Scheduling of EV Charging in Grid-Connected Parking Lots with Renewable Sources

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Declaration

I declare that this written submission represents my ideas in my own words, and where ideas or words of others have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.

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This thesis entitled **Scheduling of EV charging in grid-connected parking lots with renewable sources** by **Anil Kumar Mathur (EE16MTECH11027)** is approved for the degree of Master of Technology/ Doctor of Philosophy from IIT Hyderabad.

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Abstract

The growing concern about environmental issues is leading many countries to take measures that allow a more rational energy usage and for a more sustainable future. The improvement of systems efficiency and the use of renewable sources are some points to work on to reduce greenhouse gas emissions. That is why electric mobility is drawing the attention of companies, countries and research groups, as an important measure to face the negative consequences derived from the current energy usage. It is clear that the inclusion of electric vehicles will strongly affect the operation, management, and planning of current electric power systems. Firstly, an additional load will have to be considered, the electric vehicles charging. In an initial stage, when the deployment of electric vehicles is not significant, special measures will not be required. However, in the future with thousands of vehicles in operation, ad-hoc electric vehicle charging can lead to line congestion or voltage limits violation. Moreover, an update of the current electric power systems regarding more advanced information and communication technologies, better metering devices, as well as the presence of more renewable sources are required for the suitable integration of electric vehicles.

The increasing number of electric vehicles (EV) means there is a growing need for charging stations as well. A potential solution to address the need for charging stations is to transform traditional parking lots into smart parking lots. Due to the inherently complex and dynamic environment, a potential obstacle, from a business perspective to the process of transforming parking lots into smart parking lots is the complexity of estimating the profit of the smart parking lots owner and, consequently, the length of time required to recover the cost of the initial investment. We propose a simulation approach to estimate the smart parking lot owners profit during a certain period of time.

Thus, this thesis is intended to cover the problem of significant increase in electric vehicles arriving at the parking lot leading to a challenge for scheduling of vehicles for charging. The primary objective of parking lot owner is to charge more vehicles and increase profit. But due to stringent rules from regulators for network upgrades, increase in the number of charging slots is challenging. Installing a distributed generation like solar microgrid will benefit from allowing many vehicles to charge at the parking lot. This thesis aims in proposing an algorithm called parking lot management system (PLMS) and charging management system (CMS) for scheduling of electric vehicles with the support of solar generation with the objective of minimizing the power drawl from the grid during high peak pricing period. Power drawl from the grid is reduced by using the solar power available. Since the power drawl from the grid is reduced, it is obvious that the profit of the parking lot owner is increased. scheduling is done by shifting the cars to the abundant solar power period and reducing the peaks on the grid which helps the utility operator. The proposed algorithm is simulated using MATLAB programming, and the results are presented.

Contents

Chapter 1

Introduction

The power grid is expected to vary dramatically over the approaching decades, partly as a result of the number of consumers, their needs, and their growing expectations. On the other hand, planners and operators are compelled to operate the grid below increasingly stringent conditions due to utilization of renewable generation, energy storage systems, A large number of plug-in electric vehicles (PEV) will add a relatively large load to the utility grid. Consequently, utilities are making efforts to include operational tools into the facility grid by means of technology, communication, sensors, and digital information therefore on produce a more strong and interactive intelligent environment higher capable of handling all the uncertainties related to generation and demand. A smart grid is that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functions and applications. Smart grid conceptual model for a smart parking lot is characterized by the integration of communication networks and IT infrastructure with the power and energy layer as shown in Figure 1.1.

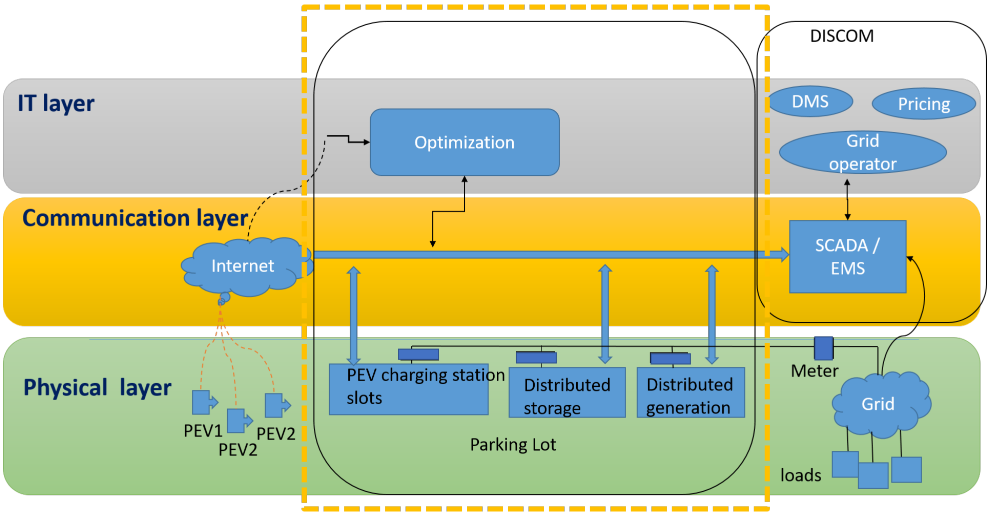

Figure 1.1: smart grid conceptual model for smart parking lot

Due to the increasing penetration rate of EVs, the local electric networks are most likely to be affected. A potential solution to address the need for charging stations is to transform traditional parking lots into smart parking lots, in a sense that smart parking lots provide not only parking

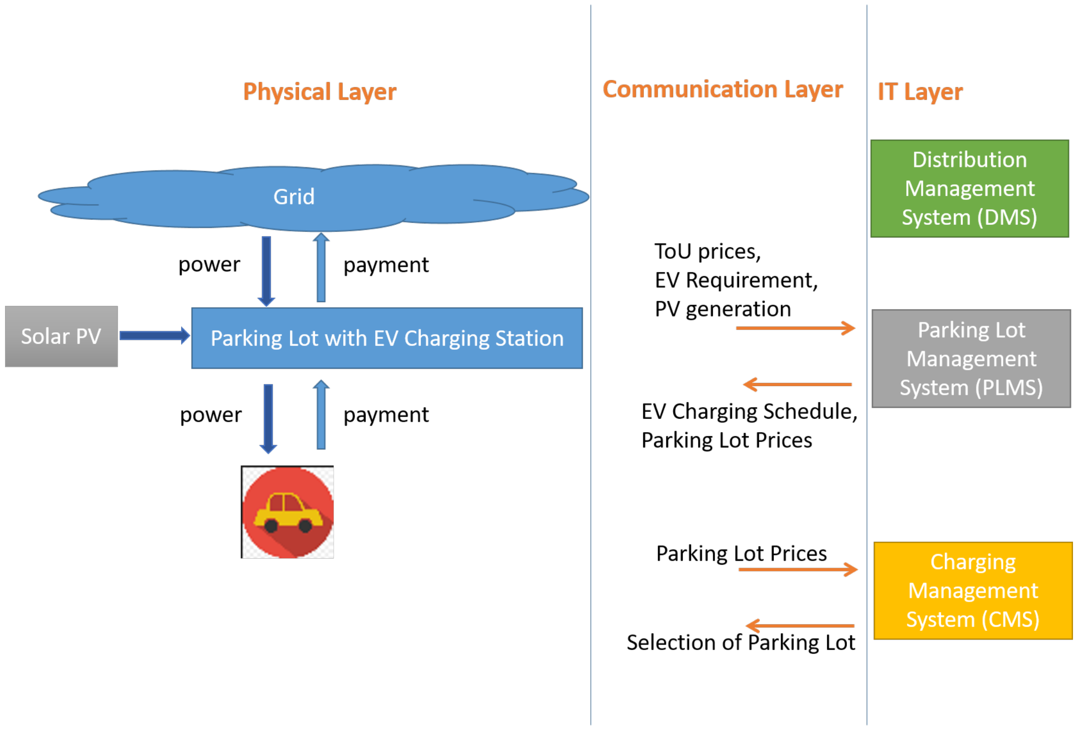

Figure 1.2: Flowchart

services but also the possibility for electric vehicle owners to charge.

