Consumer Perspective based Placement of Electric Vehicle Charging Stations by Clustering Techniques

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***Abstract*—Environmental constraints and shortage of fossil fuel has led to emergence of Electric Vehicles (EVs). As EVs take more time to charge as compared to refueling of conventional vehicles therefore deployment of Fast Charging Station (FCS) is necessary for public acceptance. Certain factors like geographical distribution, convenience of EV consumers needs to be considered for siting of FCS. In this paper, the objective is to minimize social cost by minimizing the distance travelled for charging EVs. Number of FCS to be located are determined by calculating the energy demand of EVs and the service radius of FCS. K-mean and fuzzy C-means clustering is used to find the location of FCS. Center of clusters formed are the location of FCS and the number of clusters formed are the number of FCS to be located in an area. Service area of each FCS is divided using Voronoi diagram. The effectiveness of the proposed approach is tested on IEEE 123 bus distribution system.**

***Index Terms*—distribution systems, electric vehicle, fast charging station (FCS), k-mean clustering, fuzzy c mean clustering, vornoi diagram.**

I. Introduction

Environmental concerns, energy crisis and development in battery technologies has seen the rapid growth of Electric Vehicles (EV). A development plan with the aim of increasing EVs in developing countries has been proposed. Utilization of EVs has the potential to reduce pollution, save fuel cost for EV owners. Compared with refuelling of gasoline vehicles, EVs take more time to charge. There are various level of charging for EVs available now a days. Level of charging [1] are classified on the basis of rate at which batteries are charged as shown in Table I. EVs are costly compared to conventional vehicles and charging time of EVs is more compared to refueling of conventional vehicles. Though EVs can be charged at home or at office via level 1 and level 2 charging. But during emergency conditions or for long trips, EVs has to be charged at much faster rate therefore FCS has to be installed. For popularization of EVs, fast charging station has to be installed in the planning region. Inappropriate siting of FCS may have negative effect on the development of EVs.

TABLE I
Level of Charging

Level	Battery Capacity (kWh)	Power Level	Charging Time (hours)
Level 1	5-15	1.4kW (12A)	4-11
	16-50	1.9kW (20A)	11-36
Level 2	5-15	4kW (17A)	1-4
	16-30	8kW (32A)	2-6
	3-50	19.2kW (80A)	2-3
Level 3	20-50	50	0.4-1
		100	0.2-0.5

Number of research studies have been carried out earlier for the placement of EV charging stations. In [2], location of FCS has been determined by considering environmental factors and service radius of FCS. In [3], a multiobjective method is proposed which ensures charging service and reduces power losses and voltage deviations. In [4], a multiobjective problem is solved using differential evolution algorithm to reduce power losses, improve voltage stability and to reduce charging cost. Siting and division of service area of FCS is done with the objective of minimizing social cost that is cost incurred due to travelling for charging EVs in [5]. In [6], road information has been quantified into data points and then they are converted into demand cluster by hierarchical clustering analysis. Then optimization techniques are applied on the demand clusters to meet the supplies and demands. In [7], optimal configuration of centralized charging stations are placed under the condition of large scale penetration of EVs with an objective of minimizing total transportation distance.

Previous research focused on placing FCS with the objective of minimizing total transportation distance, power loss and voltage deviation. Some researchers have tried to minimize the planning, operation and maintenance cost of FCS. The existing research does not determine optimal number of FCS based on the charging demand of EVs. In some literature, the number of EVs has been forecasted in the near future but that do not give actual number of EVs for planning the siting of FCS. Even if the number of EVs are estimated, then also number of FCS will not only depend on charging demand of EVs but also on the service radius of FCS.

Therefore in this work, to determine the number of FCS in a planning region number of EVs are estimated based on the number of households in the planning region for which secondary side of IEEE 123 distribution system is modelled to calculate the number of households. K-mean and fuzzy c means clustering are used to form the number of cluster and

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centroid of these clusters are the location of FCS. Voronoi diagram is used to determine the service radius of each FCS.

II. Estimation of Number of FCS

Investor's cost and convenience of consumer will depend on number of FCS. To estimate the number of FCS in a planning region, firstly electric vehicle population is estimated by estimating the number of households in the planning region, so the secondary side of IEEE 123 bus distribution system is modified to account for number of households. Secondly, EV population is used to calculate charging demand and subsequently the desired quantity of FCS.

