Optimization of Power Flow Through Electric Vehicle Charging

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Abstract— **In order for charging companies to make the most profit from electric vehicle charging, costs and profits must be optimized. One way of doing so is by optimizing the power flow. For a charging station, power is either flowing in or out. Thus, power is being purchased or sold. The objective of this research is to optimize the profits made from this process. To do so, the average power demanded on a given day over time intervals is necessary in this research. Then each assumed electric vehicle is assigned a charging level and a state of charge using proper probability distributions. Once finding and calculating all necessary values, the optimization function is solved under proper constraints, allowing the retrieval of an optimized power flow. The result will depict an optimum power flow over a twenty-four hour time span.**

Index Terms— Optimization, Power Flow, Occupancy, State of Charge, Charging Levels

I. Introduction

Electric vehicles are gaining popularity. Over the years, the sales of electric vehicles have increased and are expected to increase further[1]. The objective of this research is to come up with a method or algorithm that will maximize efficiency from the charging of electric vehicles when the power generated would come from rooftop solar panels, electrical grid, and storage. In this research, certain factors will be accounted for. These factors include the costs of purchases and the profits made from the services. In specific, this research is to optimize costs and profits from charging stations for electric vehicles by controlling power flow.

The goal of this project is to reach a financial surplus through the optimization of the power flow in an electric vehicle charging system under assumed prices and determined constraints. Other factors that will be involved include tendencies, such as when most people choose to charge their electric vehicles, how often an electric vehicle needs to be charged, and how quickly an electric vehicle must be charged. In order to optimize the profit/costs, in this project, MATLAB will be used to evaluate the algorithms. A system of equations and constraints will be determined and input into MATLAB to generate the necessary solutions to form a general solution for the project..

II. Parking Lot Occupancies

A sample parking lot occupancy from Western Washington University is used in this research to create the power demand curve[2].

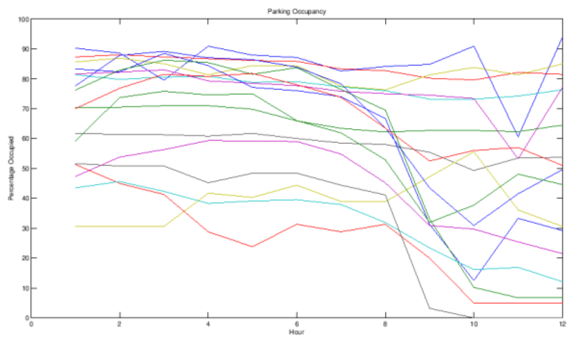

Fig. 1. Parking Lot Occupancy

Fig. 1. is a graph representing the occupancy of all parking lots in the data set over a twelve hour period. From this chart, a single lot which portrays the desired the traits is chosen and is used for the following processes. Since the sample only recorded a twelve hour occupancy period, the remaining occupancies in the remaining twelve hours have been reasonably assigned to each hourly interval. From this data, the occupancy of a parking lot is obtained as well as the change in occupancy over each hourly interval. This is obtained by finding the difference in occupancy between each hourly interval and the previous one. Using the change in occupancy, each increase in occupancy between time intervals, it is assumed that increase is equal to the number of new vehicles and that each new vehicle is an electric vehicle that is to be charged at arrival.

III. Charging Levels

Electric vehicles have mainly three charging methods. They are level one charging, level two charging, and level three charging. Level one charging is done through a 125V charger and equates to about two to five miles per hour of charging. Level two charging is done through a 240V charger and equates to about ten to fifteen miles per hour of charging. Level three charging, or DC fast charge, equates to about fifty to seventy miles per twenty minutes of charging[3]. Once the occupancy is assigned and the incoming vehicles are determined, either a level 1, 2, or 3 charging level is assigned to each incoming electric vehicle using a specific probability distribution. A random number generator function is used to generate the state of charge values. The function generates random numbers between 0 and 1 equal to the number of assumed charging electric vehicles.

