Optimal Placement of Charging and Swapping Stations for Electric Vehicles

A Thesis Submitted in partial fulfillment of the requirements for the degree

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Abstract

To counter the growing effects of climate change and greenhouse gas emissions, launching Electric Vehicles have become an unavoidable task in the current scenario. With numerous advancements and study in the direction to substitute fossil fuel based vehicles to EVs there is an urgent need to plan EV charging station facilities across major cities to properly deploy the EVs to the market.

It is a challenging job to plan and examine many aspects of the deployment of Charging Stations all across the city. However, carefully considered and optimized selections can lead to the successful and effortless adoption of alternative fuel vehicles. Several essential requirements and challenges that these vehicles may face should be addressed in the final judgments.

An optimal planning strategy can meet charging demand while also lowering the charging station's building cost.

Contents

Introduction

As Government bodies have adopted cleaner fuel consumption to reduce greenhouse gas emissions in the current day, there are high demands of substitution of fossil fuel based vehicles to Electric Vehicle in the near future. In a city like Guwahati, India with minimal existing charging station facility it is observed that there is a lack of motivation for fossil fuel based vehicle owners to switch to more clean fuel based vehicles like EVs. For the managing body to take decisions on deploying appropriate number of charging stations and their locations, proper planning need to be made that emphasis on each and every practical challenges that it might face in future.

The right placement of charging stations may not only help the vehicle owners to upgrade to EVs but also increase the driving range of electric vehicle in a single charge. This will directly impact on the battery's 'State of Charge' and improve the battery life commendably.

<u>Types of Electric Vehicles and Electric Vehicle Charging Stations</u>-

Among other developed technologies, EVs have attracted a lot of interest as an alternate mode of transportation that is becoming a component of the modern transportation system. The EVs are mainly classified into three types, based on the source of electricity for the vehicle's propulsion, namely-[1]

a) Hybrid Electric Vehicles(HEVs)
b) Plug-in Electric Vehicles(PEVs)
c) Fuel Cell Electrical Vehicles(FCEVs)[1]

HEVs use both an electric propulsion system and an internal combustion engine for propulsion. Compared to conventional internal combustion engine vehicles, this is done to obtain higher fuel economy, lower emissions, and a more extended driving range, among other benefits.[1]

The BEV is powered entirely by rechargeable batteries and has an electric propulsion system. PHEVs have an electric propulsion system powered by a battery, but they also have a gasoline engine that can be utilized as a backup if the battery runs out. FCEVs have an electric propulsion system that uses fuel cell technology instead of a battery, or in addition with a battery or supercapacitor. [1]

Electric vehicle supply equipment (EVSE) is an essential element of the charging infrastructure for electric vehicles. It provides EVs with electrical energy for charging from various energy sources. Its classification is determined by many parameters, including the type of power supply, charging station integration with the power grid, charging power levels, charging infrastructure, mobility, and power flow direction. The following is a classification of EV charging stations based on many factors. [1]

a) Alternating current (AC) power supply based EVCS
b) Direct current (DC) power supply based EVCS

Types of Charging Ports

Slow charging- Constant Current (CC) charging uses a single low-level current to charge an exhausted battery. The current level is set at 10% of the battery's maximum rated capacity. Nickel-cadmium and nickel-metal hydride batteries are the ideal choices for this method of charging. If the battery is overcharged, gassing and overheating may happen. In Taper Charging, little current is applied to compensate for the battery's self-discharge. Taper charging uses uncontrolled Constant Voltage (CV) charging, which can cause catastrophic battery damage if done incorrectly. On the other hand, Float charging uses the Constant Voltage(CV) approach below the battery's upper limit. This charging method is suited for lead-acid batteries and is commonly used for emergency power backup systems. [1]

Rapid Charging - Since Lithium-ion batteries have better power and energy densities than traditional batteries, most commercial chargers employ the Constant-Current(CC) & Constant-Voltage(CV) charging approach to charge them. The CC-CV technique has the advantage of limiting charging current and voltage through a battery controller, which prevents over-voltages and reduces thermal stress. A CC is used to charge a battery until it reaches a pre-defined voltage level, and then a CV is employed to attain a termination condition. Charging in CC mode is faster than charging in CV mode. Over-voltage charging can cause b-cell loss. Hence the CV mode is employed to prevent it. [1]

