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Optimally Schedule the Charging of Electric Vehicles in Smart Distribution System

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***Abstract*—Electric Vehicles (EVs) are more environmental friendly than the conventional Internal Combustion Engine (ICE) vehicles that are plying on the roads these days. The Green House Gases (GHG) emission content of the electric vehicles are negligible as compared to the conventional vehicles. This paper proposes a scheduling method for optimally charging of electric vehicles in a smart distribution system. In this paper we address the electric vehicles scheduling problem to maximize the total profit, by optimally minimizing the cost of slow charging, average charging, fast charging and very fast charging of electric vehicles. We should ensure that the charging time for electric vehicles should be less or equal to total time limit.**

In this paper, our aim is to minimize the overall charging cost by optimally scheduling the electric vehicles. The Electric Vehicle Scheduling problem is a Binary Integer Linear Programming (BILP) problem. This optimization problem is a NP-Hard (Non-Deterministic Polynomial-Time Hard) Problem. The optimization problem is solved, subject to the constraints of maximum charging time limit. For any vehicle only slow charging or average charging or fast charging or very fast charging is used for particular electric vehicle. We implemented the Branch and Bound algorithm to schedule the electric vehicles problem optimally in order to maximize the the total profit.

***Index Terms*—Electric Vehicles (EVs), Green House Gases (GHG), EVs Charging, Binary Integer Linear Programming (BILP) problem.**

I. INTRODUCTION

Conventional vehicles mostly depends on fossil fuels. At the present time the fossil fuels are considered as the world primary energy source. All the technological advancements in the fields of agriculture, transportation, industry, military protections etc, depends heavily on fossil fuels. These fossil fuels reserves shrink rapidly and their usage pollutes the environment.

Globally transportation is one of the major sources of the fossil fuel consumption such as gasoline, petrol, diesel etc. Fossil fuel is considered as a type of the non-renewable energy sources which will eventually runs out after a finite period of time in the near future. Therefore it is necessary for the nations to take such steps to secure the fossil fuels reserves as much as possible for future stability.

Due to this fact now the nations are moving towards the alternating energy sources for their survival particularly the alternative in their daily mobility needs. Electricity is considered to be one of the most cleanest form of the energy and can be easily and effectively transformed from one form of energy to another form of the energy. As we know that burning of the fossil fuels is very harmful for the environment and health such as it creates global warming effect and also has a harmful effect on the health of the living organisms. Burning of the fossil fuels is the largest source of the green house gases (GHG) due to the emission of carbon dioxide CO_2 during burning process. There has been a phenomenal increase in the observed temperatures during the second half of twentieth century, solely because of the green house gases (GHG) emissions by the leading industrial nations of the world.

[1] Carbon monoxide, nitrogen oxides, and hydrocarbons are released when fuel is burned in an internal combustion engine and when air/fuel residuals are emitted through the vehicle tailpipe. Gasoline vapors also escape into the atmosphere during refueling and when fuel vaporizes from engines and fuel systems caused by vehicle operation or hot weather. The pollutants in vehicle emissions are known to damage lung tissue, and can lead to and aggravate respiratory diseases, such as asthma. Motor vehicle pollution also contributes to the formation of acid rain and adds to the greenhouse gases (GHG) that cause climate change.

According to U.S.A climate Action Report 2010 [25], approximately 28% of the total Greenhouse Gases Emissions in United Sates of America are from transportation sector that includes automobiles, cars, buses, motorcycles, aircrafts, ships, trains etc.

Fig.1 depicts the greenhouse gases (GHG) emission trends in Seattle (city in Washington).

[2] Figure shows green house gases (GHG) emissions consists

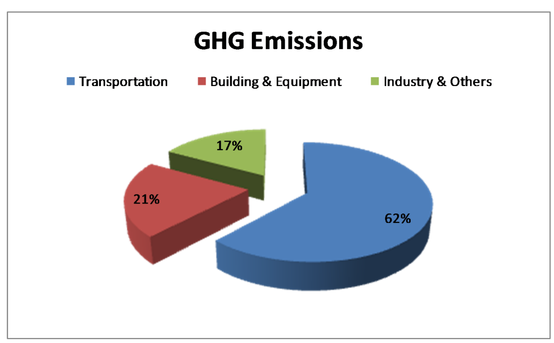

Fig. 1. **Green House Gases Emissions**

[1]http://www.dec.ny.gov/chemical/8394.html

[2]http://hugeasscity.com/2009/12/13/seattles-carbon-footprint-assessing-the-assessment/

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of 62% of the transportation sector, 21% of building areas and 17% of the emission are due to the Industry sector. So that is why we need to take drastic steps in order to reduce these pollution/emission in our environment and make the atmosphere healthy and clean. One of the way to reduce the transportation emission by using electric vehicles instead of conventional (ICE) vehicle because the emission rate of the electric vehicle is negligible as compared to the conventional (ICE) vehicles.