Figure 1.2 shows the flow of power and payment between utilities to Parking lots and from parking lots to the electrical vehicle. But at the same time introducing the new challenges for the parking lot manager as well as utility in terms of the operation of grid and charging schedule. Conventionally, PEVs are charged using the grid power. If the parking lot owner is completely relying on the grid will increase the cost of purchase of power from the grid which eventually reduces his profit. In order to increase the profit of the parking lot owner a solar-powered micro-grid for charging the cars in one of the solutions. By using the solar power during high grid prices parking lot owner will have an increased profit.

1.1 Motivation

Investing vast sums to upgrade the distribution grid for the charging of increasing number of PEVs would be economically not much viable. Although PEV charging scheduling have been introduced as a component of operational plans for facilitating the adoption of PEVs. Mass PEV operation would significantly amplify energy demand. Scheduling of PEV for charging should ideally benefit both customers and utilities through reduced energy costs and lower grid-operating expenses, respectively. There is the involvement of multiple stakeholders each having their own interests. the stakeholders can be identified as the EV owners. EV Owners want to charge their EVs as fast as possible in order to have them ready for use again. The second stakeholders are identified as the PEV Parking lot owners. The PEV parking lot owners aim to minimize the charging costs for the EV users as well as to maximize their own profit by optimizing the electricity procurement times.

The third stakeholders are the DSOs whose responsibility and interest is to maintain the electric networks operational with high efficiency. Therefore, common rules are needed to enable the real implementation of controlled charging. a new charging strategy, which distinguishes the different entities and their responsibilities. Although opinions are divided about the impact of PEVs on distribution grids, there is a general agreement with respect to the considerable effects that mass PEV operation under an uncontrolled charging scheme will have on electric grid assets (mainly on local distribution infrastructure and possibly on the transmission sector). Electric grid operators and planners are therefore concerned with deploying PEVs effectively and mitigate their impacts. Planning alternatives include meeting demand growth through upgrades to grid infrastructures or installation of Distributed Generation (DG). However, planning alternatives reflect long-term horizons, and feasible solutions require consideration of several prospective factors, such as load growth, updated PEV models, and newer technologies.

1.2 Related Work

In order to provide green energy economy benefit [1] & [2], electric power utilities are showing their great interest in the smart grid technology that incorporates distributed generation with effective communication and control. In addition to the primary purpose of distributed generation (DG), which is energy injection, strategically placed and operated DG units can provide several other advantages to the grid such as voltage and load-ability enhancement, reliability improvement of network upgrade are discussed in [3] and [4] However this large PEVs penetration to grid should have addressed properly, since uncoordinated charging management would effect on power grid and electricity market operation at the distribution level [5], so there is a wide research interest available to find the efficient solution to address these challenges.

Some work has been introduced in the area of distribution system planning to investigate PEV charging load its impacts on the system [6]. In [7] the results are based on rigid charging schedule and ignored the PEV arrivals and departures times. however, the work in [8], [7], have considered only the uncoordinated charging scheme, although coordinated PEV charging scheme is more beneficial to the utilities and customers as compared to the uncontrolled charging scheme [9]. The DG placement for minimizing peak load has attracted the interest of a large number of researchers in the recent past. Most of them have focused on developing methodologies for power loss reduction with the assumption that firm DG sources were to be allocated at the peak load. Such methodologies may not be able to solve a practical case of variable demand and generation and the size of DG units at the peak demand may not remain optimal at other loading levels are mentioned in [10]. By charging the EV batteries in a controlled manner, the heavily congested peak load times and under-voltages can be avoided [11]. Enabling Coordinated charging could also help maximize the integration of the decentralized energy generation by RE [12]. However, the controlled EV charging cannot be easily implemented as it involves multiple stakeholders each having their own interests. The concept of coordinated PEV charging is similar to energy shifting programs that aim at shifting electricity use from peak to off-peak times. some work has been introduced in the area of coordinated PEV charging. work done in [13] to quantify the benefits of smart metering and energy management in the distribution system. The work presented considers controlling the PEVs charging but the driver's travel pattern has been ignored. [14] proposes a method to optimally allocate PEV charging stations taking into consideration drivers preferences. Different techniques were provided for charging station scheduling problem but there are still challenges in modeling and coordinating PEV demand.

1.3 Thesis Objectives

Research on the coordinated charging of electric vehicles with solar generation is scarce. So, this thesis proposes an algorithm for parking lot management which we defined as parking lot management system(PLMS) and Charging management system(CMS). The key contributions include mathematical modeling of vehicle data, the proposal of the algorithm for increasing the profit of the parking lot owner by reducing the power drawl from the grid. This profit for Parking lot owners perspective is achieved by introducing a solar generation for parking lot system and using the coordinated charging schedule algorithm and profit for PEV owners perspective is achieved by introducing Tariffs for charging PEV at charging station.

We know grid prices are variable based on the demand on the grid. In perspective of the Parking lot, owner profit objective of PLMS(Parking lot management system) use more of the available solar generation so that less electricity drawn from the grid at peak price time and with use of coordination in scheduling to charge the electric vehicle.

Parking Lot Owner:

$$Profit = Revenue - Cost \tag{1.1}$$

In perspective of PEV owner profit, PEV owner has the flexibility to select from any multiple parking lots and PEV charging prices can be defined by the Parking lot owner for a different parking lot.

CMS(Charging management system) will suggest for a minimum of Price between nearest charging station so that PEV owner can minimize there charging the cost of charging by selecting the particular Parking lot charging station.

1.4 Scope of Work

the proposed work is part of IT layer in the conceptual model and provided an insight on the present and future requirements regarding scheduling charging infrastructure to satisfy EV Owners and parking lot owners, in order to promote wider adoption of EVs for utility advantage. It has also provided a review of the difficulties and challenges that arise from integrating EVs into the distribution network without an appropriate management system and what is required of utilities to mitigate these adverse effects and turn them into positive impacts, that is the deployment of smart charging schedules.

Smart parking lots are the complexity of estimating the profit of the parking lot's owner and, consequently, the length of time required to recover the cost of the initial investment. The parking lots owner must deal with the uncertainties related to the electric vehicles, including:

- How many cars will be parked on the parking lot and for how long will they stay parked?
- How much electricity a car owner is willing to buy?

- How much money a car owner is willing to pay for a certain amount of electricity?
- How much incentives they can provide to EV owners?
- How scheduling can be done to maximize profit?

Research on the coordinated charging of electric vehicles with solar generation is scarce. So, this thesis proposes an algorithm for parking lot management which we defined as parking lot management system(PLMS). The key contributions include mathematical modeling of vehicle data, the proposal of an algorithm for increasing the profit of the parking lot owner by reducing the power drawl from the grid. This profit is achieved by introducing a solar generation for parking lot system and using the coordinated charging schedule algorithm.

1.5 Organization of Thesis

The rest of the thesis is organized into specific chapters. Chapter 2 proposes a system model for multiple EV charging in a parking lot with renewable generation, including a proposal of optimization formulation that maximizes use of renewable generation and maximizes profits for parking lot operators. Chapter 3, develops a Parking lot management system PLMS scheme that uses arrival time, departure time, TOU electricity pricing and Renewable generation data, resulting in a favorable load profile for electric utilities. Chapter 4 proposes a system model for multiple EV charging in multiple parking lots with renewable generation and develops Charging management system CMS Finally, Chapter 5 summarizes the major contributions of this research and presents ideas for future work.

Chapter 2

Benefit Maximization for Parking Lot Owner

This chapter only proposes the only formulation for optimization Resource Allocation and Charging Prices for Benefit Maximization in Smart PEV-Parking Lots. the output of this optimization in order to determine the investment decisions for smart PEV-parking lots (i.e., the size of solar-based DG and storage units), optimal PEV charging decisions, and the optimal charging prices of PEVs. the purpose of this benefits analysis is for parking lot owners to plan to charge station in a parking lot(size of slots, DG and DS unit in a Parking lot)

2.1 Introduction

The electric power grid is transformed from the conventional to the smart grid which includes integration of the existing conventional facilities and sensors and monitoring technology, distributed storage(DS) and distributed generation (DG) units. In order to provide green energy economy benefit, electric power utilities are showing their great interest in the smart grid technology that incorporates DG and DS units with effective communication and control. the smart grid allows bi-directional flows of power energy and information go through the smart grid infrastructure from generation and end consumers. these two bi-directional flows enable all components of the smart grid to communicate with each other, which promotes end consumers to participate in the decision-making management.