Literature Review

In the previous studies, researchers have worked to address major problems that are encountered in finding the right method to place charging stations

In the study proposed by Henrik et al, the possibility of an Electric vehicle running out of energy without being given a chance to reach the nearest charging station is emphasized as the top priority and minimizing the total number of charging station with keeping this constraint in mind. As inside an urban city it is more likely that an EV owner may consider a round trip more than a trip with distinct initial and final positions. Henrik's work focused on Non-Urban & Long distance non-cyclic trips.[2]

The traffic flow behavior & data is considered using link flow models, which is the average number of vehicles travelling across each of the links in the known network using sensors such as pneumatic tubes.

An iterative approximation technique using Route-Node Coverage method is adopted in Henrik's study. A "random walk" is done and the distance walked is measured continuously. As soon as this measured distance crosses a certain limit, a charging station is allocated at that place. The distance variable is reset to 0 and the process is repeated until sufficient iterations. As a result, a map consisting charging stations placed at constant distance is obtained. The problem of a vehicle running out of energy with not a charging station in its driving range is hence solved here. But, this may not be the optimal number of charging station.

The major drawback in this approach was the scarcity of resources. Developing nations like India, there are very limited funds to develop the infrastructure.

Hence, with this huge number of charging facilities it becomes infeasible for the governing authority to take actions.

Huag Kai et al observed in the most reserces done before, demand is take in discrete points, but this is not particularly true. Because demand can be anywhere Hence only partial coverage is addressed.[3]

The approach given in his paper was to use 'Lease common demand coverage units(LCDCUs)' that either cover the candidate's location or do not cover it at all. Now another question may arise that how the demand is defined. In Huang Kai's research, each road weight is taken as road length multiplied by road traffic. Then minimize the total cost of charging stations with constraints like each point is covered by one charging station. Fast and Slow charging stations are allocated in Huang Kai's work. Since fast charging stations have larger coverage than a slow charging station as per convention, both fast and slow charging stations are fitted such that there is the least common coverage area and the least uncovered area.

Another study by Ying-Wei Wang et al gives an approach to use Mixed Integer Linear Programming to solve the charging station placement problem. The main objective taken in this approach is that a vehicle starting from one node should have sufficient if not less amount of fuel to cover the distance to next charging station else it shall refuel to current charging station only. [4]

As linear models focusses on maximizing/minimizing each objective functions in the constraints, which may not give global optimum with non-ideal combinations of objectives. It is in this context Heuristic Algorithms are adopted to get the global optimum.

Yantao Huang el al's study, assumes that most Electric Vehicle owners wish to charge their vehicles during the journey or on highways. Aiming to increase the EV owner's profit and convinience, the traffic congession is taken into consideration as a deciding factor for an EV owner to charge a vehicle at a particular charging station. On the other hand, Charging station profit is also maximized by analyzing appropriate number of charging cord and session of chargings. [5]

Another study by Long Pan et al, worked on developing an algorithm that analyse the behaviour of EV owner in charging his electric vehicle. After the analysis, the coverage of the charging station is taken into consideration for optimal placement. Then a case study is done on a large scale of Bejing metropolitian to validate the results. from the study it is evident that an increase in the home charging facility may decrease the missed trip chances. [6]

The introduction of Electric Vehicles in the market shall bring an additional load to the existing electrical power grid system. While coverage area of fast charging station have a direct impact on the load and disturbances generated by charging stations. Locating Charging station problem needs to consider this issue. In Jian Liu's work this problem is addressed and a model is given in the accordance for the same. [7]

Methodology

Definitions and Notations-

I. Roads as edges- A digraph is used and the major road network is taken as edges and the road length (i.e. length between two end points of a road) is taken as the edge weight.

II. Road end points as Nodes- The meeting point of two roads are taken as Nodes of the graph

III. Distance between two nodes- The shortest distance between two nodes is taken as the distance between two nodes. To calculate the shortest path, Dijkstra's Algorithm for two pair shortest path is used (as edge length is always positive, hence Dijkstra's Algorithm works well here)

IV. Distance between a point on an edge(AB) and a node(C), $d(x_{AB}, c)$- This distance is calculated by taking the minimum of the distances obtained from each node of given edge to the node(C).

