A hybrid algorithm for planning public charging stations

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***Abstract*—Green mobility solutions are receiving currently an enormous attention. Indeed, during last years, electric vehicles, being part of the field of the smart-grid, entered the automobile market of the whole world. This technology requires an effective deployment of charging stations of electric refill since the main problem in this system remains over the duration of refill of the batteries. In this work, we propose an optimized algorithm to locate electric charging stations. The main task of the algorithm is to find the best site of charging stations locations so as to minimize loss on the way to the charging station, as well as minimize investment cost, we take into account several constraints to find the optimal number and placement of charging station . Our hybrid algorithm with improved K-means clustering and genetic algorithm can be used to find optimal number and place of charging stations.**

Keywords-component; Smart-Grid; electric vehicles; charging stations; genetic optimization; k-means clustring.

I. INTRODUCTION

Economic, security, and environmental pressures are driving countries around the world to electrify transportation, which currently accounts for nearly 72 percent of global oil demand [1]; Electric vehicles (EVs) could play a central role in decarbonizing road transport. But this new type of electricity load will need careful management.

A lot of efforts are done to install the necessary infrastructure such as charging stations, electricity factory and solar panels. It is therefore crucial that the deployment of charging stations be as much as possible in tune with the expected mobility of electric vehicles. It is also important that new variables, specific for electric charging stations, be cast in the problem to be addressed. Although charging at home is the first choice for many EVs owners living in their houses, many other EVs users who don't have private parking places or garages will have to use public charging facilities [2].

In this paper we study the problem of public charging stations deployment through the lenses of optimization. We consider in our study several constraints (installing cost, distance between charging stations and clients, charging stations capacity, etc.). Proposed hybrid algorithm includes improved k-means clustering which is employed to minimize the distance towards charging stations. Then genetic algorithm with a new representation is used to amend result and find optimal place for charging stations with minimal cost.

II. OPTIMIZATION PROBLEM MODELING

Optimization algorithms can be used to find the optimal location of public charging stations with minimizing the sum of users' cost on the way to the charging station and the investments of station's installation.

A. The establishment of the objective function

In order to determine the location of the charging stations, the objective function can be modeled as follows:

$$c = \min(\alpha c_{inv} + \beta c_T) \tag{1}$$

In the equation, c_{inv} is the construction investments cost; c_T is the loss cost of users on the way to the charging station.

α and β =1 represent the weight of each function

- The cost of transportation loss:

$$c_T = \sum_{j=1}^{n} \sum_{i=1}^{m} Cij \times x_{ij} \tag{2}$$

In the formula (2) , $j \in \{1 \dots, n\}$ is the set of customers, $i \in \{1 \in m\}$ is the set of possible locations to establish a charging station CS, c_{ij} is the distance toward charging stations i , and c_T represents the cost of the closeness of client i to the charging station j.

Let X be the binary matrix, such that:

$$x_{ij} = \begin{cases} 1 \text{ if client j is assigned to station i} \\ 0 \quad \text{other wise} \end{cases}$$

- Investment cost of charging station, can be expressed as:

$$c_{inv} = \sum_{i=1}^{m} a_i \times y_i \tag{3}$$

Where m is the number of the charging stations; a_i is the investment cost to build charging station; y_i Decision variable to open or not charging station i.

B. Constraints

The solution feasibility depends on different constraints represented by the following equations:

$$\sum_{i=1}^{m} x_{ij} = 1 \quad (4)$$

$$\sum_{j=1}^{n} dj \times x_{ij} \leq w_{min} y_i \quad (5)$$

(4): ensures that client j is affected only to one charging station.

(5): guarantees that the sum of energy demand d_j is smaller than the charging station capacity.

B. The initial number of charging stations

It is calculated based on the demand d_j of clients and the minimum capacity of charging station (CS) as

$$N = \frac{Q}{w_{min}} \quad (6)$$

Q: The total charging demand of clients

N: The number of charging stations

w_{min}: The minimum capacity of charging station

And

$$Q = \sum_{j=1:n} dj \quad (7)$$

B. Service area partitioning and selection of initial location of the charging station

Based on the estimated number of charging stations, we partition the studied area such that the number of partitions is equal to the number of initial charging station; we initialize the location of charging stations in the center of each small area.

III. PROPOSED ALGORITHM

A. The central idea

In this work we use a hybrid genetic algorithm and k-means clustering to solve the problem of public charging station location. In the proposed method we use an improved k-means algorithm, which includes capacity as one of the constraints for clustering the items to split data to k cluster.

The initial centroids of k clusters are the center of zone mentioned above. The iterative procedure is used to assign the clients to the nearest cluster (station) based on the minimum distance between stations and client such that a cluster's total demand does not exceed the delivery capacity of the station [3].Then, genetic algorithm improves the quality of obtaining solutions with his deferent operators : selection, crossover and mutation.

B. Genetic k-means algorithm for location of charging stations

1. Fitness

The objective function evaluates the performance of each genome in the population, this function takes a genome as input and returns a number that measures the genome's performance

K-means clustering steps:

a) Define k objects (k = number of stations) using (6), and their initial location as initial cluster centers (cluster centers = station location),
b) Measure the distance (Cij) from each vehicles to the nearest cluster center
c) Calculates the new centers for the clusters. These new representatives of clusters correspond to the average of the individuals of the cluster
d) Compute the fitness value using (8).
e) Return to step (b) until two successive iterations lead to the same partition

$$c = \min(\sum_{i=1}^{m} a_i \times y_i) + \sum_{j=1}^{n} \sum_{i=1}^{m} Cij \times x_{ij}) \quad (8)$$

It is important to note that our k-means clustering algorithm includes the constraint of capacity. For that, we calculate the charging demand of clusters $d_k$in each step. If $d_k \geq w_{max}$ or $d_k < w_{min}$ we assign clients to the second nearest station.