Each generated value, x_n, is assigned a charging level where

$$charging\ level = \begin{cases} 2\ if\ 0 < x_n \leq 0.7 \\ 3\ if\ 0.7 < x_n \leq 0.9 \\ 1\ if\ 0.9 < x_n \leq 1 \end{cases} \quad (1)$$

These three levels represent the charging method used by the consumer. The level one charging method is an inefficient but cheap charging method as opposed to level three which is efficient but expensive. Level two charging falls in between these two.

IV. State of Charge

Similarly, each incoming electric vehicle is assigned a state of charge, which would represent the percentage of power in each battery as it would enter a charging station. A probability distribution is generated representing the expected state of charge for all incoming electric vehicles. In order to create the desired curve, two parameters are chosen, in this project they are 2 and 4. The parameters used are input into a Matlab function to generate a set of random numbers representing the state of charge for each incoming electric vehicle. The number of generated values equals to the number of incoming electric vehicles plus the number of electric vehicles already present at the starting time that are assumed to be charging. Fig. 2. is a graph depicting the ideal probability distribution for the state of charges for incoming electric vehicles.

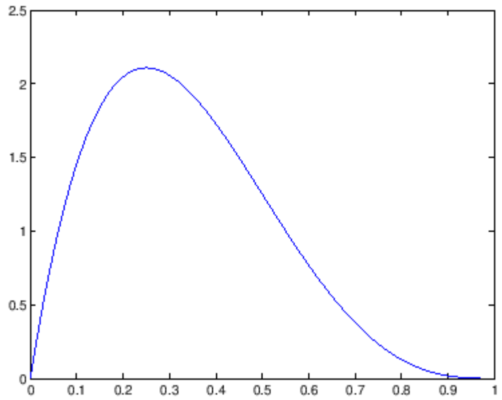

Fig. 2. SOC probability distribution

With the parking lot occupancy, number of net incoming electric vehicles, charging levels, and state of charge for the electric vehicles, the charging time for each electric vehicle is calculated using the equation below.

$$T = (1 - SOC)e/p$$

In this equation, T represents the time in hours, SOC is state of charge in decimal form, e is the charging capacity for the car battery, and p equals charging power. The charging capacity of batteries using level one two and three charging are 12kwh, 24kwh, and 60kwh respectively.

V. Charging Curve

In this project, two charging curves have been created, a deterministic curve and a stochastic one. The charging curve represents the amount of power demanded in an electric vehicle parking garage over a time interval. The factors that are involved in generating this curve include parking lot occupancy, charging levels, and state of charge, which at this point have already been accounted for.

With this information, the total amount of power that is required can be determined for each hourly interval, thus allowing the formation of a charging curve.

Since each electric vehicle is assigned a charging level, where the distribution of charging levels obey a proper probability distribution, the charging power for each electric vehicle will vary between 1.9kW, 7.2kW, and 50kW. For each hourly interval, the total power demanded can be calculated by summing the charging powers for each electric vehicle with its respective charging level during each hour. The graph below depicts a deterministic model of the power demanded in a 24 hour span.

Table I. Power Demand

9-930pm	930-10pm	10-1030pm
50	50	
7.2	7.2	7.2
7.2	7.2	7.2
7.2	7.2	7.2
7.2	7.2	7.2
7.2	7.2	7.2
50		
7.2	7.2	7.2
7.2	7.2	7.2
1.9	1.9	1.9
7.2	7.2	7.2
7.2	7.2	7.2
50		
1.9	1.9	1.9
7.2	7.2	7.2

7.2	7.2	7.2
1.9	1.9	1.9
7.2	7.2	7.2
50	50	
	7.2	7.2
	7.2	7.2
		7.2
292.1	206.5	113.7

Table 1. is an example of how the process is solved. This chart only covers an hour With a charging time and charging power for each electric vehicle, the charging powers are summed at each time interval. This process was coded in MATLAB and the graph below