A. Electric Vehicles

Nowadays most of the researchers avert their intensions and objectives towards the vehicles driven by the electric motor instead of gasoline or petrol as in Internal Combustion engine (ICE) based vehicles. [3] Emissions from burning fossil fuels such as oil, gas and coal are one of the main contributors to global warming. National and international targets to reduce CO2 emissions have led the electricity industry to diversify and to develop electricity generation from renewable resources such as wind and ocean energy. Ireland has one of the richest wind and ocean energy resources in Europe. This is just one of Ireland's many natural advantages which are attracting the world's leading car companies to use our country as the ideal test bed for their electric cars.

The concept of the electric vehicle is comparatively new in automobile sector, but history shows that the first electric vehicle was manufacture in 1832 to 1839 (Correct date is uncertain) but the more practically useable and successful electric vehicle were made around 1842 [4]. Electric vehicle is driven by the electricity energy which is stored in the electricity storage devices like rechargeable batteries. Currently the EVs came into existence with considerable reliability and have gained popularity in all the developed countries. Still these EVs are used for small distances. The range anxiety can be considerably resolved by carefully scheduling these EVs and placing EVs charging stations or charging infrastructures along the serving areas.

Why electric vehicles?

There are many advantages of the electric vehicles some of them are as follow [5].,

1) No Green House Gases (GHG) Emissions: The electric vehicles are environmental friendly because they emit no green house gases (GHG) which are very harmful for the health of human being as well as other living organisms. These vehicles helps the atmosphere to remain clean and results in improving the health of the living thing. So we can say that electric vehicles has no contribution to global warming or green house effect.

2) Fuel Economy: In the electric vehicles electricity is used for propulsion instead of fossil fuels like petrol, gas, diesel etc. the price of the electricity is much less than the price of the fossil fuels. Once the vehicle owner invested the money to buy electric vehicle, he can get back his money in many ways, by buying electricity at less prices than refueling conventional fossil fuel based Internal Combustion Engine (ICE) vehicles, or, in many developed countries government has provided incentives to the electric vehicles owners at the cost of controlling GHG emissions, or, by both.

3) Noiseless Vehicles: It is interest to know that during driving the electric vehicle it make very less noise. Electric vehicles helps to reduce the noise pollution. So Electric Vehicle provides a smooth noiseless and comfortable drive.

4) Increasing Popularity: Electric vehicles becoming popular all around the world and successfully adopted and used especially in countries like USA, China, Canada, Japan, Norway etc. In these countries government motivate the people to use electric cars instead of conventional fuel based vehicles in order to make the environment green.

5) Requires Less Maintenance: Another advantage of the electric vehicle is that it requires very less amount of money to spend on maintenance of the vehicle and does not need to send to the workshop at regular interval.

[6] Electric Cars use the energy stored in a battery (or series of batteries) for vehicle propulsion. Electric motors provide a clean and safe alternative to the internal combustion engine. There are many pros and cons about electric cars. The electric vehicle is known to have faster acceleration but shorter distance range than conventional engines. They produce no exhaust but require long charging times.

[7] Using less fossil fuels is inherently green. But when you consider that using an electric vehicle results in a 30% reduction in carbon dioxide emissions compared to a gas powered car.

'Electric vehicles can offer benefits due to their flexibility in charging and discharging time span and introduce a useful concept called Vehicle to Grid (V2G) capability. V2G is defined as the option to return the stored electrical energy to the grid from the vehicles battery. In other words, an Electric vehicle can act as a controllable load as well as a distributed storage device. Being connected to the electricity network when not in use, the battery of an EVs can supply power during peak load times and thus increase the reliability of the grid. As a result, taking into account the total number of available EV's in a locality, distributed storage capacity provided by V2G can have a relevant impact on distribution system operation.' [1]

What is scheduling?