A. Estimation of EV population

Number of households are estimated by modifying IEEE 123 bus distribution system. For this spot loads of distribution system is replaced by equivalent residential loads [8].

- Spot loads ranging from 44-72 kVA are replaced by 10 residential houses supplied by 50 kVA transformer.
- Spot loads ranging from 22-36 kVA are replaced by 5 residential houses supplied by 25 kVA transformer.

Total number of residential houses obtained by replacing spot loads with their equivalent residential houses are the number of households in the planning region. Number of EVs in a planning region will depend on the number of households, penetration of EV and the number of vehicles per household. EV population is calculated by the equation (1).

$$N_{EV} = N \times p \times \alpha \tag{1}$$

where

N is number of households in planning region
p is penetration of EVs
α is number of vehicles per household

According to National Household Travel Survey (NHTS) 2009 [9], each residential house has 1.86 vehicles per household and it has been assumed that the penetration of EV ranges from 0-50%. In this study it has been considered as 42% as Union of concerned scientist states [10] that 42% of US household can use today's EV.

B. Charging Demand Prediction of FCS

Electricity demand of EV per day will depend on EV population, power consumption of EV and the distance travelled by the EV per day [5]. Let P_{avg} is the average electricity demand of an EV per day.

$$P_{avg} = P \times r \times c \tag{2}$$

where

P is the power consumption of EV in kWh/mile.
r is the average distance travelled by the EV in miles.
c is the charge cycles per day.

Total electricity demand of EVs in a planning region is given by equation (3)

$$W = P_{avg} \times N_{EV} \tag{3}$$

The number of charging station N_{FCS} required in a planning region can be calculated from equation (3) as:

$$N_{FCS} = \beta \frac{W}{P_{FCS} T_{EV}} \tag{4}$$

where

β is the adjustment factor of FCS
P_{FCS} is the capacity of FCS
T_{EV} is the time needed to charge EV to its full capacity

III. Siting of FCS

In a planning region, the objective is to locate FCS such that the total distance travelled by the EV owners for charging to its nearest FCS should be minimum. Therefore the objective function to be minimized is given as:

$$min\ F = \sum_{i=1}^{N_{FCS}} \sum_{j=1}^{N} \lambda \sqrt{(x_i - a_j)^2 + (y_i - b_j)^2} \tag{5}$$

$$\lambda = \begin{Bmatrix} 0 & i^{th}\ FCS\ is\ not\ the\ nearest\ FCS\ to\ j^{th}\ house \\ 1 & i^{th}\ FCS\ is\ the\ nearest\ FCS\ to\ j^{th}\ house \end{Bmatrix}$$

From equation (5), it can be deduced that the clusters of houses are formed with FCS lying in the center of the clusters of houses. Clusters have to be formed such that the total sum of distance within the clusters between households and FCS has to be minimum. Therefore clustering analysis of the planning region is done. In clustering or cluster analysis, sets of objects are grouped together which are more similar than those objects lying in other groups. In this study, clustering of households is done that are closer to certain FCS than other FCS. Location of FCS is the centroid of clusters formed. K-means clustering is the simplest and most popular clustering technique. Another clustering technique, fuzzy c means clustering is used for the comparison of locations of FCS obtained from two methods.

A. K-means Clustering

K-means clustering is the simplest unsupervised learning algorithms that solves clustering problems. K-means clustering [11] also known as hard clustering classifies a given data set into K clusters so that the within-cluster sum of squares is minimized. Partitioning the objects into mutually exclusive clusters (K) is done by it in such a fashion that objects within each cluster remain as close as possible to each other but as far as possible from objects in other clusters. There are various ways to find optimum number of cluster k. In this study, number of clusters are the number of FCS that has been already calculated. This algorithm minimizes squared error objective function given in equation (6). Algorithmic steps for calculation of location of FCS is given in algorithm (1)

$$J_k = \sum_{i=1}^{k} \sum_{j=1}^{c_j} (||X_i - V_j||)^2 \tag{6}$$

where

$||X_i - V_j||$ is the euclidean distance between X_i and V_j
k is the number of clusters
c_j is the number of data points in j^{th} cluster

k-means uses an iterative algorithm that minimizes the sum of distance from each object to it cluster center for overall clusters. The algorithm moves until the sum cannot be decreased further.
Let $X = \{X_1, X_2, ...X_n\}$ be the set of data points and $V = \{V_1, V_2, ...V_k\}$ be the set of clusters.