For instance, end consumers could have an impact on the operation of marketing by installing distributed storage(DS) and distributed generation (DG) units, such as photovoltaic (PV) panels and small wind turbine, and interacting with real-time pricing signals. New Smart PEV-parking lots would be introduced to satisfy the growing requirements of PEVs. There would be more opportunities for owners of these parking lots to make revenue from generating, storing, purchasing and selling electricity to their customers. The stringent rules from regulators for network upgrades, increase in a number of charging slots is challenging. Integrating additional generation units or storage facilities required to control the net demand of the parking lot.

Several research works have introduced the problem of sizing energy storage in order to reduce the congestion in the grid. To improve the reliability of the distribution system and demand-side management, some authors presented a probabilistic approach for sizing and siting energy storage in distribution systems. moreover, determining the optimal capacities of DG and DS in smart households has been done, however, only a few of the previous works incorporated models of PEV demand. Therefore, the main objective presented in this paper is to determine the optimal resource allocation to maximize the profit of smart PEV-parking lots.

In these new smart grid technologies, several technologies improved the prediction of electricity produced by DGs according to the weather information and load demand in specific regions. Distributed generation is small-scale electric power generation which is strategically implemented for improving the reliability of the grid as a backup supplier. The typical DGs include photovoltaic systems, fuel cells, micro-turbines and small wind power systems. DG technologies produce less pollution rate which allows a DG to be installed near enough to a city. By this way, the amount of energy loss in power transmission could be significantly reduced in comparison to the operation of the conventional power systems. Apart from the small diesel, gas, fired generator, wind turbine and rooftop solar generators are proliferating in India. This also could help to cut down the expensive investment on the infrastructure of power transmission and distribution systems.

Distributed storage of the smart grid is also played important role in the power system, the main feature of having DSs is that to store electrical energy during the period when electricity supply exceeds the power demand and returns to end consumers when the supply falls below the demand. In addition, one of the main drawbacks of renewable energy resources is uncertainty which affects demand when it is required. The idea of using DSs is to store excess energy from intermittent DGs, that is solar power and wind power and rapidly feed it back when needed. The integration of distributed storage and distributed generation has the following advantages:

- Electricity produced by DGs can be stored in advance and used when required.
- The large-scale power generation for base load, that is coal and natural gas could be more efficiently and easily controlled at a constant output.
- Power generation and transmission capacity for peak load demand can be reduced in terms of investment on infrastructure by the total potential of DSs.
- Fast responding can be reachable, where DSs could provide backup electric power for the increasing reliability requirement.

2.2 Problem Identification

The rationale of this research work is to determine the investment decisions for smart PEV-parking lots whose owners may consider making benefit from accommodating high penetration levels of PEVs. The overall objective is to maximize the parking-lot owners benefits from selling electricity to PEVs and satisfy the technical constraints. In this section, the the methodology proposed is described. The modeling approaches of PEV consumption and the different costs/benefits are further presented. The input to the methodology proposed is the different models of load, PEV coordinated/uncoordinated charging schemes, and available energy resources that can be integrated to facilitate installing the charging units, i.e., solar-based DG units. Moreover, the input data comprises the cost parameters of the different equipment including the storage units. The output of this methodology is the optimal

PEV charging decisions, the optimal size of solar-based DG and storage units, and the optimal charging prices of PEVs.

2.3 Mathematical Formulation

The objective is to maximize the expected profit,

$$maximize = (Total\ revenue - Total\ costs) \tag{2.1}$$

The cost of purchasing electricity from the grid to supply the PEV demand and charge any installed DS units. Electricity costs for small business customers are categorized into average spot market prices distribution service charge and distribution and transmission network charges (in per monthly demand peak) and The fixed capital and maintenance costs of installing any DS and solar-based DG units. The benefit of selling electricity to PEVs and solar-based DG units to the grid via feed-in-tariff (FIT) program.
Revenue of selling electricity to PEVs:

$$PEVbenifit = \sum_{hr}\sum_{ch}(PEV_{ch,hr} \times P_{ch,hr} \times \rho PEV_{hr}) \tag{2.2}$$

Cost of purchasing electricity from the grid:

$$Grid = \sum_{hr}\sum_{ch}(PEV_{ch,hr} \times P_{ch,hr} + PDS_{hr}^{ch} - PDS_{hr}^{dis}) \times \rho_{hr} + \sum_{m}(\rho_{fix} + Peak_m \times \rho_{peak}) \tag{2.3}$$

Capital costs of DS unit:

$$DS = (\frac{C_p}{PVF} + C_M) \times PDS_{rated} + C_E \times \frac{EDS_{rated}}{PVF} \tag{2.4}$$

DS Operational Constraints:

$$EDS_{hr} = EDS_{hr-1} + PDS_{hr}^{ch} \times \mu_{DS} - PDS_{hr}^{dis} \qquad \forall hr \tag{2.5}$$

$$0 \leq PDS_{hr}^{ch} \leq PDS_{rated} \qquad \forall hr \tag{2.6}$$

$$0 \leq PDS_{hr}^{dis} \leq PDS_{rated} \qquad \forall hr \tag{2.7}$$

$$0 \leq EDS_{hr} \leq EDS_{rated} \qquad \forall hr \tag{2.8}$$

The available historical data are utilized in order to represent the variations of solar irradiance with a certain number of states that achieve a trade-off between the accuracy and the the simplicity of analysis. the simulated values of solar irradiance are converted into output power based on the characteristics of the photovoltaic panel as discussed in [15].

Capital costs of solar-based DG unit:

$$Sol = (C_s \times \frac{PSol_{rated}}{PVF}) \tag{2.9}$$

Revenue of selling the energy of the solar-based DG unit to the grid:

$$solarbenifit = \sum_{hr} Psol_{hr} \times Psol_{rated} \rho FIT \tag{2.10}$$

Solar-Based DG Size Constraints:

$$Psol_{rated} \leq Psol^{max} \tag{2.11}$$

The basic difference between uncoordinated and coordinated PEV demand is that the former implies no coordination between the charging decisions for every vehicle at every hour. In this work, a novel approach is proposed for modeling the energy consumption of uncoordinated and coordinated PEV demand. The proposed approach is based on the vehicles arrival rates and parking times generated. Moreover, the energy required by PEV, which is set by the vehicle driver upon parking is assumed dependent on the average charging price estimated over the entire parking time. This dependency is simplified to a linear relationship [16], as given in , which implies that the drivers tend to set their required energy to the maximum value or zero if the average charging prices are at a minimum or maximum market prices, respectively. In real life, such relationship can be estimated via interpreting the behavior of vehicles drivers in response to the different charging prices.

As mentioned earlier, the energy required by PEVs and charging prices of PEVs are related to each other through a linear function as in [16]. Furthermore, the required energy by PEV is used to determine the decision variables of PEV charging using the

$$E_{ch}^{PEV} = E^{PEV-max_{ch}} \times (\frac{\rho PEV^{max} - \rho PEV^{av}}{\rho PEV^{max} - \rho PEV^{min}}) \tag{2.12}$$

$$\rho PEV^{av} = \frac{\sum_{hr}(PEV_{ch,hr} \times \rho_{hr}^{PEV})}{\sum_{hr}(PEV_{ch,hr}} \tag{2.13}$$

$$E_{ch}^{PEV} \leq E_{ch}^{PEV-max} \tag{2.14}$$

$$P_{ch,hr} = min(CHR, P^{PEV-max}) \tag{2.15}$$

In this constraint, the net demand at the transformer terminals is evaluated in, and the absolute value of this demand should be less then the transformer rating as in. It is worth mentioning that the net demand could take either positive or negative values that correspond to power drawn from or reversely supplied to the grid, respectively.

$$Pnet_{hr} = Pload_{hr} + PDS_{hr}^{ch} - PDS_{hr}^{dis} - Psol_{hr} \times Psol_{rated} + \sum_{ch} PEV_{ch,hr} \times CHR \quad \forall hr \tag{2.16}$$

$$-P_{Traf}^{max} \leq Pnet_{hr} \leq P_{Traf}^{max} \tag{2.17}$$

In this work, the different costs incurred by the owner of the the smart PEV-parking lot are as follows:

- The cost of purchasing electricity from the grid to supply the PEV demand and charge any installed DS units. Electricity costs for small business customers are categorized into average spot market prices (in Rs per energy consumption), distribution service charge (in Rs per month), and distribution and transmission network charges (in per monthly demand peak).