V. Charging Station Location(c_j)- As charging station can both present on an edge or a node, hence the charging station location is specified accordingly. The charging station location can range as integer values that exists as distance between two nodes of the edge. For initialization, the charging station location is taken randomly over the map.

VI. Edge based demand to Node based demand- In worst case scenario, the EV owner decides to go to refill when his vehicle battery meter falls below a threshold limit. Now he should be able to reach the nearest charging station without exhausting its battery charge. As this work focuses on demand based placement of charging station the data for demand over an edge is converted to node based by dividing demands on an edge to the two adjacent nodes and subsequently generating the demand weights.

VII. For each demand point, the distance to its nearest charging station should be minimized according to its demand weight. Hence, a function 'Best cost' is defined as-

$$\text{Bestcost} = \sum_{j=1}^{m}\sum_{i=1}^{n} D_i * d(x_i, c_j)$$

Where,

If $x_i = demand\ node\ location$

$c_j = charging\ station\ location$

$D_i = demand\ weight\ of\ the\ demand\ node\ 'i'$

Optimization-

Genetic Algorithm(GA) is used to optimize the location of charging station to get the best possible combination.

- Each gene of a chromosome contains the information of location of a single Charging station
- Each chromosome carries the location of all the charging stations and their respective locations
- We define the fitness function by calculating the objective function for each chromosome and saving the results to 'Best cost'.

- The chromosome length is varied from 2 to 8 which is also the number of charging stations.
- The population size is taken 50 and the parents for GA operations are randomly selected from the pool of best population obtained the least fit are discarded at every iteration
- The proportion of the children to the main population is kept to be 1
- One-point crossover is chosen to operate on the two parents selected, the point of crossover is chosen randomly through random module
- For mutation operation $\mu = 0.30$ is taken for this problem(because on an average, to change one gene out of 4 we need to keep μ above 25%)
- While iterating it is seen that the solution converges at 500 iterations

<u>Results & Discussion</u>

Figure1(a), 1(b) and 1(c) are semi-log plots with log ('Best cost') vs Iterations performed. The figures show the convergence of the 'Best cost' function over the run of 500 iterations for different number of charging station chosen. The 'Best cost' obtained for varied number of charging stations are-

Number of Charging stations taken	'Bestcost' function value
2	83.83
3	65.02
4	52.67
5	42.87
6	37.56
7	32.06
8	27.42

Figure 1(a)

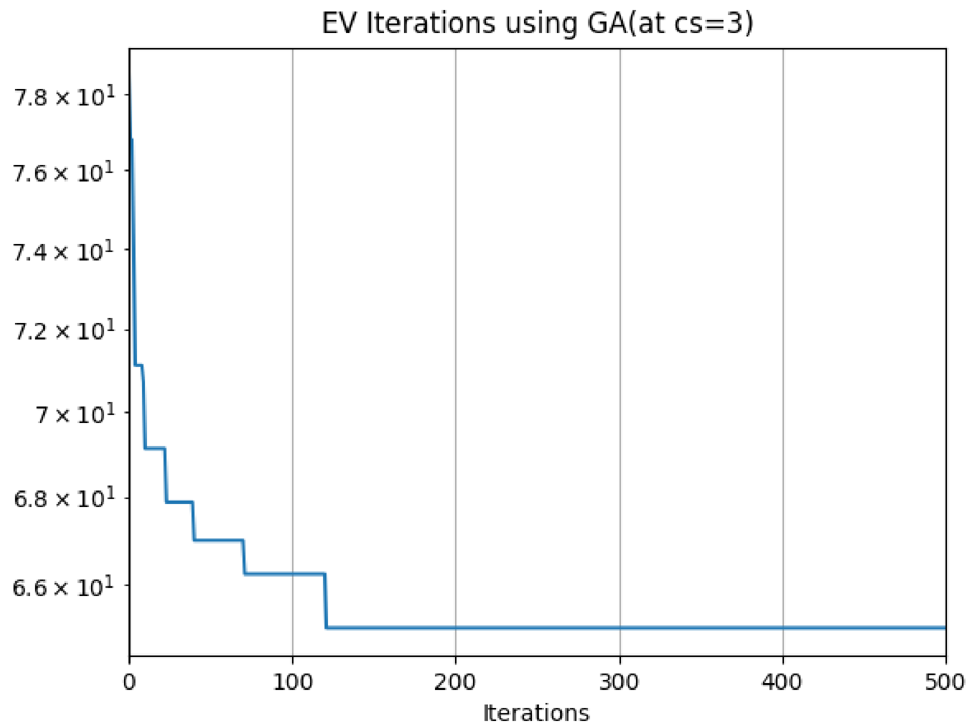


Figure 1(b)