Algorithm 1 Steps to find location of FCS using k-means

1: Determine number of clusters using equation (4)
2: Randomly select cluster centers
3: Determine data points that are closer to the cluster centers of all the cluster centers and assign data point to that cluster
4: Recalculate cluster centers using equation (7)

$$V_k = \frac{1}{c_j} \sum_{j=1}^{c_j} X_i(j) \tag{7}$$

5: Recalculate the distance between each data points and new obtained cluster centers and assign data points to new clusters
6: Go to Step 4, if there are no change in centroid of the new cluster centers obtained then **STOP**, otherwise go to step 5

B. Fuzzy c means clustering

Conventional clustering techniques generate clusters and each data point belongs to one and only one cluster. Bezdek [12] introduced Fuzzy c means clustering method in 1981. Fuzzy clustering associates each data point with every cluster using a membership function. The output of such algorithms is a clustering, but not a partition some times. This algorithm is used for analysis based on distance between various input data points. The clusters formed are according to the distance between data points and the cluster centers. Fuzzy c means is a data clustering technique in which every data point of data set has been assigned membership to state its relation with every other cluster [13]. Data points are assigned higher degree of membership to the cluster which has similar properties and lower degree of membership to the clusters that are dissimilar properties. It is based on the minimization of the objective function given in equation (8).

$$J_m = \sum_{i=1}^{k} \sum_{j=1}^{c_j} \mu_{ij}^m (||X_i - V_j||)^2 \tag{8}$$

$$1 < m < \infty$$

where m is any real number greater than one, μ_{ij} is the degree of membership of X_i in the cluster k^{th}. Degree of membership μ_{ij} and cluster center V_j is given by equation (9) and (10) respectively.

$$\mu_{ij} = \frac{1}{\sum_{p=1}^{k} \left(\frac{||X_i - V_j||}{||X_i - V_p||} \right)^{\frac{2}{m-1}}} \tag{9}$$

$$V_j = \frac{\sum_{i=1}^{N} \mu_{ij}^m X_i}{\sum_{i=1}^{N} \mu_{ij}^m} \tag{10}$$

Fuzzy c means is an iterative procedure and it will terminate when $||\mu_{ij}^{(p+1)} - \mu_{ij}^{(p)}|| < \xi$, where ξ is temination criteria whose value ranges from 0 to 1. Algorithmic steps for calculation of location of FCS is given in algorithm (2).

Algorithm 2 Steps to find location of FCS using fuzzy c-means clustering

1: Determine number of clusters using equation (4)
2: Initialize $U = [\mu_{ij}],\ U^{(0)}$
3: Calculate μ_{ij} using equation (9)
4: At k-step: calculate centers $C^k = [c_j]$ with U^k using equation (10)
5: Update U^k and U^{k+1}
6: Calculate value of the objective funtion using equation (8)
7: If $||U^{(p)} - U^{(p-1)}|| < \xi$ or the minimum J_m is achieved then **STOP**, otherwise go to step 4

In this algorithm, relation between data points to each cluster is established by means of a membership function that represents the fuzzy behaviour of the algorithm. U matrix is developed whose elements have values ranging from 0 to 1. It represents the degree of membership between data and centers of clusters. It introduces fuzzy behaviour in the algorithm and is more close to natural technique to cluster the data points. In this problem, each household is associated with every FCS by a membership value. Higher value of membership is assigned to the household in a cluster lying near to the FCS and low membership values are assigned to households that lies far away from that FCS.

After locating FCS in distribution system, the service area of each FCS has been divided using Thiessen polygons also known as voronoi diagram [14]. Voronoi diagram is often used to solve the distance related geometric problems. It has been widely used for geospatial facility analysis problems. Vornoi diagram divides a plane into n hyperplanes containing exactly one generating point such that the points lying in that hyperplane are nearest to that generating point. Here generating points are the location of FCS in planning region.