- The fixed capital and maintenance costs of installing any DS and solar-based DG units.

On the other hand, there are several benefits that could be achieved by the owner of the smart PEV-parking lot, as follows:

- The benefit of selling the energy from solar-based DG units to the grid via feed-in-tariff (FIT) program.
- The benefit of selling electricity to PEVs.

2.4 Summary

The goal of this work is to improve the performance of energy management in the context of the smart grid. The overall objective is to maximize the parking-lot owners benefits from selling electricity to PEVs/utility and satisfy the constraints. the input data comprises the cost parameters of the different equipment including the storage units. The input to the methodology proposed is

- PEV coordinated/uncoordinated charging schemes.
- different models of load,
- different energy resources that can be integrated to facilitate installing the charging units.

The output of this proposed formulation for is Benefit Maximization in Smart PEV-Parking Lots

- the optimal PEV charging decisions.
- the optimal size of solar-based DG and storage units,
- optimal charging prices of PEVs.

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Chapter 3

Parking Lot Management System (PLMS)

The smart parking lot is defined in terms of a variable representing the amount of money it is willing to pay for a unit of electricity at a certain time-slot. Parking lot management system (PLMS) will actually schedule the cars for charging. Here it is considered that the solar generation that is obtaining is used only for charging of vehicles in the parking lot. Fig 3.1 shows the schematic diagram of the implementation of the proposed algorithm for PLMS. The algorithm proposed in this paper runs in PLMS and will schedule the cars for charging in the parking lot. The following section explains the related work happened in this area.

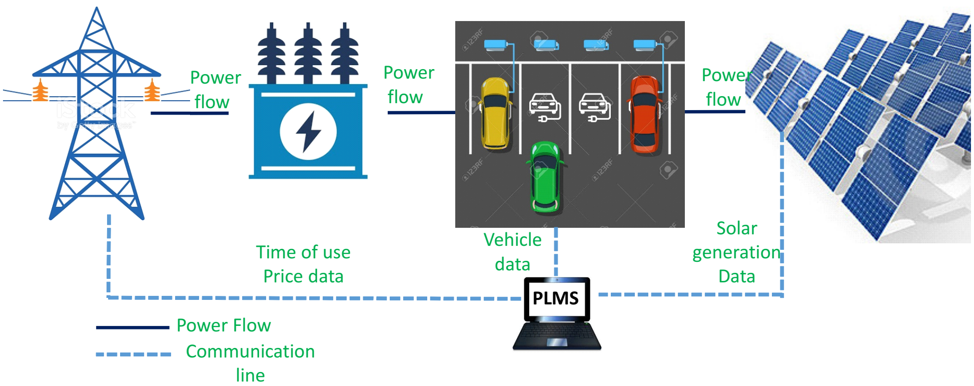

Figure 3.1: Schematic diagram of the implementation of the proposed algorithm PLMS

3.1 Proposed Charging Schedule Algorithm for PLMS

In this section, an algorithm is proposed for charging schedule of electric vehicles in a parking lot. This algorithm is deployed in the parking lot management system (PLMS) for scheduling of vehicles. The following are the steps involved.

1. Inputs that are considered for this algorithm includes the vehicle data, solar generation, and time of use(TOU) price data. In this vehicle data includes

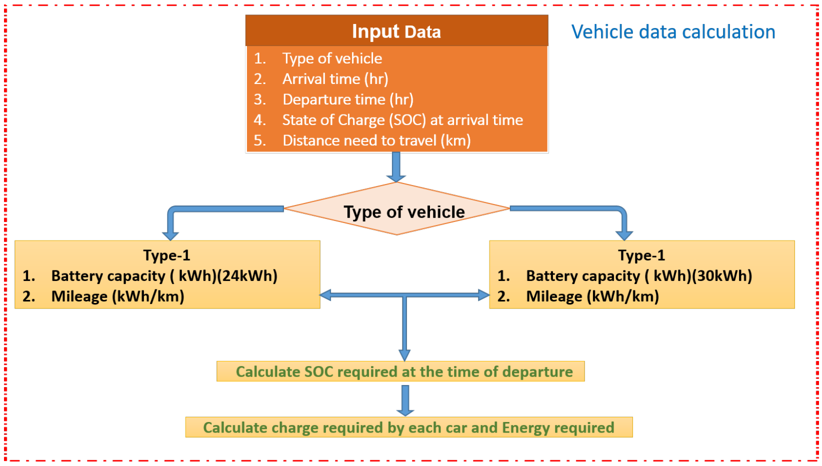

Figure 3.2: Flowchart for implementation of algorithm PLMS

- Type of vehicle: This is defined based on the mileage and the battery capacity of the vehicle.
- Arrival time of the car.
- Departure time of the car.
- Distance needs to travel after the departure of the car.
- State of Charge (SOC) at the time of arrival.

2. Based on the type of vehicle and the distance intended to travel charging required is calculated using the equation (3.1).

3. Once the energy is calculated to the total time required for charging of the vehicle is calculated using equation (3.2). Here the total time depends on the charger rate.

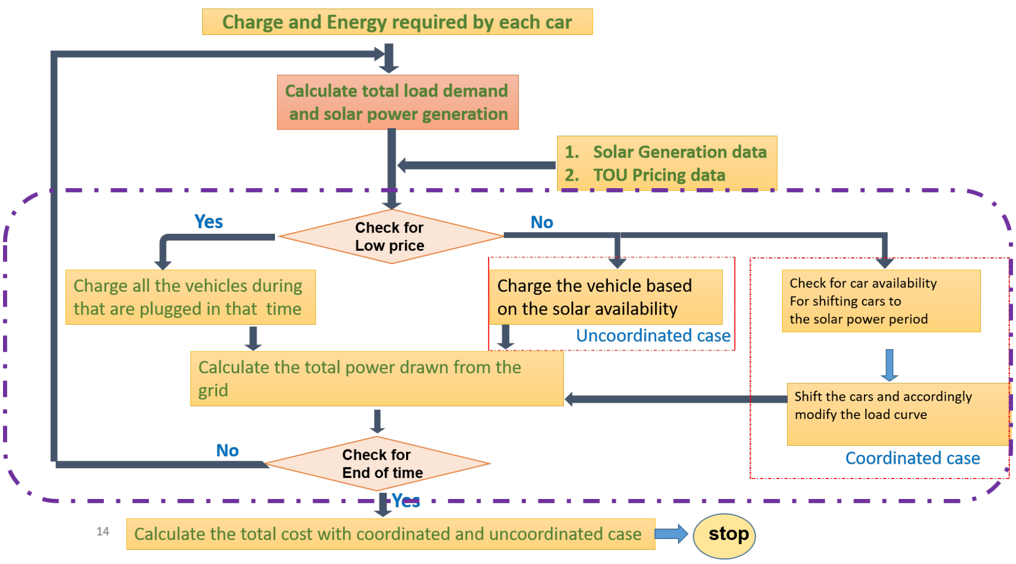

Figure 3.3: Flowchart for implementation of algorithm PLMS

4. If the price is low then the strategy is to charge all the vehicles that are available during that time period. Else there are two cases one is the uncoordinated case and the coordinated case. For uncoordinated case go to step 5. For coordinated charging case go to step 6.

5. In uncoordinated case charge the vehicles based on first cum first serve (FCFS) basis and utilize the solar also. Goto step 10.