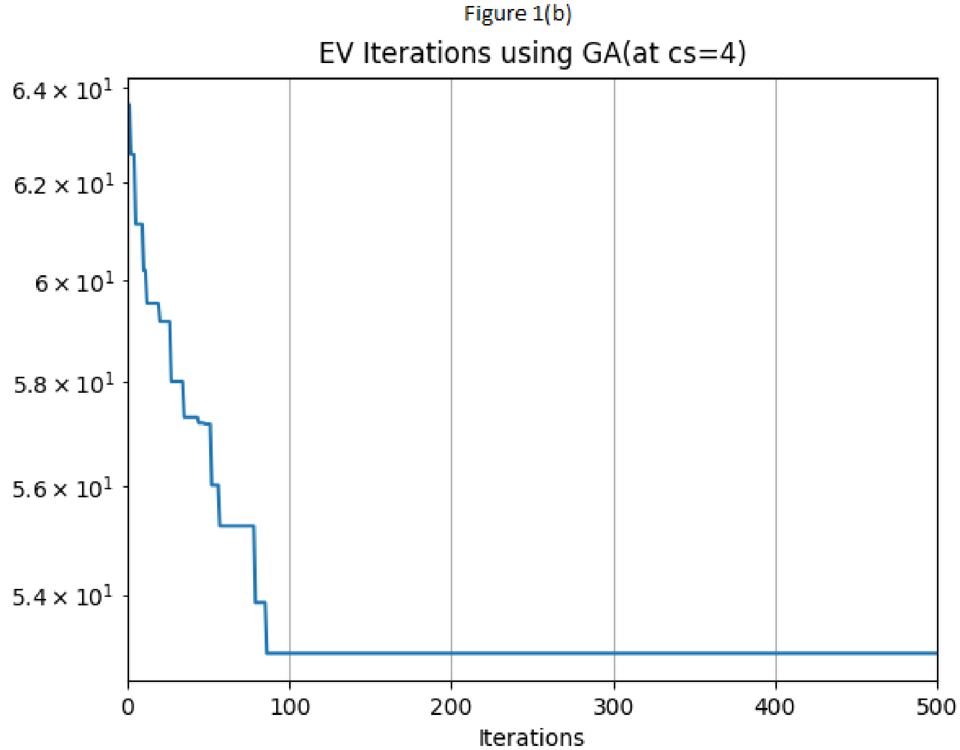


Figure 1(c)