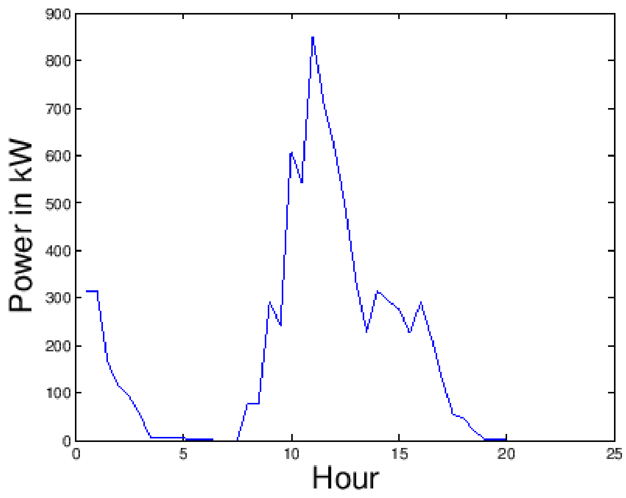

Fig. 3. Deterministic charging curve

Fig. 3. a deterministic modal and a visual representation of this process after completion for every time interval. 9PM is indexed on this graph at x = 0 and ends at 9PM the follwing day at x = 24.

This model has been created using an average in occupancies of multiple days in a week. Although it is an average, it would be more accurate to account for some randomness in the occupancy. This will be accounted for. In the next step, a stochastic model is created in order to project a more accurate charging curve that can account for some randomness in the parking lot occupancy.

In order to create a stochastic model of the charging curve, the Poisson Process has been implemented into the research. Using the mean change in occupancy for each hourly interval in the sample occupancy, a Poisson function is used to generate new changes in occupancies. In other words, this function is used to determine a number of net incoming electric vehicles for each hourly interval for the new model, giving a new occupancy.

With this new occupancy, the same steps used in the deterministic modal are applied in order to create a charging power curve that accounts for some randomness in the occupancy. The result of applying the Poisson function to the charging curve are shown in Fig. 4.

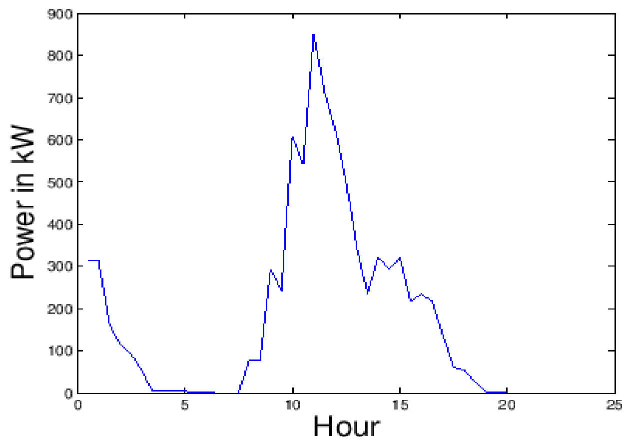

Fig. 4. Stochastic charging curve

For the most part, the visuals of the deterministic curve and the stochastic model look similar with minor changes. For the remainder of the project, the values from the stochastic model are to be used.

VI. Optimization

The final process is to optimize the power flow of the parking garage. To do so, necessary constraints must be determined. This is where the objective function is identified and power constraints are taken into account. Below are the objective functions, constraints, and values to be used in the function.

Problem Formulation

- Objective: Maximize power efficiency function

$$\sum_t \pi(t) \cdot \mathrm{n}(t) + \sum_t \alpha \cdot P_c + \sum_t P_g \cdot \rho - \sum_t P_d \cdot \rho \quad (2)$$

Subject to Constraints

-Boundaries for state of charge of garage battery

$$SOC_{min} \leq SOC \leq SOC_{max} \quad (3)$$

-Boundaries for power output

$$P_{smin} \leq P_s \leq P_{smax} \quad (4)$$

-Power transfer equivalency

$$P_d + P_v + P_s = P_c + P_g \quad (5)$$

$$P_g \geq 0 \quad (6)$$

$$P_d \geq 0 \quad (7)$$

$$\mathrm{SOC}_{24} = 0.5 \quad (8)$$

Where

P_s = Outflow power from battery at hourly interval

n(t) = Parking lot occupancy during hour t

$\pi(t)$ = Parking rate per hour parked

α = Charging rate per kwh
P_c = Power demanded
P_g = Power sold to the grid
P_v = Power produced by PV
P_d = Power bought from the grid
ρ = Price of electricity (12 cents per kwh)
SOC = State of charge of garage battery
SOC_{min} = Desired minimum SOC boundary
SOC_{max} =Desired maximum SOC boundary
P_{smin} =Minimum outflow power from battery storage
P_{smax} =Maximum outflow power from battery storage