We calculate the one-hour demand of each cluster using (9), and table II. This demand depends on the rate of electric vehicles, traffic, charging station capacity and daily driving trip [4].

$$d_k = \sum_{k=1}^{nb} T_k * E_r * CS_{cap} * dur * D_r \quad (9)$$

Where d_k is the demand of charging in cluster k, and nb is is the number of clusters.

2. Genetic code

Every genetic algorithm must have a representation of each member of the population. As depicted in fig 1, the top box represents the genome observed and referenced by the user, this genome is denoted as a vector $g = (s_1,.., s_k)$ where $(s_k = (x_k, y_k)$ is the chromosome for the k_th charging station . The bottom box represents the bit string manipulated by the system

Note that each charging station attribute, namely the center coordinates of the cluster, maps to an N bit binary string. All genetic operations are performed on this bit string [5].

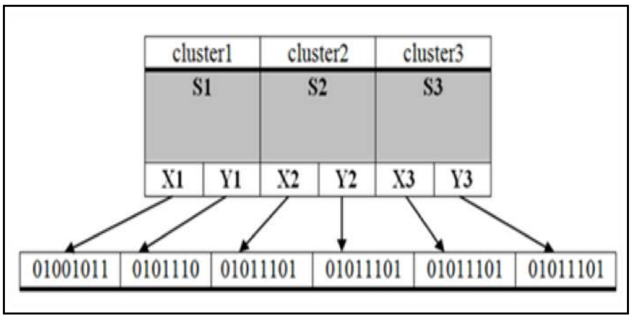

Fig. 1. Genetic code

IV. Experimental Analysis and Validation

In order to provide the algorithm, we study in this section the planning of charging stations in “TAPAS Cologne’’ city, we use our approach to find optimal place and number of charging stations in this area .

The "TAPAS Cologne" simulation scenario describes the traffic within the city of Cologne (Germany) for a whole day; this system computes mobility wishes for an area population generated based on information about travelling habits [6]. In this study we considered the case of a peak hour.

The charging demand and the preliminary positions of charging stations in the initial partitions are shown in the Table below.

TABLE I. NUMBER AND LOCATION OF CHARGING STATIONS

Num of zone	Coordinate of initial stations (km)	Number of vehicles in each zone
1	1.7377 1.0420	308
2	2.1745 0.8284	477
3	1.6407 0.6599	06
4	1.7960 0.8464	05
5	1.1405 1.2469	724
6	1.1166 1.7790	792
7	1.5139 1.3818	160
8	1.7293 1.5490	223
9	2.0691 1.6316	236
10	1.7650 1.7118	02
11	1.4927 2.2097	14
12	1.8235 1.6951	490

As the above table show, there are 3437 electrics vehicles in the development zone. The capacity of every vehicle’s battery is 30 kWh with average of 100 km; electric price is 3.3 Euro. It is supposed that the maximum capacity of charging station is 30% of her minimum capacity wish is 274 Kva and sufficient charging duration (dur) for daily driving 1/4 hours. The investment cost of one charging station (materiel+ installation) is 800 euro.

We found that the maximum number of charging stations is 12. This number can be obtained by solving equation (6).

Matlab is adopted to program our algorithm, equation (9) is taken as the objective function, equation (4), (5) as constraints to initially search the optimal solution, and then the optimal number of charging stations, their locations is shown hereafter.

TABLE II. BEST LOCATION OF EV CHARGING STATIONS

Optimal number of charging stations : 5	
Item	**Location (km)**
Charging station 1	(1.0155 1.1471)
Charging station 2	(0.8566 1.7164)
Charging station 3	(0.3290 1.7686)
Charging station 4	(2.0417 0.8406)
Charging station 5	(1.3139 1.3967)

As can be seen from table I, 12 charging stations were basically located in the gravity center of each partition, by applying our method we tend to reduce this number to only 5 charging stations , their best location are shown in table II.

Table III summarized the results of 400 simulations for different scenario where we vary the capacity of charging stations.

TABLE III. RESULTS

Num of initial CS	CS_CAP (kvA)	Number of CS final	Fitness
12	274	5	4576
18	200	7	6283
33	100	12	10496

V. Conclusion

This paper presents a hybrid algorithm, which includes genetic and k-means clustering algorithm in order to search the best location of public charging stations in a studied area, first an improved k-means clustering witch considered the capacity of charging stations is used to minimize distance toward charging stations; then genetic algorithm is applied to increase space of research and find optimal places of charging stations. Our algorithm searches the optimal location of charging stations with the objective of minimizing both the investment and transportation cost. The test results shows that our model and the method proposed are feasible to find the minimum cost and optimal place for charging stations.

Optimal deployment of charging station for electric vehicles is a heavily studied combinatorial optimization problem, many other factors can be considered to develop our algorithm such as defending the optimal capacity of charging stations by defining optimal number of chargers in charging stations which affect on investment cost and waiting time to refill.

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