Total annual distance travelled for charging the EVs to the nearest FCS and annual social cost are calculated to compare the two proposed methods for finding the location of FCS in distribution system. Social cost is the total energy consumption cost for travelling to the nearest FCS by the EV owners for charging EVs. Annual social cost is given by equation (11).

$$C_{SC} = D_{avg} \times P \times C_{re} \tag{11}$$

where

D_{avg} is total annual distance travelled for charging EVs in miles
P is total energy consumption in kWh/mile
C_{re} is the rate of electricity in Rs/kWh

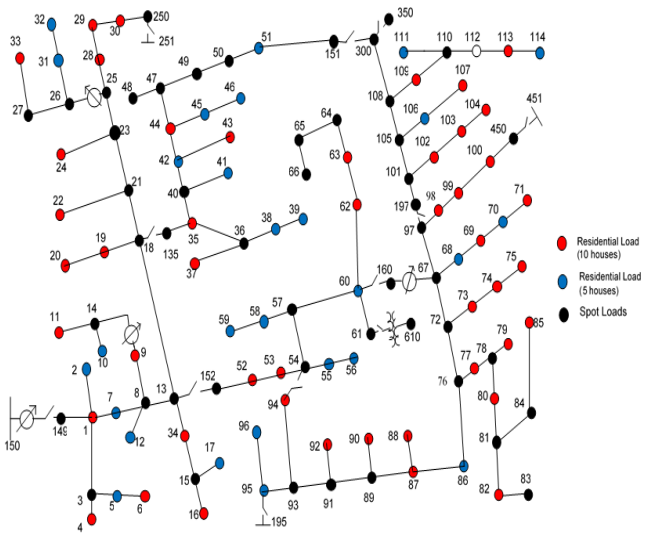

Fig. 1. Modified IEEE 123 bus distribution system

IV. Simulation and Results

Standard IEEE 123 bus distribution system [15] is used to test the effectiveness of the proposed approach to find the location of FCS. 85 nodes out of 123 nodes are the spot loads and 78 spot loads are replaced with equivalent residential loads having 10 households for spot load ranging from 44-72 kVA and 5 households 22-36 kVA. Total 625 households are obtained by replacing spot loads with residential loads. Modified IEEE 123 bus distribution system that accounts for residential loads is shown in Fig. 1. System coordinates are obtained with the help of line data. Parameters required for calculation of number of FCS to be located in IEEE 123 bus distribution are obtained from NHTS (2009). Number of EVs in the planning region comes out to be approximately 500. Values of all the parameters are given in table IV. It has been assumed that the number of EVs that a FCS can charge simultaneously is 10. With help of these parameters, power consumption of all the EVs in the system per day is calculated which is approximately 1260 kWh and the number FCS to be placed are 6.

In this study, random locations of six FCS are generated and service area of each FCS is divided using voronoi diagram. Total distance travelled by the EV owners to reach nearest FCS is calculated using equation (5). The location and service area of every FCS is shown in Fig. 2.

The location and service area of each FCS determined using k-means clustering and fuzzy c means clustering and are shown in Fig. 3 and Fig. 4 respectively. Ordinates and abscissa of FCS in distribution system is given in Table III and Table IV respectively.

Total annual distance travelled by the EV owners for charging EVs and total annual cost incurred for travelling are calculated. It has been considered that energy consumption by the EV is 0.29 kWh/mile and the rate of electricity in Rs/kWh is 6.

From the table V, it can be seen that k-means clustering gives best result for this problem while fuzzy c means clustering also gives satisfactory results. Total savings when FCS are placed using k-means clustering is 44820 rupees annually and difference in annual distance travelled is 25759 miles when compared with random location of FCS in distribution system. Total savings when FCS are placed using fuzzy c means clustering is 36145 rupees annually and difference in annual distance travelled is 20773 miles when compared with random location of FCS in distribution system.