In this problem some of the constants have an assumed value. The parking rate is five dollars per hour per vehicle. The charging rate per kwh is fifteen cents. In the United States, the average price of electricity is twelve cents per kwh[4], so the price of electricity is twelve cents per kwh. The power outflow constraints are -100 and 100 and the SOC constraints are 0.1 and 0.9. P_v in this problem is a 1 by 24 matrix representing the power output from solar panels over twenty-four one hour intervals starting at 9pm. For the first six and last six hours, the power produced equals zero. During the twelve hour period in between, the power output $y = 50\sin(x)$ where x is a 1 by 24 matrix generated by MATLAB function linespace(0,π,12).

VII. Results

When this function with the necessary constraints are solved using MATLAB, optimized values for the power variables are determined.

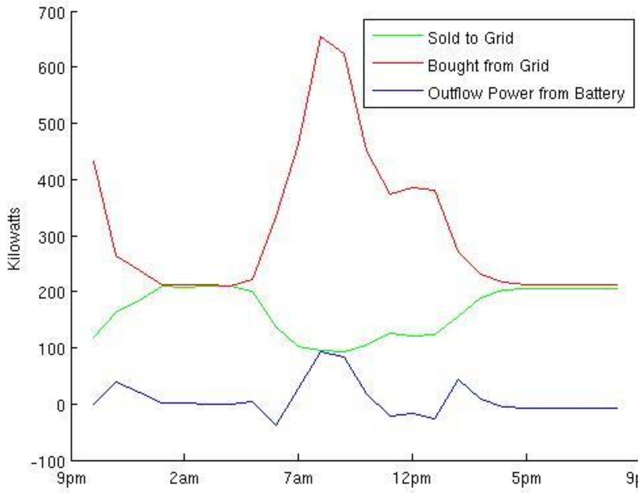

Fig. 5 Optimized power flow

Fig. 5. displays three different power trends. One line shows the amount of power that is to be purchased from the grid for optimum power flow. Another shows the amount of power that is to be sold to the grid. The third line shows the amount of power that is released from the battery. This graph can be simplified as shown below

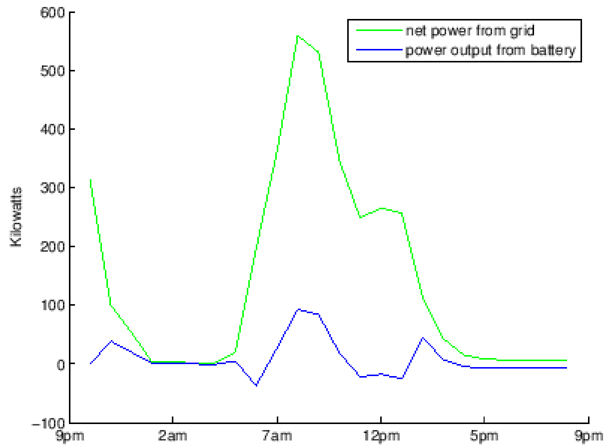

Fig 6. Optimized power flow with net values

Fig. 6. depicts an optimum power flow between the power grid, battery, and consumers. In this depiction, the power that is sold to the grid is subtracted from the power purchased from the grid, creating a net value. At no point does the power being sold to the grid exceed the power being purchased, therefore this new resultant line can labeled as the net purchased from the grid.

VIII. Conclusion

The results of this project is a power flow that is to optimize profits for charging companies. The results in this project are formed around data and assumptions that are specific to this project. The assumptions made to as a reasonable extent as possible and could possibly be referred to in the future for optimization or further research.

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