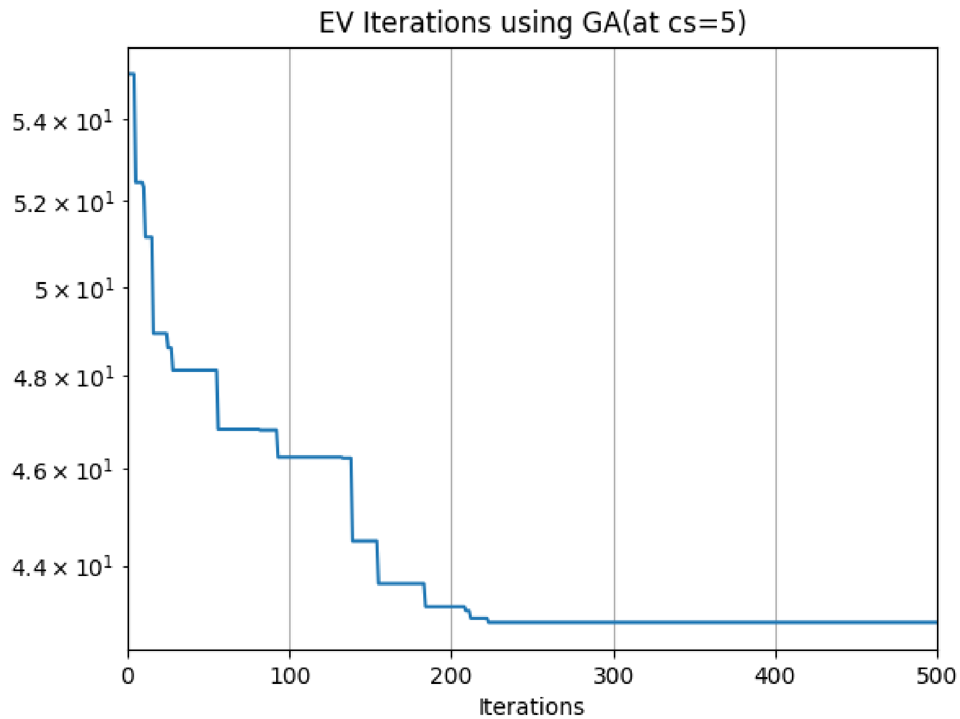


Figure 2(a), 2(b) and 2(c) shows the optimized location of charging stations in the Sioux Fall's plot of 24 nodes.

Figure	Number of charging station placed
Figure 2(a)	3
Figure 2(b)	4
Figure 2(c)	5

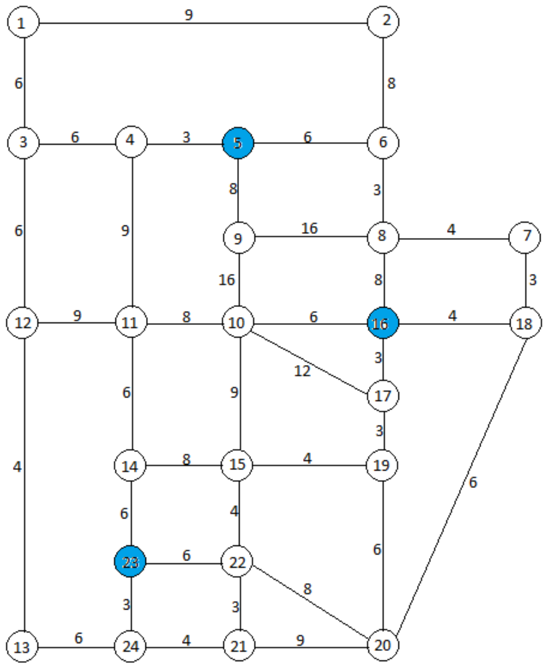


Figure 2(a)

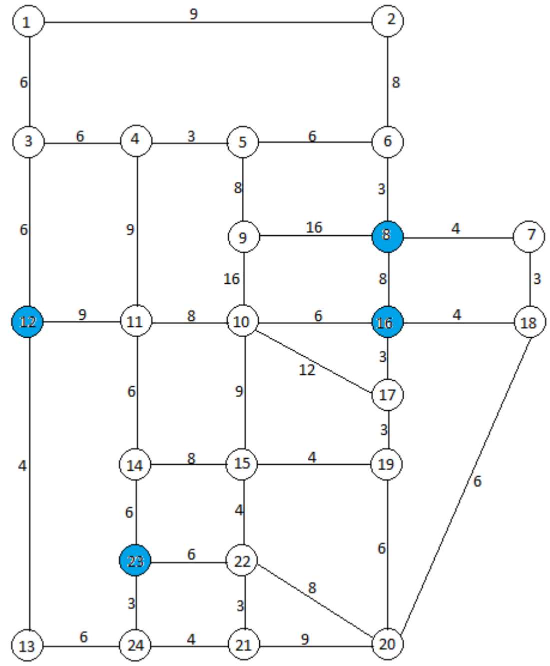


Figure 2(b)