6. In coordinated case abundant solar periods are checked and the vehicles during the high price periods are shifted to abundant solar periods by considering their departure time and the total time required for charging.

7. Rescheduled cars are taken and the new load curve is formed for the calculation of the grid price and the car ids are noted for reference such that the parking lot owner will charge accordingly. goto step 10.

8. Calculate the power drawn from the grid using equation (3.6).

9. Calculate the total cost using equation (3.5).

10. Repeat the process till the end of time.

3.2 Mathematical Formulation for Charging Schedule of Electric Vehicles

In this section mathematical modeling is explained. Subscript t indicates time block. Mathematical modeling of car data includes the battery energy required during the departure of the car. The energy required is calculated by considering the input from the vehicle owner about the distance he intends to travel after his departure. The energy required is calculated by using the equation(3.1)

$$E_{car,n} = E_{min} + d_n * m_n \tag{3.1}$$

where n is car ID, $E_{car,n}$ is the energy required during the vehicle departure, d is the distance intend to travel after the car departure which is a user input and m is the mileage of the car which depends on type of vehicle.

Total time required for the car to complete its charging depends on the charger rate and the energy required. Mathematically it is shown by the following equation(3.2)

$$T_{ch,n} = \frac{E_{car,n}}{Ch_{rate}} \tag{3.2}$$

Load curve corresponding to the charging of electric vehicles is formed by aggregating the charge requirements during that hour and considering the charger rate. Mathematical equation corresponding to the formation of load curve is given in equation(3.3)

$$P_{load,t} = \sum_{t_{ar}=1}^{T} E_{car,n,t_{ar}} \tag{3.3}$$

where $P_{load,t}$ is the total charging required in kWh. $E_{car,n,t_{ar}}$ is the energy required for car n during its departure in kWh. Here the summation is done by considering the first come first serve (FCFS) basis. This is the reason for considering the summation considering the arrival time of the car.

Objective: The objective is to minimize the cost of purchasing of power from the grid.

$$minimize\ C_{pg,t} \tag{3.4}$$

where $C_{pg,t}$ cost of power that is purchased from the grid in INR(₹).

This cost $C_{pg,t}$ is calculated using equation(3.5).

$$C_{pg,t} = P_{grid,t} * \rho_t \tag{3.5}$$

where $P_{grid,t}$ is the power drawn from the grid in kWh and ρ_t is the time of use pricing in INR(₹). Power drawn from the grid is the subtraction of load and solar generation. Here load is the total charging load during that particular hour. $P_{grid,t}$ is calculated using equation(3.6)

$$P_{grid,t} = P_{load,t} - P_{solar,t} \tag{3.6}$$

where $P_{load,t}$ is the total load or total charging required by cars in kWh during which varies with respect to number of cars and time. $P_{solat,t}$ is the total solar power generated in kWh.

Constraints: Constraints that are considered in this optimal charging schedule model are as follows: (i) Charging of car battery should not exceed its maximum capacity as well as it should not go below the soc limit. (ii) Charger rate should not exceed its maximum limit. (iii) Solar power should not exceed its maximum capacity. (iv) An electric vehicle that is coming should charge before its departure time. The following equations show the mathematical stating of constraints.

$$E_{car,min} \leq E_{car,n,t} \leq E_{car,max} \tag{3.7}$$

where E_{car} is the energy in the vehicle battery in kWh.

$$Ch_{rate} \leq Ch_{rate,max} \tag{3.8}$$

where Ch_{rate} is the charger rate in the parking lot in kW.

$$P_{solar,t} \geq P_{solar,max} \tag{3.9}$$

$$t_{ar,n} \leq Tch, n \leq t_{dep,n} \tag{3.10}$$

where $T_{ch,n}$ is the total charging time required for car number or ID n . So, this total charging time should be between the arrival time t_{ar} and the departure time t_{dep}. The car should be allocated for charging considering this constraint.

3.3 Case Study and Results PLMS

In this section validation of the above-mentioned algorithm is done by simulating using MATLAB programming. For simulation, it is considered a smart parking lot where there are 20 slots for charging. The input to the parking lot management system (PLMS) is the arrival time and departure time of the car. Along with this the distance that the customer intended to travel at the time of departure is also considered as input. Here in the simulation two types of vehicles are considered. This classification is done based on the battery capacity and mileage of the vehicle. For type-1 vehicles battery capacity is considered as $24kWh$ and mileage of $0.3kWh/km$. Similarly for type-2 vehicles battery capacity is $30kWh$. and mileage is $0.4kWh/km$ [17]. Also, the minimum battery soc is considered as 10% of the total capacity. This means that the battery cannot discharge below

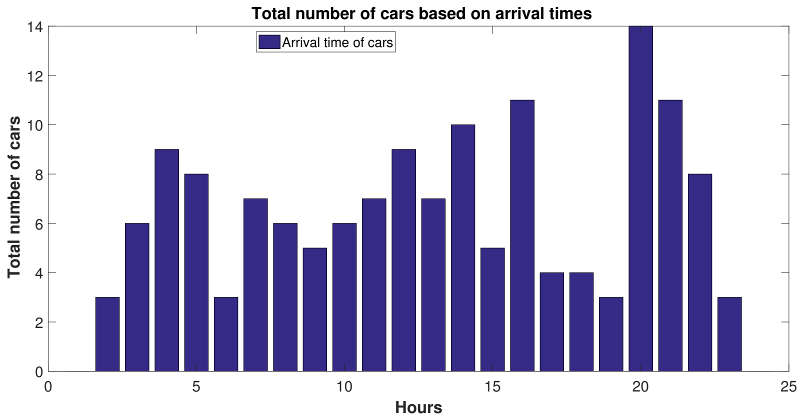

Figure 3.4: Arrival rate of cars

this value. Based on this considerations the and distance intended to travel at the time of departure battery charging required is calculated. Fig 3.4 shows the number of cars arriving in each hour. Here cars having the car ids. This data is generated using a random function which is in between 1 and 24.

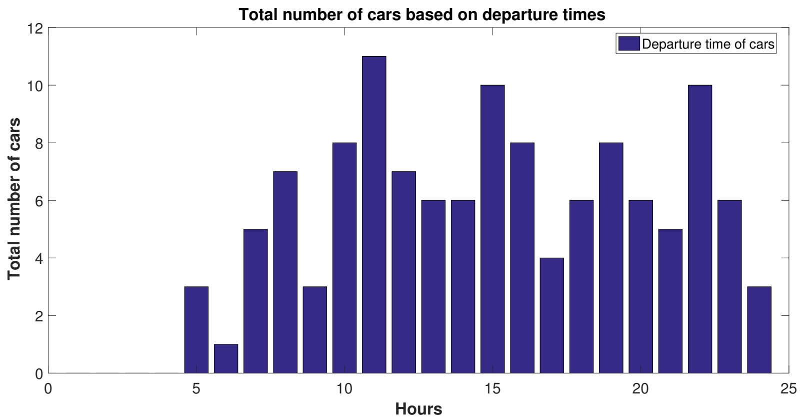

Figure 3.5: Departure rate of cars

Figure 3.5 shows the number of cars that are departing during each hour. Here this data is generated is using the same random function used for arrival time which lies between 1 and 24. But it is taken care that the departure time of the car should not be less than the arrival time.

As explained above based on the distance intend to travel during departure, mileage and battery capacity required charging for each car at the time of departure is calculated and is depicted in fig 3.6.

