Research on Location of Charging Station of Electric Vehicle Based on Improved TLBO

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Abstract—With the rapid development and popularization of electric vehicles, people pay more and more attention to the construction and planning of charging stations for electric vehicles. In this paper, an improved Teaching-Learning-Based optimization algorithm is proposed in the problem of charging station for electric vehicles. From the user's perspective, the objective of optimization is to minimize distance and driving cost. Simulation experiment is carried out for planning an area. The results show that ITLBO can solve this problem with the good stability and fast convergence speed.

1. INTRODUCTION

1.1. Electric vehicle charging station
In recent years, with the increasing use of electric vehicles, there are many research in this area such as the research on load forecasting of electric vehicle charging station[1, 2] and the research in economy[3]. The planning and construction of charging stations for electric vehicles has also attracted the attention of many scholars at home and abroad. Literature[4] is based on the travel chain and plans the construction of charging station from the view of user’s travel demand. Literature[5] uses game theoretical framework to optimize the placement of charging station. Literature[6] plans the charging station according to the weights of Voronoi diagram. Literature[7] optimizes the planning of charging station which is based on the distance traveled. Literature[8] considers the distance and sets a model to plan the construction of charging station.

Because literature[8] only considers one factor, this paper will take the driving cost into consideration on the basis of that literature. Therefore, based on Hu et al.[8], this paper proposes an improved Teaching-Learning-Based optimization algorithm to plan the charging station of EV, taking the distance between the user and the charging station and the driving cost of the user as the objective function.
1.2. Basic Algorithm
Teaching-Learning-Based optimization is a intelligent optimization algorithm proposed by Rao et al.[9, 10] to simulate the process of teaching students and students' learning in real classes. Compared with some intelligent algorithms, teaching optimization algorithm has many advantages such as fewer parameters, simple process and high accuracy. Therefore, it has also attracted the attention of scholars at home and abroad. Gao Liqun et al.[11] put forward a Teaching-Learning-Based optimization algorithm with cross operation. Zhao Naigang[12] improved the Teaching-Learning-Based optimization algorithm for solving unconstrained optimization problems. Yu Kunjie et al.[13] proposed an improved Teaching-Learning-Based optimization algorithm by adaptively adjusting the teaching factors and applying trust weight into the algorithm. Zhai Junchang et al.[14] improved the teaching effect through random perturbation strategy in the teaching phase. In the learning phase, they introduced the strategy of learning from poor students to excellent students and from better students to teachers, and then proposed the AITLBO algorithm combined with the process of self-learning reflection.

By referring to the improvement of the two algorithms, this paper adaptively changes the teaching factors in view of the problems in this paper. And takes into account that in the process of practical teaching and learning, students will firstly review their knowledge after learning from teachers, and then communicate with other students. Therefore, a self-learning phase is added between teachers' teaching and students' mutual learning phase, thus improving the Teaching-Learning-Based optimization algorithm.

2. Problem Instructions

2.1. Model Establishment
The planning area is divided into regions with the number of vehicles in each region \( s = \{s_1, s_2, ..., s_n\} \). The central point is the place where the vehicles are concentrated in each region, and the coordinates of the central point in each region are as follows:

\[
(X, Y) = \{(x_1, y_1), (x_2, y_2), ..., (x_i, y_i), ..., (x_n, y_n)\}
\]  

(1)

Because the charging station of electric vehicle is built to charge the car, the distribution of charging station can’t exceed the planned area. If \( j \) is the point selected to construct charging station, the distance between the central position of each area \( i \) and charging station is as follows:

\[
D_j = \sum [(x - x)^2 + (y - y)^2]^{\beta}
\]  

(2)

Assuming that the 100 km of power consumption of K-type vehicles is \( q_k \), and the distance between the central point of the region and the charging station is \( D_i \), the driving cost of K-type is:

\[
C_i = \sum q_k D_i
\]  

(3)

