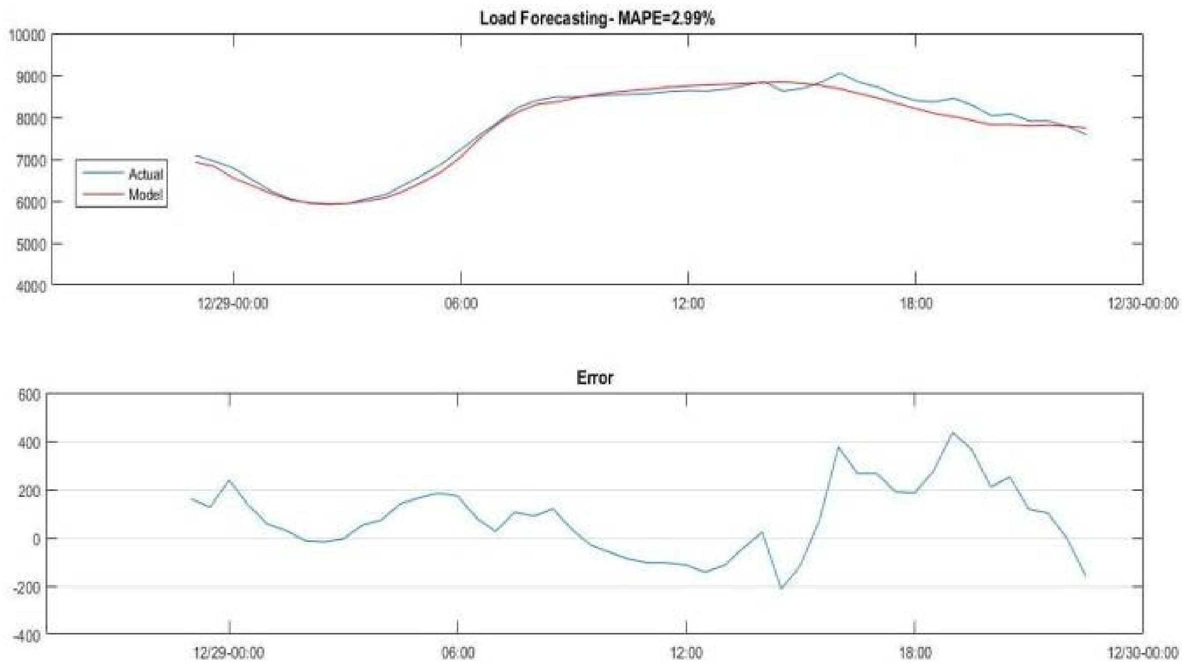

Fig 4.Load Forecast Output

B. Optimized Charging and Discharging Schedules

The graded price data is obtained from the predicted load curve and is used to develop the optimized schedules. The optimization is to be done for 350 vehicles connected to the grid. The sample schedule for 4 vehicles is as shown in theFig.5. Here 1 represents charging, 0 represents no action and **-**1 represents discharging.

From the output it can be seen that the charging and discharging of different vehicles are distributed over the time period. Thus the peak load is distributed to the valley points and since not all vehicles are connected at once the burden on the system is also reduced.

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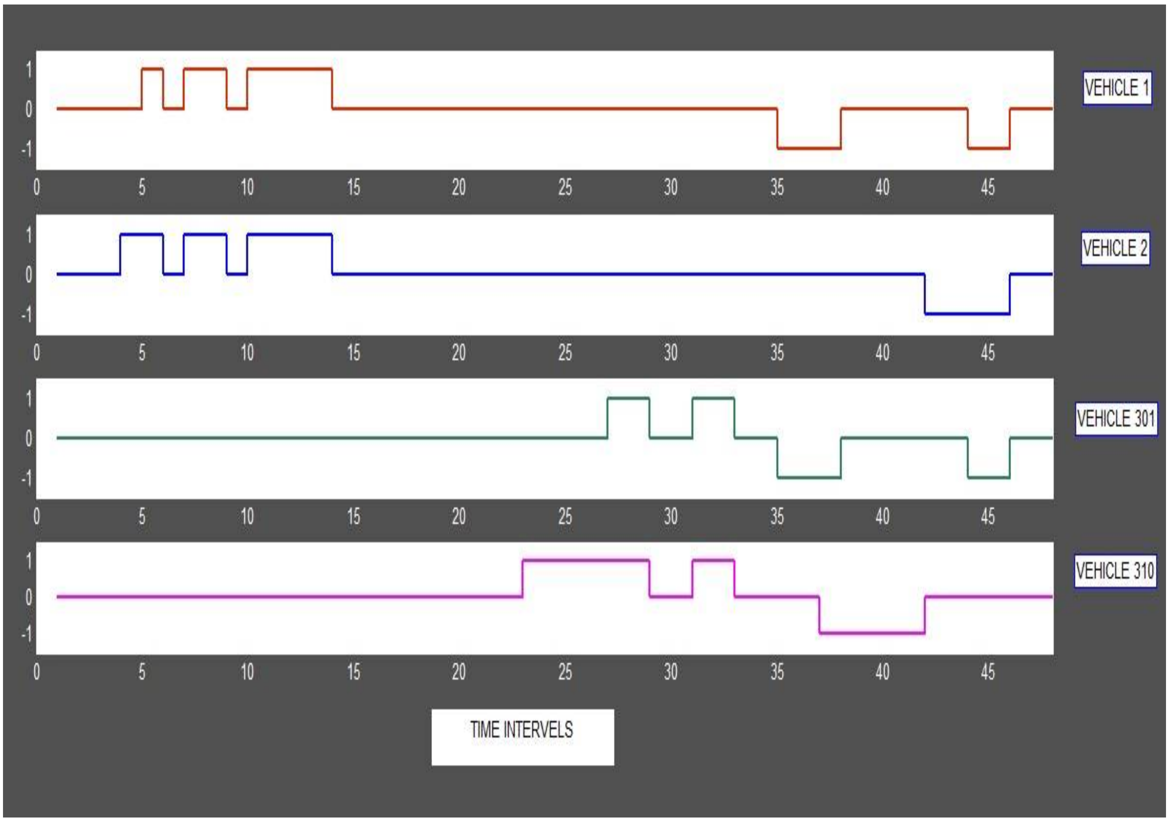