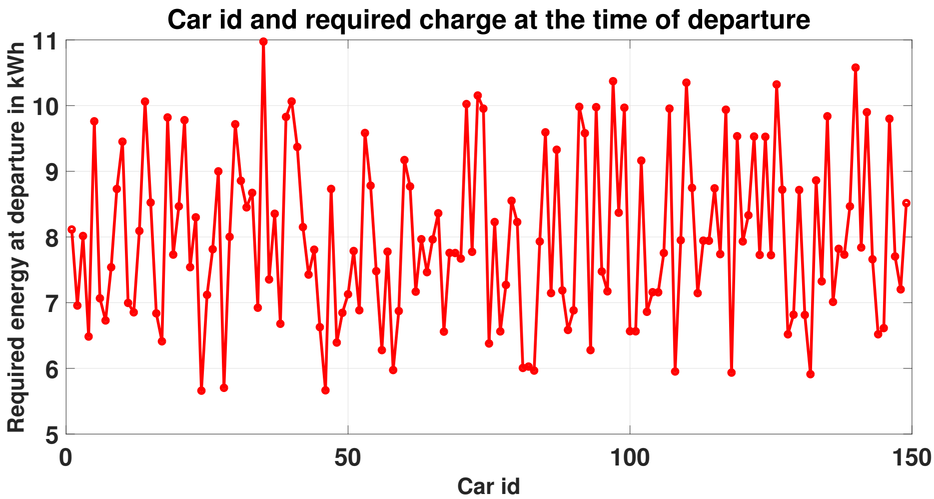

Figure 3.6: Cars and their required charge at the time of departure

Demand curve of the parking lot is formed by aggregating the required charge during the particular time period and. This demand curve is used for building the energy management strategy considering the time of use pricing. Time of use pricing considered is shown in fig 3.7 [18].

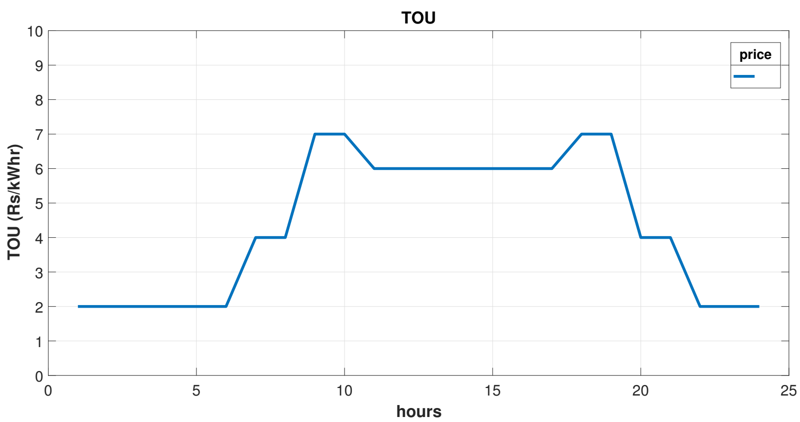

Figure 3.7: Time of use (TOU) price

Solar generation is considered for the IIT Hyderabad location from NREL website. Here the data obtained from the website is given in $watt/m^2$. The data available in this data is for one panel. A number of panels considered for this simulation are 85. This number is selected to actually test the algorithm in different cases. Based on the number of panels and the solar generation data from NREL website [19], solar generation is calculated. Fig 3.8 shows the solar availability and the required demand during each hour. It is observed from the figure that sometimes solar is more and the demand is less. Since selling of power to grid i.e., V2G is not considered, the objective is to utilize more solar.

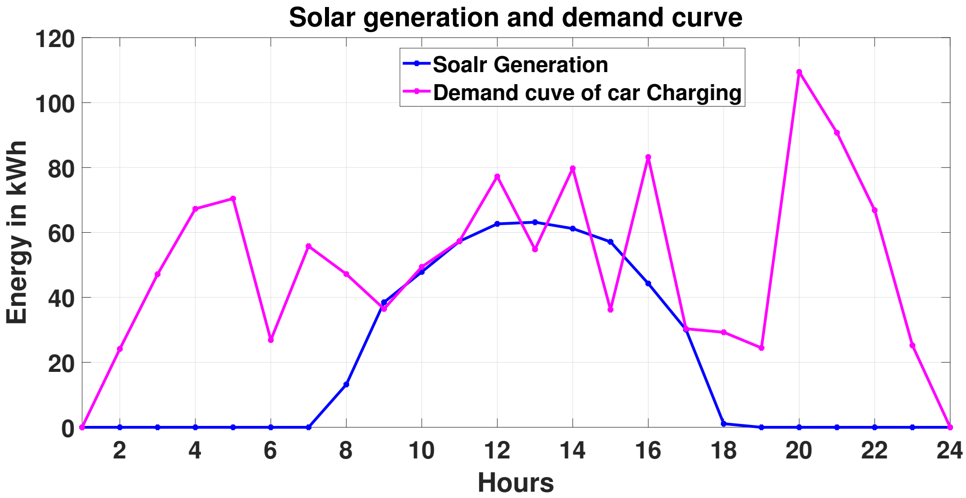

Figure 3.8: Solar Generation and Demand curve for charging of cars

In the simulation, it is considered that if the price is low all the cars are charged by utilizing solar. If the price is high then the shifting of the cars is done. In this simulation, the price low is defined as the price which is less than ₹ 4. In a condition where the price is ₹ 4 and the solar is available, this program prefers to use solar than charging from the grid.

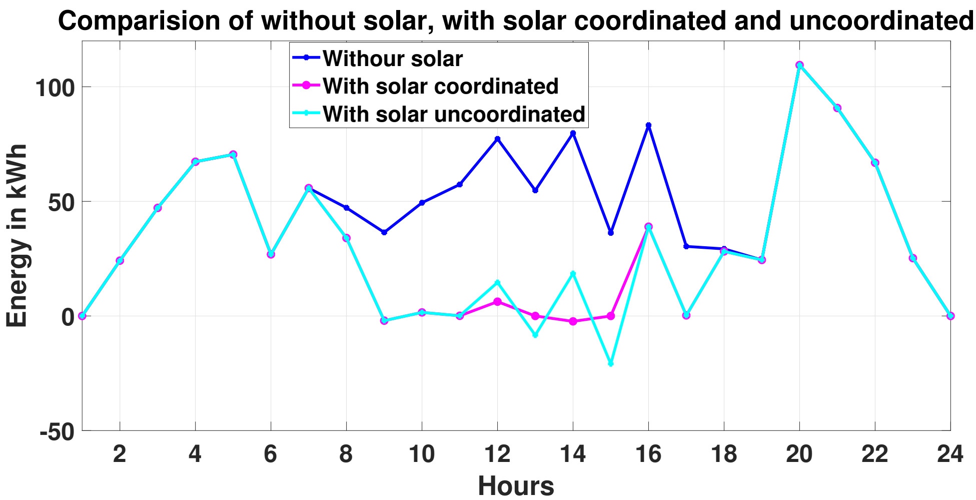

Figure 3.9: Comparison of without solar, with solar uncoordinated and with solar coordinated

Figure 3.9 shows the comparison of charging strategy between without solar, with solar uncoordinated case and with the solar coordinated case. Here uncoordinated case means the first cum first serve (FCFS) basis. For coordinated case cars availability and the total time required for charging is calculated and based on the departure time the cars are selected that are shiftable and those cars are shifted for charging.

Table 3.1 shows the comparison of three cases that are considered for simulation. Here selling

Table 3.1: Cost comparison of three cases

	Without solar	With solar uncoordinated	With solar coordinated
Cost	₹ 5359.15	₹ 2629.56	₹ 2467.96

of power to the grid is not considered. It is observed that with the coordinated case the parking lot owner is achieving minimized cost. The savings obtained in the uncoordinated case by the installation of solar is ₹2729.59. Similarly, the savings obtained with coordinated case compared to without solar is ₹2891.19. Thus it is suggested that more profit is achievable by using the coordinated case algorithm.

hour	car IDs
1	No cars
2	5, 37, 82,
3	47, 83, 97, 112, 123, 148,
4	39, 50, 53, 78, 101, 118, 128, 141, 145,
5	15, 30, 92, 99, 104, 121, 134, 135,
6	22, 41, 74,
7	4, 58, 60, 73, 108, 125, 126,
8	36, 40, 42, 54, 56, 67,
9	3, 81, 85, 93, 100,
10	70, 84, 102, 109, 113, 115,
11	10, 25, 55, 63, 80, 86, 94,
12”	12, 18, *35, 51, 61, 68, 117, 143, 147,
13’	19, 23, 33, 59, 69, 122, 132,
14	8, 24, 34, 43, 66, *91, 103, *110, 120, *130,
15	6, 26, 45, 90, 137,
16	17, 29, 32, 44, 77, 89, 106, 129, 144, 146, 149,
17	46, 65, 88, 124,
18	20, 38, 48, 138,
19	1, 75, 107,
20	2, 7, 14, 27, 28, 31, 49, 62, 64, 79, 95, 96, 114, 119,
21	57, 71, 76, 105, 111, 116, 131, 133, 136, 139, 142,
22	9, 11, 13, 16, 21, 87, 98, 127,
23	52, 72, 140,
24	0