Scheduling is an arrangement or plan (an event) to take

[3] https://www.esb.ie/electric-cars/environment-electric-cars/renewable-electricity-generation-electric-cars.jsp

[4] http://inventors.about.com/od/estartinventions/a/History-Of-Electric-Vehicles.htm

[5] http://www.conserve-energy-future.com/advantages-and-disadvantages-of-electric-cars.php

[6] http://www.alternative-energy-news.info/technology/transportation/electric-cars/

[7] http://www.rd.com/home/cleaning-organizing/5-things-you-should-know-about-electric-cars/

place at a particular time [8]. Electric vehicle scheduling or electric vehicle charging and discharging strategies is essential to avoid grid congestion. Efficient EV's scheduling can ensure the proper running of the distribution system. We should focus on how to schedule and allocate energy from energy sources to places where energy is needed but keeping in mind the proper running of the system without overloading and congestion the main grid [4]. Electric vehicle scheduling in smart distribution systems helps us to minimize the operational cost that which results in form of reduction in electricity bills. We know that emission rate of the EV's is negligible as compared to conventional (ICE) vehicles so EV's results in minimizing the emissions that pollutes the environment and atmosphere.

B. Electric Vehicles Types

These are the following types of the vehicles. PEV (Plug In Electric Vehicle), PHEV (Plug In Hybrid Electric Vehicle), PET (Plug In Electric Train), HEV (Hybrid Electric Vehicle), EV (Electric Vehicle), SV (Sensor Vehicle), BEV (Battery Electric Vehicle) and GV (Energy Storage Vehicle).

C. Electric Vehicles Charging/Discharging Techniques

These are following Vehicle To Grid (V2G), Grid To Vehicle (G2V), Vehicle To Vehicle (V2V), Vehicle To Home (V2H) and Home To Vehicle (H2V).

[9] Vehicle to grid (V2G) describes a system in which plug-in electric vehicles, such as electric cars (BEVs) and plug-in hybrids (PHEVs), communicate with the power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate.

In [2] authors present charging schedule of electric vehicle, Grid to vehicle (G2V) technology is used to charged the vehicles, [3] authors proposed the reliability in communication of electric vehicles EVs charging station using (G2V) technology.

In [2], [3], [13], [22], [23], and in some others papers as shown in the figure, authors proposed a technique Grid To Vehicle (G2V) for charging of electric vehicle from the main grid to electric vehicle. By optimally scheduling the charging of the electric vehicle we can receive the incentives by charging the vehicle during non-peak hours. By utilizing this technique it helps in valley filling during non-peak hours.

In [5], [10], authors present a method for off line optimization towards an online optimization control strategy for a PHEV connected/disconnected to home by using Vehicle To Home (V2H) and Home To Vehicle (H2V) technique. The above mentioned method helps in minimizing the pollution/emission, also helps in reducing the rate of depletion of fossil fuels and also reduces the overall cost.

In [6], authors present a method for optimal placement of charging stations in smart city by using a technique Vehicle To Vehicle (V2V) charging/discharging. This technique of charging/discharging of electric vehicle is one of the way of fast charging/discharging. In this manner customer can generate revenue as well.

II. System Model And Problem Formulation

In this paper we describe the problem of the electric vehicles scheduling in smart distribution system and provide its formal definition.

We define the models of the electric vehicles, models of the charging station with its charging points and models of the charging schedule [26]. Then we discuss the evaluation profit function and show the formulation of the problem as a Binary integer programming problem. [10]An integer programming problem is a mathematical optimization or feasibility program in which some or all of the variables are restricted to be integer. In many cases the the term refers to integer linear programming, in which the objective function and the constraints are linear.

A. System Model

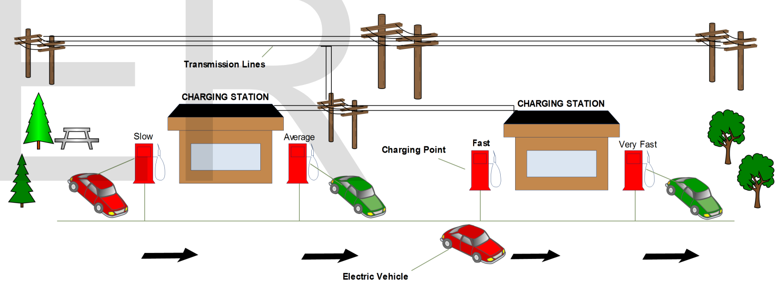

Fig. 2. **Electric Vehicles Scheduling System Model**

The system model for electric vehicle scheduling is described in Fig.2 The main aim and goal is to maximize the profit by electric vehicle scheduling. There are different costs of different charging levels. The cost of slow charging for electric vehicles is very low but it takes more time to charge the vehicle. Similarly the cost of average charging for electric vehicles is higher than the slow charging cost but it takes less time as compared to slow charging. Similarly the cost of fast charging for electric vehicles is higher than the average charging cost but it takes less time as compared to average charging. Similarly the cost of very fast charging for electric vehicles is higher than the fast charging cost but it takes very less time as compared to other charging levels. The difference in these charging time is due to the charging power, more the charging power it takes less time to charge the vehicle. We have discussed the different charging levels