Fig. 5.Optimized charging and discharging intervals

C .Effect of Optimization on Load profile

The effect of optimization on the load curve can be studied by the analysis of the load profile before and after optimization. Both the conditions are shown in Fig.6. The effect of optimized charging can be seen clearly from the graph. The charging load is shifted to the valley points and thus the peak demand is reduced. Further reduction in peak load is obtained by the coordinated discharging of EV batteries. The reduction in peak load is shown in Table 1. As the penetration of EV increases the degree of load leveling that can be achieved also improves as more vehicles will be available for discharging during the peak hours and the valley points will be filled more effectively.

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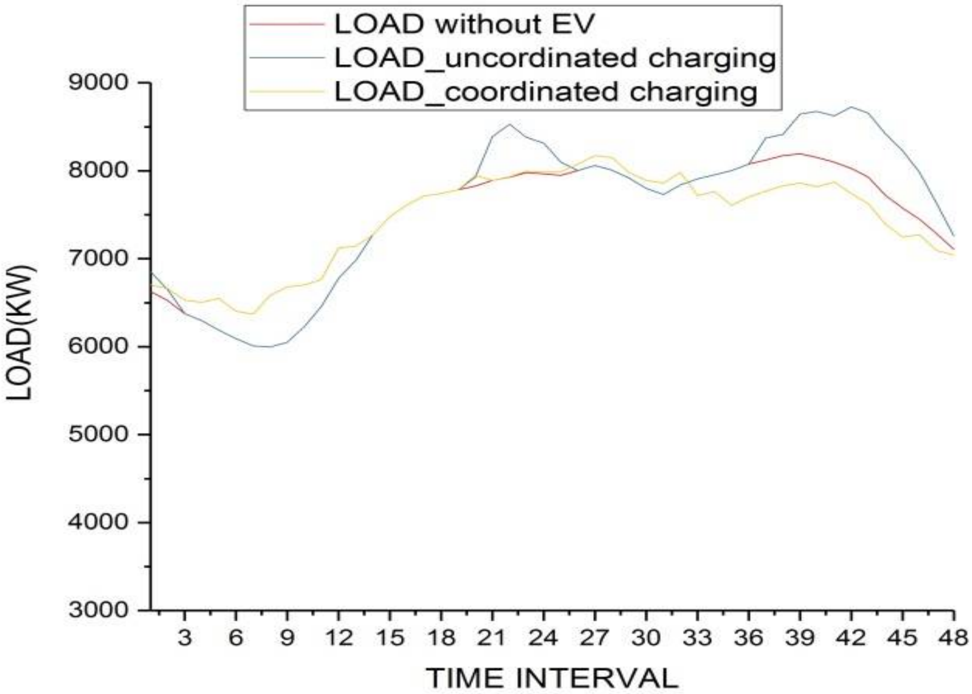

Fig 6.Load Profile with Optimized and unoptimized Charging

	Unoptimized charging	Optimized charging	Percent reduction
Peak Load (kW)	8726.821	8171.459	6.363852
Average load during peak hours (kW)	8460.764	7721.664	8.735617
Average load during morning peak hours(kW)	8087.17	7904.92	2.25357

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IV.CONCLUSION

Electric vehicles and smart grid technology are closely related as EVs can be used to benefit the grid by utilizing bidirectional power flow capability with proper communication and control. In the future EVs are expected to dominate over fossil fuel vehicles and will be a burden to the grid if operated merely as a power consuming device.EV batteries add up with the already increasing load demand. The algorithm proposed in the paper provides an efficient way to properly co-ordinate the charging of EV's and thus making use of the excess energy stored in the EV batteries to reduce their burden on the load curve. The paper presents a clear idea of achieving load leveling and load shifting by utilizing the energy used in EV's. The optimized schedules can be used to control the switches on the onboard charger on electric vehicles and thus provide a centralized charging strategy.

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