Table 3.2: Uncoordinated case

hour	car IDs
1	0
2	5, 37, 82,
3	47, 83, 97, 112, 123, 148,
4	39, 50, 53, 78, 101, 118, 128, 141, 145,
5	15, 30, 92, 99, 104, 121, 134, 135,
6	22, 41, 74,
7	4, 58, 60, 73, 108, 125, 126,
8	36, 40, 42, 54, 56, 67,
9	3, 81, 85, 93, 100,
10	70, 84, 102, 109, 113, 115,
11	10, 25, 55, 63, 80, 86, 94,
12	12, 18, 51, 61, 68, 117, 143, 147,
13”	19, 23, 33, *35, 59, 69, 122, 132,
14’	8, 24, 34, 43, 66, 103, 120,
15	6, 26, 45, 90, *91, *110, *130, 137,
16	17, 29, 32, 44, 77, 89, 106, 129, 144, 146, 149,
17	46, 65, 88, 124,
18	20, 38, 48, 138,
19	1, 75, 107,
20	2, 7, 14, 27, 28, 31, 49, 62, 64, 79, 95, 96, 114, 119,
21	57, 71, 76, 105, 111, 116, 131, 133, 136, 139, 142,
22	9, 11, 13, 16, 21, 87, 98, 127,
23	52, 72, 140,
24	0

Table 3.3: Coordinated case

Table 3.2 shows the car ids that are charging during the hours. This table corresponds to the uncoordinated case. Similarly, table 3.3 shows the coordinated case for car charging. It is observed from the two tables that the car id 13 is being shifted from 12th hour to 13th hour, and car ids 91,110 and 130 also shifted from 14th hour to 15th hour. This happened since there is more availability of solar during that time and these cars are available for shifting. Availability of shifting is taken by back calculation of the time required for charging and the departure time. Here a new variable is introduced as the car must start charging. This variable actually looks for the cars that are available for shifting. Thus shifting of cars is done. .

3.4 Conclusion

Proposed algorithm called parking lot management system(PLMS) for scheduling of electric vehicles. The proposed algorithm considers the time of use pricing of the utility grid which changes for every one hour. From the results, it is concluded that the coordinated case algorithm reduces the power drawl from the grid during high peak price periods. Since the high peak periods power drawl is compensated by the solar power and the parking lot owners profit is also increased. Further, this can be extended by introducing selling of power to the grid. Also, transactions between the vehicles like charging the uncharged vehicle with the abundant charged vehicle can be introduced.

Chapter 4

Charging Management System (CMS)

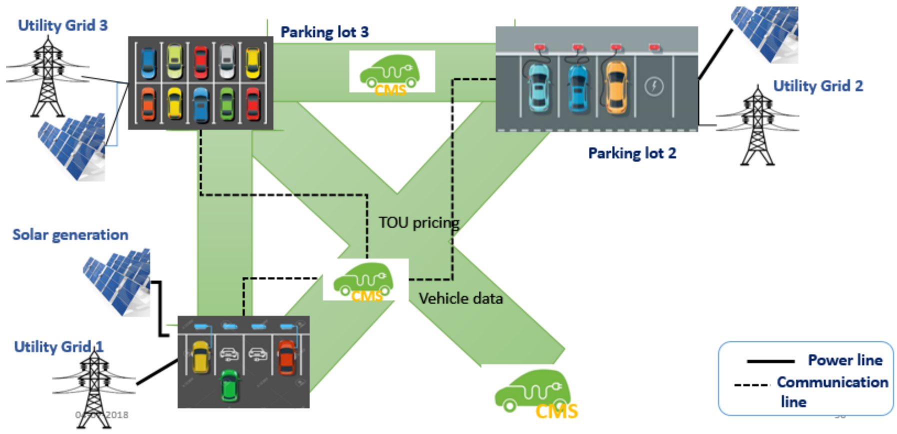

Figure 4.1: Schematic diagram of the implementation of the proposed algorithm CMS

Charging management system (CMS) by scheduling the charging based on prices offered by the parking lots so EV owner can minimize the cost of the charging required for EV. Here three parking lot have been considered that are offering different TOU tariff for EV charging. The electric vehicle is having the flexibility to charge at any of parking lot charging station. Figure 4.1 shows the schematic diagram of the implementation of the proposed algorithm for CMS.

4.1 Processing of EV Test Data

This dataset includes the driving traces of 536 taxis in San Francisco, CA. The data recording starts on May 17, 2008 and ends on June 10, 2008. For each taxi, each data record comprises a time-stamp, latitude, longitude, and a flag indicating whether or not the taxi has a passenger in [20]. The GPS tracking system is switched off every time that the vehicle is turned off. Recording resumes once the vehicle is turned on. we processed again the data for movements and parking of each of the 536 vehicles for the entire three weeks of data traces. The results are shown in Fig 4.2 for a sample

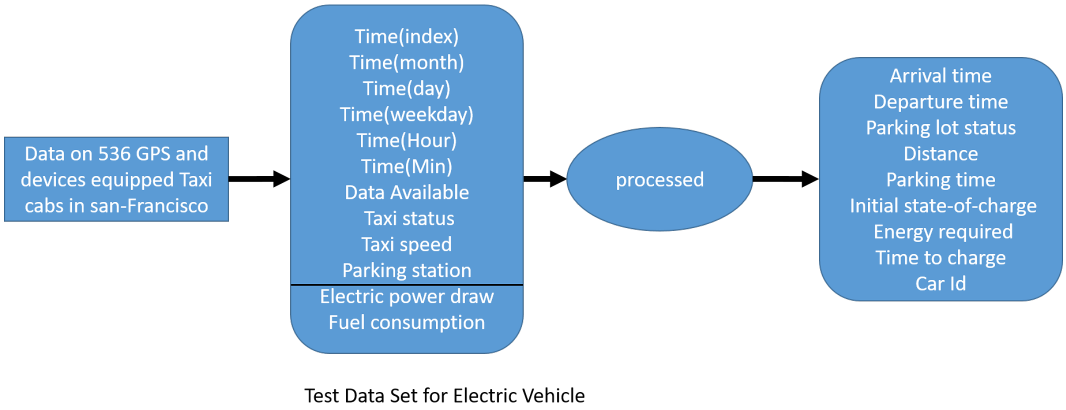

Figure 4.2: Data Flow

vehicles over a time window of three weeks. Here, the value Parking lot values 1,2 and 3 on the y-axis indicates that the vehicle is parked at one of the three charging stations; and the value of 0 means otherwise. The index number of the charging station for each parking event is shown with numbers 1 to 3. As the first step in this analysis, we would like to identify the number of times that a vehicle is parked in each of the Parking lots. The parking events are important as they are later interpreted, under certain conditions on their location and duration, as PHEV plug-in events. Fig 4.3 shows the parking events for the car ID 385. In this, we can observe the EV movement among the parking lots and we can conclude the duration and rate of parking at a particular parking lot station

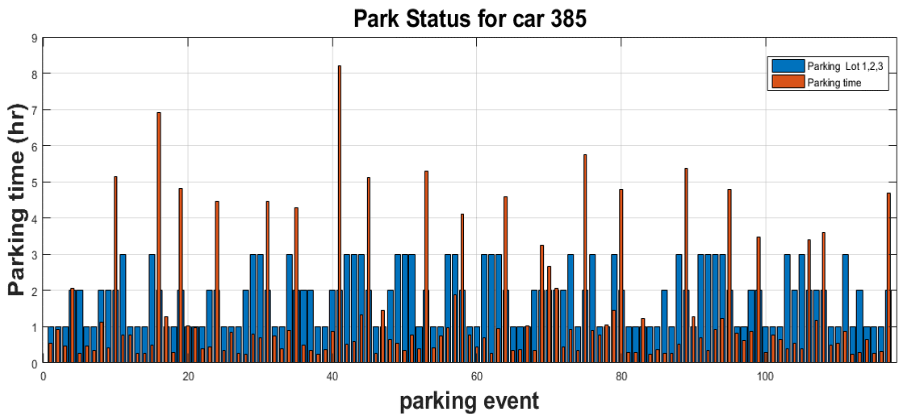

Figure 4.3: Flowchart for implementation of algorithm

We can also see in Fig 4.3 that different taxis have different movement and parking patterns. Another interesting observation is that, as expected, the longest duration parking events are recorded at the second charging station, i.e., the Taxi Headquarters. By putting together the detailed driving and parking traces of all vehicles, we can next calculate the number of vehicles that are parked at each station at any time of interest. The results are shown in Fig. 3. Here, the resolution is one minute. That is, we have calculated the number of vehicles that are parked at each charging station during every one-minute interval of each day. We can see that the parking patterns are quite different across different charging stations, depending on the dynamics of vehicles movements.