[8]http://www.businessdictionary.com/definition/scheduling.html
[9]http://en.wikipedia.org/wiki/Vehicle-to-grid
[10]en.wikipedia.org/wiki/integer-programming

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in detail.

Electric vehicles can play an important roll in making environment green and economical transportation. There are many ways to charge the electric vehicles, depending on charging time. The charging time required to charge the electric vehicle, can be explained in terms of levels of charging [11] and the charging power.

Level 1 (L-1) charging, is the slow charging, and the vehicle battery is charged by applying 120VAC/16A for the 1.92kW charging, by using the on-board battery charger. The charging time required to charge the vehicle battery with full capacity, is about 10 hours [6]. Electric vehicle charging that take place at home, can be considered as level 1 charging, where the charging process is completed during the whole night.

Level 2 (L-2) charging, also called the standard charging, here, the vehicle battery is charged by applying 208V-240VAC, 12A-80A for the 2.5kW-19.2kW charging, by using the on-board battery charger. In level 2 the charging time required to fully charge the empty battery is 6-8 hours. The best implementation of level 2 charging, is at the places where the user stays for a long time, for example at work.

Level 3 (L-3) DC fast charging, the charging is done with upto 200A for 75kW charging power, using off-board charger. The charging time for the fast charging is about 30 mints [6], and the charging price will be high.

Level 4 (L-4) DC very fast charging, the charging is done with upto 400A for 240kW charging power, using off-board charger. The very fast charging is required at the places, where the user can not wait for long time, for example at public charging stations. The charging time for the fast charging is about 15 mints [6], and the charging price will be very high.

The time horizon T is divided into discrete time slots (15 minutes time slot). So the time required to charge the electric vehicle with very fast charging is 15 minutes (One Time Slot), the time required to charge the electric vehicle with fast charging is 30 minutes (2 Time Slots), the time required to charge the electric vehicle with average charging is 45 minutes (3 Time Slots) and the time required to charge the electric vehicle with slow charging is 60 minutes (4 Time Slots). We always ensures that the numbers of time slots for charging the electric vehicles should be greater or equal to the number of electric vehicles, otherwise the solution will not be feasible.

So we are using four charging Levels for electric vehicles charging. The very fast charging level, fast charging level, average charging level and the slow charging level. Table 4.1 provides an overview of the notation that we are using in our problem formulation.

B. Problem Formulation

In this paper, we formulated an Electric vehicle scheduling problem, which is Binary Integer Linear Programming problem. Our aim is to maximize the total profit by optimally scheduling the slow charging, average charging, fast charging and very fast charging of electric vehicles. This problem is quite similar to knapsack problem and is a NP-Hard (Non-deterministic Polynomial time hard) problem. Mathematically we can formulate, electric vehicle scheduling problem as follows.

[11] http://www.evtown.org/about-ev-town/ev-charging/charging-levels.html

C. Design Variable

The binary integer variables, w_i,x_i,y_i,z_i $\in$ {0,1}, $\forall$ i $\in$ $\{1, 2, 3, ..., N_v\}$ are considered as the decision variables, in order to formulate Electric vehicle scheduling problem as an optimization problem. If w_i is "1" then electric vehicle is charged through slow charging level, if x_i is "1" then electric vehicle is charged through average charging level, if y_i is "1" then electric vehicle is charged through fast charging level, if z_i is "1" then electric vehicle is charged through very fast charging level.