TABLE II
Parameters for Calculation of Number of FCS

Parameter	Description	values	unit
N	Number of households	625	-
p	penetration of EVs	42%	-
α	Number of vehicles per household	1.86	-
P	Power consumption of EV	0.29	kWh/mile
r	Average distance travelled	28.97	mile
c	Charge cycles	0.3	-
β	Adjustment factor	1.4	-
P_{FCS}	Capacity of FCS	600	kW
T_{EV}	Time needed for each recharge	0.5	hour

TABLE III
Coordinates of FCS obtained using k-means clustering

No.	Abscissa	Ordinate
1	4150	979
2	2496	1418
3	1244	3356
4	4269	2468
5	2406	2825
6	1186	1633

TABLE IV
Coordinates of FCS obtained using fuzzy c means clustering

No.	Abscissa	Ordinate
1	4179	1378
2	4302	2653
3	1171	1475
4	2339	2765
5	1269	3359
6	2625	1266

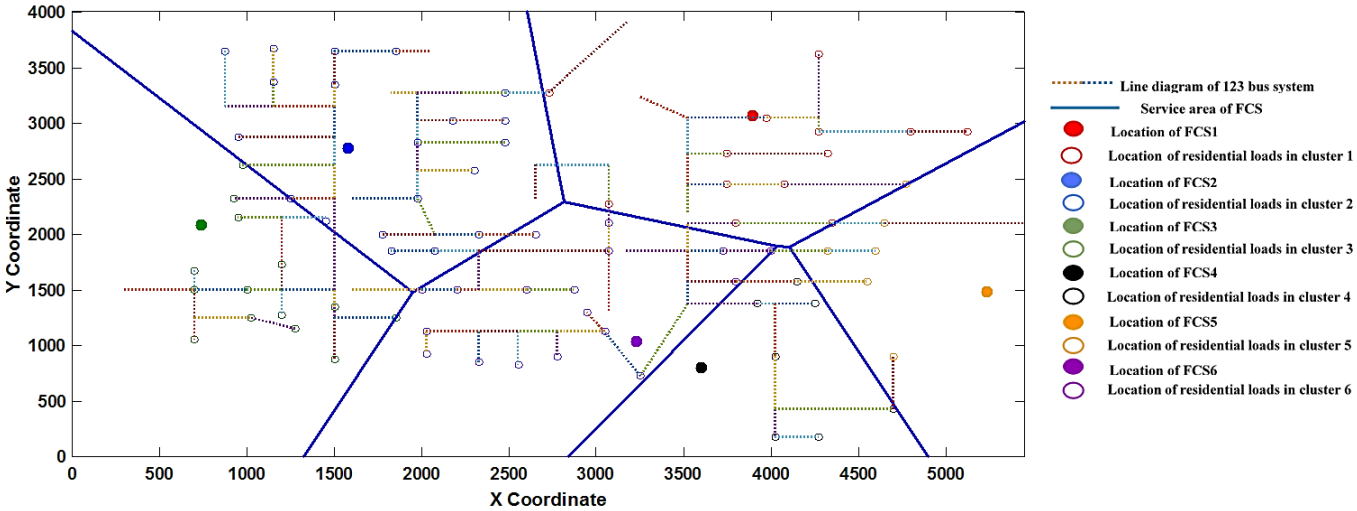

Fig. 2. Random location and service area of FCS

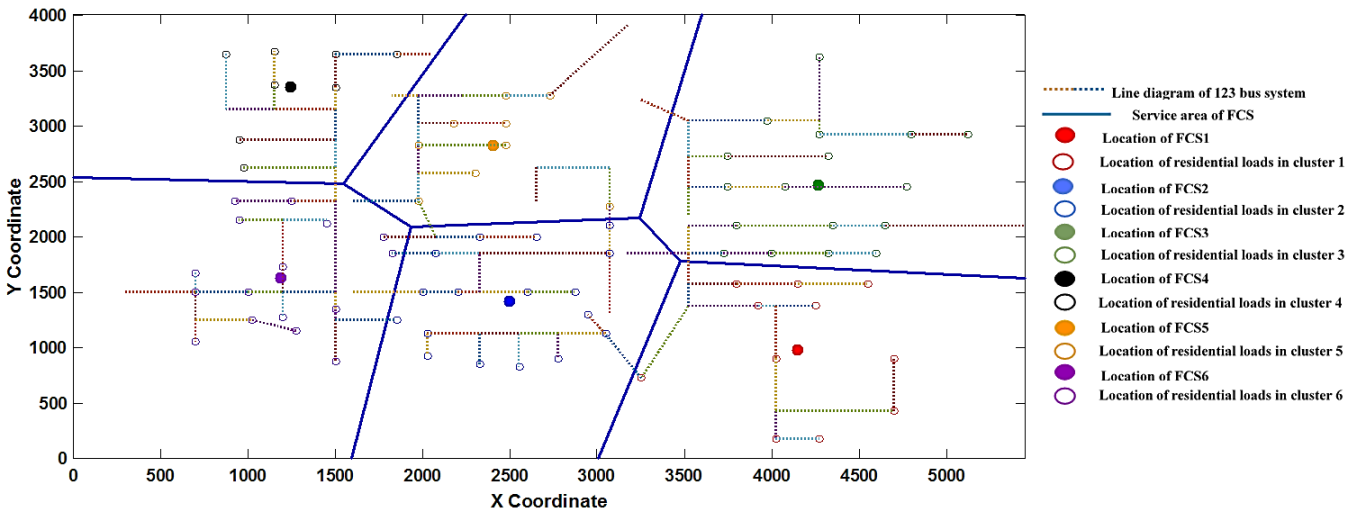

Fig. 3. Location and service scope of each FCS using k-means clustering

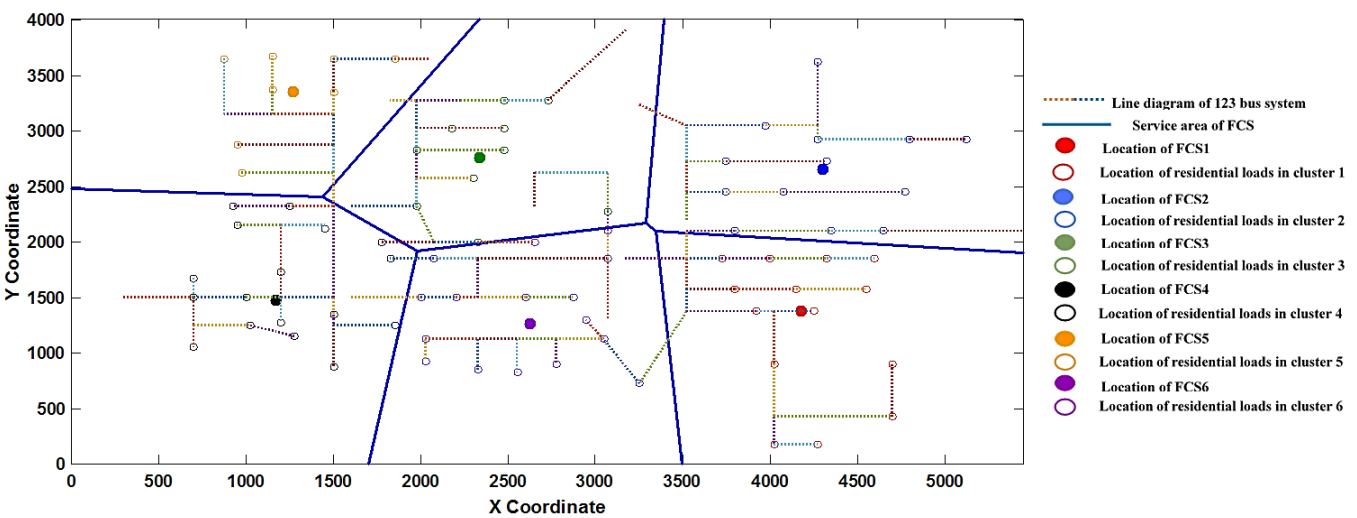

Fig. 4. Location and service scope of each FCS using fuzzy c means clustering

TABLE V
TOTAL ANNUAL COST FOR CHARGING EVS

Method to locate FCS	Average Annual Distance in miles	Annual cost in Rupees
Random	86323	150202
k-means	60564	105382
fuzzy c means	65550	114057

V. CONCLUSIONS

EVs are growing rapidly and for public acceptance fast charging stations has to be placed in the planning region. To solve the optimal location problem of EV FCS, number of FCS required in distribution system is calculated by calculating the total charging demand of EVs in the planning region. To calculate the total charging demand of EVs, number of EVs are estimated by estimating the number of households which in turn is estimated by modifying IEEE 123 bus distribution system. Location problem is formulated such that the distance travelled by the EV owners can be minimized. k-means clustering and fuzzy c means clustering techniques are used to find location of FCS. From the results, both k-means and fuzzy c means clustering perform satisfactorily and k-means gives the best results. For future work, traffic data and electrical components like power loss and voltage deviation will be considered for locating the EVs in distribution system.

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