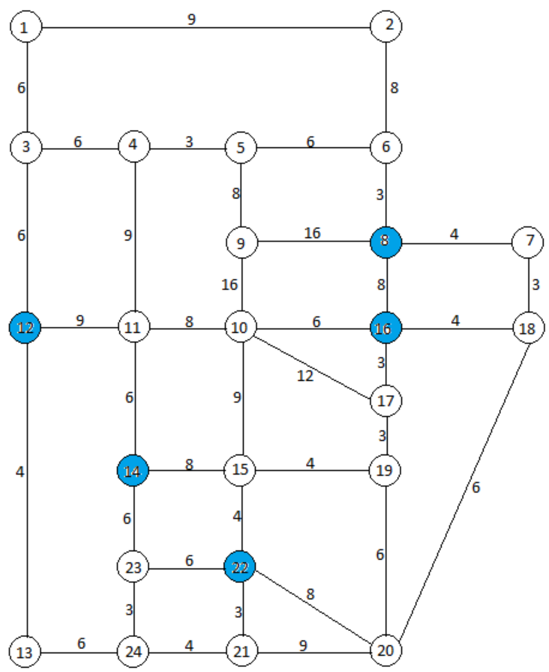
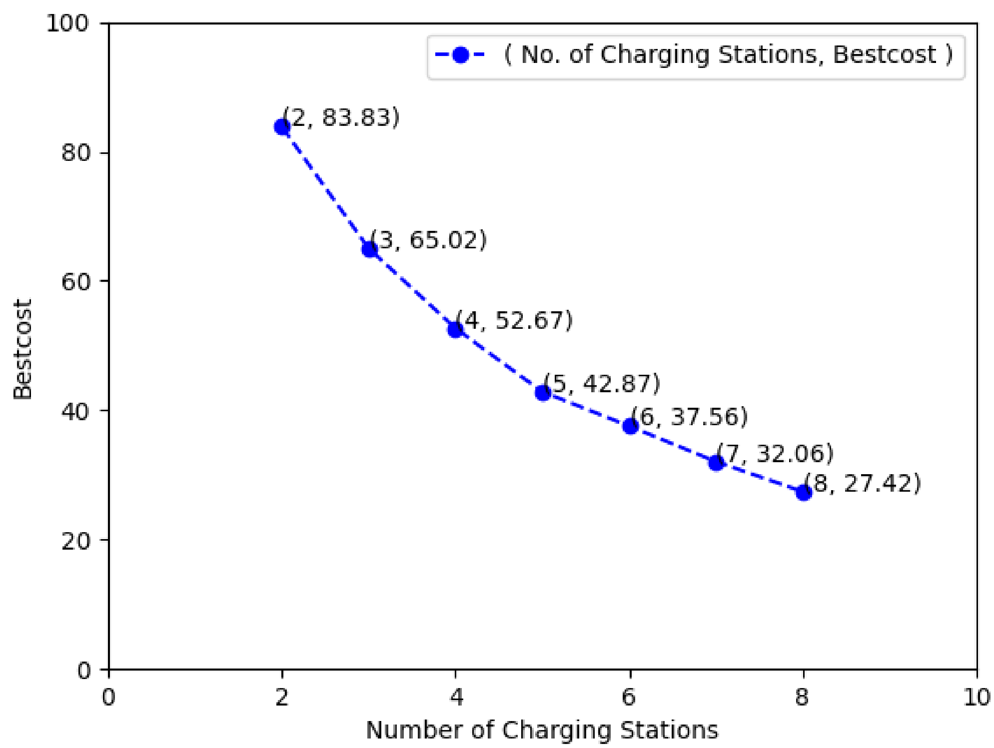


Figure 2(c)

Figure 3 is a plot of 'Best cost' vs the number of charging stations. 'Best cost' gives the overall cost of reaching the nearest charging station from the current position of an EV owner. It is clear from this plot that as the number of charging stations are increased for placement, the 'Best cost' is decreased.

Figure 3



Conclusion

Finding good optimal outcomes for this problem using revolutionary meta-heuristic techniques is quite challenging. There are numerous approaches of allocating charging stations based on various objectives. However, employing Genetic Algorithm to solve this problem is a more powerful technique than using linear models. The demand points data generated have a significant impact on the accuracy of CS location prediction.

Future steps may include study in mainly three directions.

- ✓ Firstly, more accurate and easy data collection for predicting the promising results needs more attention.
- ✓ Secondly, considering more practical problems that may be encountered over the time should be taken into account while solving the problem.
- ✓ Thirdly, the EV driver behavior need to be studied more closely through some agent based simulations which may bring more practical validation to the work.

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