D. Objective Function And Constraints

The formulation of this optimization problem is given below in which c^s represents the cost of slow charging, c^a represents the cost of average charging, c^f represents the cost of fast charging and c^{vf} represents the cost of very fast charging. N_v denotes the total number of electric vehicles available for charging either slow charging or average charging or fast charging or very fast charging.

t^s represents the time required to slow charge the electric vehicle, t^a represents the time required to average charge the electric vehicle, t^f represents the time required to fast charge the electric vehicle and t^{vf} represents the time required to very fast charge the electric vehicle. We must ensure that slow charging time, average charging time, fast charging time and very fast charging time of the electric vehicle should be less or equal to total time T. It means that the service provider must ensure that all the vehicles and batteries should be charged before that time limit.

$$\min_{w_i,x_i,y_i,z_i} \sum_{i=1}^{N_v} \left[w_i c^s + x_i c^a + y_i c^f + z_i c^{vf} \right] \qquad (1)$$

Subject To:

$$C_1: \quad w_i + x_i + y_i + z_i = 1, \qquad \forall i \in \{1, 2, 3, ..., N_v\}$$

$$C_2: \quad \sum_{i=1}^{N_v} w_i t^s + x_i t^a + y_i t^f + z_i t^{vf} \leq T$$

$$C_3: \quad w_i, x_i, y_i, z_i \in \{0, 1\}$$

The main objective is to maximize the total profit as shown in Equ.1, by optimally minimizing the cost of slow charging, average charging, fast charging and very fast charging but satisfies the all demand of customers, The constraint C1 shows that only slow charging or average charging or fast charging or very fast charging of the electric vehicle can take place. The constraint C2 make sure that the slow, average, fast and

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very fast charging time of the electric vehicle should be less or equal to total time. The constraint C3 represents that the w_i is the selection of electric vehicles for slow charging, the x_i is the selection of electric vehicles for average charging, y_i is the selection of electric vehicles for fast charging and the z_i is the selection of electric vehicles for very fast charging.

III. SIMULATION RESULTS

The Optimization Toolbox is a collection of functions that extend the capability of the MATLAB numeric computing environment. In this paper we have used 'bintprog' , which is used to solve binary integer linear programming problem. 'bintprog' uses a linear programming (L-P) branch and bound algorithm to solve the binary integer programming problems.

we have considered nine different cases. In each case there is different costs for slow charging time slots, average charging time slots, fast charging time slots and very fast charging time slots. These charging time slots also vary in every case. In each case we have to charge ten electric vehicles. The simulation results are shown graphically one by one.

A. Case 1

In Case 1 we have to charge 10 electric vehicles. The optimal Slow Charging, Average Charging, Fast Charging and Very Fast Charging of these electric vehicles at different time slots is shown in Fig.3. The rates for different charging levels such as Slow Charging Level, Average Charging Level, Fast Charging Level and Very Fast Charging Level time slots are as follow:
For Slow charging 4 time slots costs 1 $
For Average charging 3 time slots costs 3 $
For Fast charging 2 time slots costs 5 $
For Very Fast charging 1 time slot costs 6 $

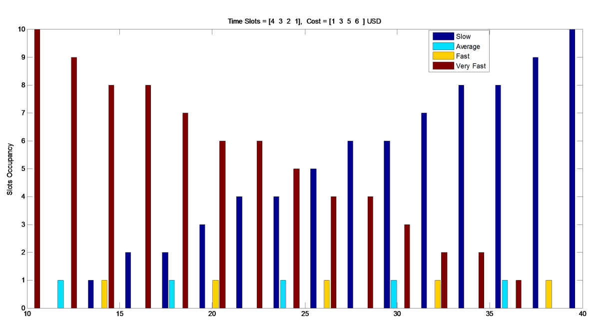

Fig. 3. **Case 1**

B. Case2

In Case 2 we have to charge 10 electric vehicles. The optimal Slow Charging, Average Charging, Fast Charging and Very Fast Charging of these electric vehicles at different time slots is shown in Fig.4. The rates for different charging levels such as Slow Charging Level, Average Charging Level, Fast Charging Level and Very Fast Charging Level time slots are as follow:
For Slow charging 6 time slots costs 1 $
For Average charging 4 time slots costs 3 $
For Fast charging 2 time slots costs 5 $
For Very Fast charging 1 time slot costs 6 $

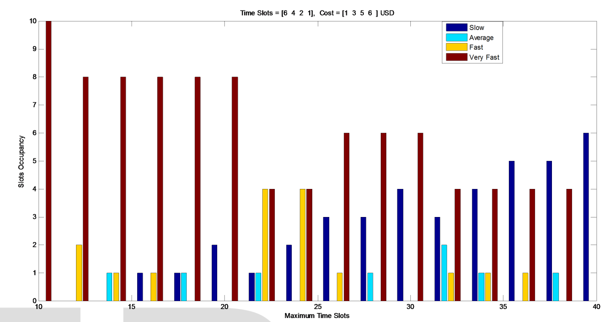

Fig. 4. **Case 2**

C. Case 3

In Case 3 we have to charge 10 electric vehicles. The optimal Slow Charging, Average Charging, Fast Charging and Very Fast Charging of these electric vehicles at different time slots is shown in Fig.5. The rates for different charging levels such as Slow Charging Level, Average Charging Level, Fast Charging Level and Very Fast Charging Level time slots are as follow:
For Slow charging 6 time slots costs 1 $
For Average charging 5 time slots costs 3 $
For Fast charging 4 time slots costs 5 $
For Very Fast charging 1 time slot costs 6 $