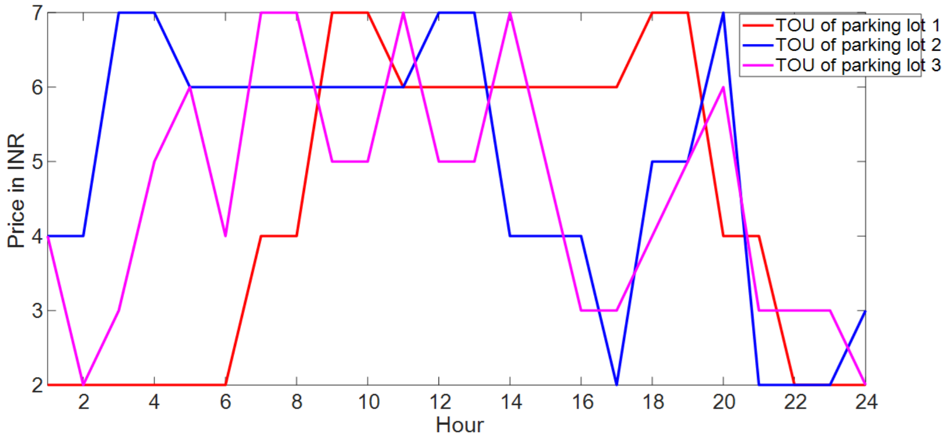

Figure 4.4: Flowchart for implementation of algorithm

Figure 4.4 TOU tariff offered by each Parking lot to charge the EV is generated using random function considering constrains and conditions for tariff.

4.2 Proposed Charging Schedule Algorithm for CMS

In this section, an algorithm is proposed for charging schedule of electric vehicles in a parking lot. This algorithm is deployed in Charging management system (CMS) for scheduling of vehicles. The following are the steps involved.

1. Inputs that are considered for this algorithm includes the vehicle data and time of use(TOU) tariff price for Charging PEV in three different parking lot. In this vehicle data includes
   - Type of vehicle This is defined based on the mileage and the battery capacity of the vehicle.
   - Arrival time of the car.
   - Departure time of the car.
   - State of Charge (SOC) at the time of arrival.
2. Based on the type of vehicle and the distance intended to travel charging required is calculated using the equation (3.1).
3. Once the energy is calculated to the total time required for charging of the vehicle is calculated using equation (3.2). Here the total time depends on the charger rate.
4. Calculate the total cost using equation (3.5).
5. Repeat the process till the end of time.
6. Based on given data calculate the total cost of charging for each PEV
7. compare the TOU tariff offered by each parking lot and find the minimum of the price at which EV can charge.

8. allocate the scheduling of PEV according to Price suggested by CMS

9. compare the profit of the proposed CMS schedule with given data schedule and calculate the overall savings.

4.3 Results CMS

Figure 4.5 shows the comparison of cost of charging for the customer with and without CMS. It is observed from the plot that almost every car obtained the savings.

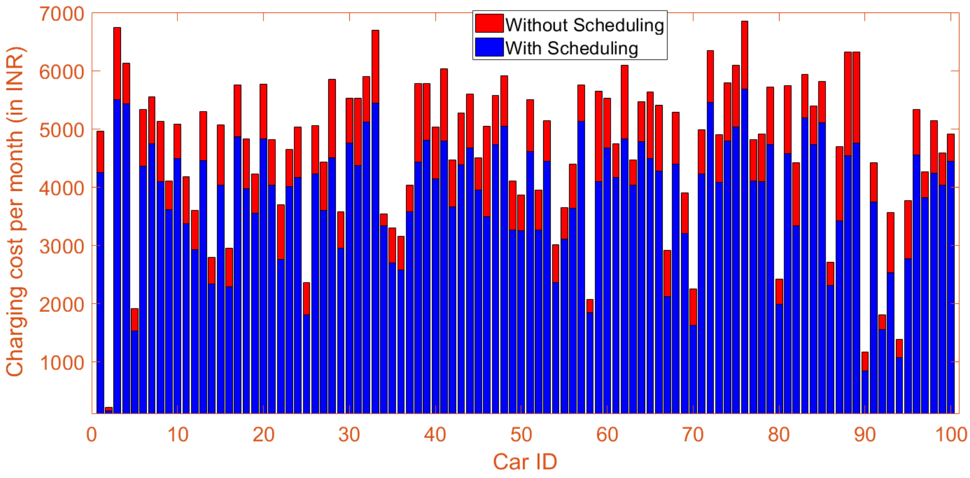

Figure 4.5: Flowchart for implementation of algorithm

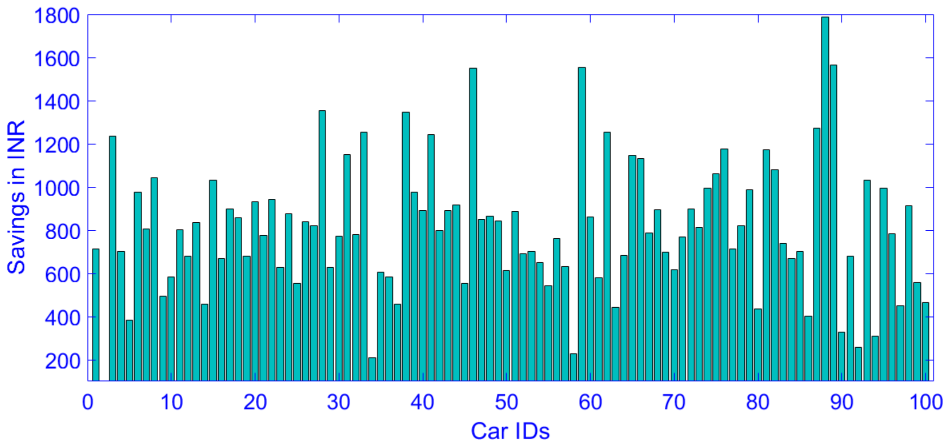

Figure 4.6: Flowchart for implementation of algorithm

Fig 4.6 shows the savings of each customer per month for charging his electric vehicle.

4.4 Conclusion

In order to reduce the cost of EV charging for customer an algorithm proposed which is named as Charging management system(CMS). This algorithm runs in a app or in car for guiding the customer to drive for charging when three charging stations are there nearby and fed by different utilities. As it is observed from the results that the objective of reducing the charging cost EV is attained by using this algorithm.

Chapter 5

Conclusion and Future Research

This thesis proposes an algorithm called parking lot management system(PLMS) and Charging management system (CMS) for scheduling of electric vehicles. The proposed algorithm considers the time of use pricing of the utility grid which changes for every one hour. From the results, it is concluded that the coordinated case algorithm reduces the power drawl from the grid during high peak price periods. Since the high peak periods power drawl is compensated by the solar power the parking lot owners profit is also increased. Further, this can be extended by introducing selling of power to the grid. Also, transactions between the vehicles like charging the uncharged vehicle with the abundant charged vehicle can be introduced.

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