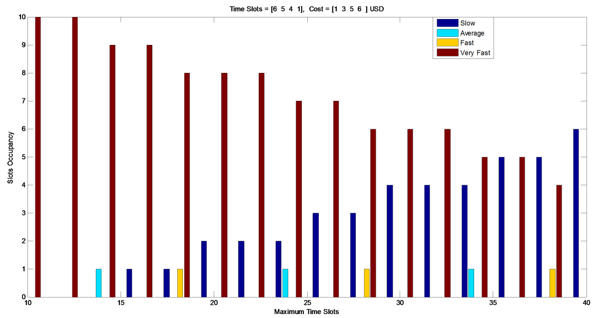

Fig. 5. **Case 3**

D. Case 4

In Case 4 we have to charge 10 electric vehicles. The optimal Slow Charging, Average Charging, Fast Charging and Very Fast Charging of these electric vehicles at different time slots is shown in Fig.6. The rates for different charging levels such as Slow Charging Level, Average Charging Level, Fast Charging Level and Very Fast Charging Level time slots are as follow:
For Slow charging 6 time slots costs 1 $
For Average charging 5 time slots costs 3 $
For Fast charging 4 time slots costs 5 $
For Very Fast charging 1 time slot costs 6 $

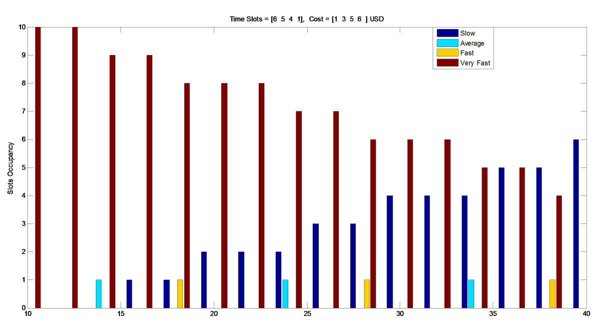

Fig. 6. **Case 4**

E. Case 5

In Case 5 we have to charge 10 electric vehicles. The optimal Slow Charging, Average Charging, Fast Charging and Very Fast Charging of these electric vehicles at different time slots is shown in Fig.7. The rates for different charging levels such as Slow Charging Level, Average Charging Level, Fast Charging Level and Very Fast Charging Level time slots are as follow:
For Slow charging 4 time slots costs 1 $
For Average charging 3 time slots costs 2 $
For Fast charging 2 time slots costs 3 $
For Very Fast charging 1 time slot costs 4 $

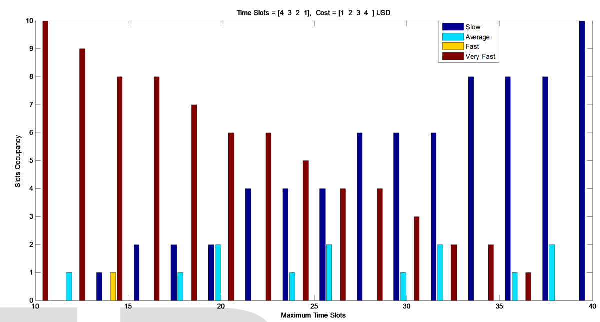

Fig. 7. **Case 5**

IV. Conclusion

The Green House Gases (GHG) emission content of the electric vehicles are negligible as compared to the conventional Internal Combustion Engine based vehicles. The dependency of internal combustion engine (ICE) vehicles can be reduced significantly by introducing electric vehicles into the transportation system. It is concluded that, in order to the successful penetration of the electric vehicles into the transportation system, we optimally schedule the charging of all the electric vehicles and it also enable the customer to purchase cheap electricity for charging of electric vehicles. In order to maximize the total profit, we optimally minimize the cost of slow charging, average charging, fast charging and very fast charging of the electric vehicles keeping in mind the total time limit should be satisfied. And the results of different cases as discussed earlier shows the charging level for all electric vehicles in various time slots are optimal.

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