Refer to the actual situation, when users choose charging station for charging, they usually consider two factors, one is distance, the other is driving cost. When choosing charging station, users decide the proportion of the two factors according to the residual electricity ratio of electric vehicle which is \( q_{rest} \). \( q_{rest} = \{0.1, 0.2, ..., 0.9\} \). Total number of K-type vehicles in target area is \( N \). Objective function is shown as follows:

\[
F = \min \{\sum \sum \sum \sum N[(1 - q_{rest})D_i + q_{rest}D_j]\}
\]  

(4)
2.2. Constraint
Because the charging station should satisfy the needs of users, assuming that the charging demand of vehicles in area \( i \) is \( d_i \) and the number of the charging pile in area \( i \) is \( p_i \), the charging pile of the charging station should satisfy the following conditions:

\[
\sum_{i=1}^{n} d_i \geq \sum_{i=1}^{n} p_i \quad \text{and} \quad d \geq p_i \quad i=(1,2,...,n) \tag{5}
\]

Since the charging station must be built in the planned area, then:

\[
(x)_{min} \leq x \leq (x)_{max} \quad \text{and} \quad (y)_{min} \leq y \leq (y)_{max} \tag{6}
\]

2.3. Algorithm description

2.3.1. TLBO
Teaching-Learning-Based optimization algorithm is divided into two phases: teaching phase and learning phase. In the teaching phase, teachers teach students knowledge and students study with each other. Through two phases, students’ scores can be improved.

2.3.1.1. Teaching phase
In the teaching phase, the best individual in the group is selected as the teacher, and other individuals improve their scores by learning from the teacher, so as to improve the average of the whole group. Assuming that the current student is \( x_i \), the new solution in the teaching phase is as follows:

\[
x_{new} = x_{old} + rand \times (x_{teacher} - TF \times x_{mean}) \tag{7}
\]

\( x_{new} \) and \( x_{old} \) are the new and current positions of student \( i \), \( rand \) is the random number of \([0,1]\), \( x_{mean} \) is the average of students’ scores, \( TF \) is the teaching factor, and its value is random 1 or 2, the formula about \( TF \) is:

\[
TF = \text{round}[1 + rand] \tag{8}
\]

After the teacher phase, the position will be updated when the new solution is better than the current solution; otherwise, it will not be updated.

2.3.1.2. Learning phase
In the learning stage, TLBO algorithm randomly takes two students such as \( x_i \) and \( x_j \), compares the objective function values of \( F(x_i) \) and \( F(x_j) \) of the two students, and chooses the worse one to learn from the better one.

\[
x_{new}^{\text{\_\_\_}} = \begin{cases} x^\text{new} + rand \times (x^\text{new} - x^\text{old}) & \text{if } F(x) < F(x) \\ x^\text{old} + rand \times (x^\text{old} - x^\text{new}) & \text{otherwise} \end{cases} \tag{9}
\]

If \( x_{new} \) is superior to \( x_{old} \), it will be updated after students study with each other. Otherwise, no updates will be made.

2.3.2. ITLBO
Because the search range of charging station planning problem is large, the convergence speed of the algorithm needs to be improved. Considering that too fast convergence speed may lead to falling into local optimum, this paper improves the TLBO for charging station planning problem.

2.3.2.1. Improved teaching phase
Because the teaching factors in TLBO teaching stage can only take 1 or 2, the teaching method is relatively single. In TLBO, the teaching factor determines the change degree of the average. Referring to the actual teaching process, there are many differences between students and teachers in the initial stage. At this time, students learn more knowledge and faster. When students are close to teachers' level, the learning speed will gradually decrease. Therefore, the literature proposes an adaptive
teaching factor. With the increase of the number of iterations, the teaching factors are linear reduce. The formula is as follows:

\[
TF = TF_{max} - \left( \frac{TF_{max} - TF_{min}}{iter_{max} - iter} \right) \times \text{iter}
\]  

(10)

In the formula, \( TF_{max} \) and \( TF_{min} \) respectively are the maximum and minimum values of teaching factor; \( iter_{max} \) is the maximum iteration algebra and \( iter \) is the current iteration algebra.

2.3.2.2. Self-learning phase

In the actual learning process, students usually learn from teachers, self-consolidation and review, so as to improve themselves, and then communicate with students, and improve again. After referring to the literature, according to the actual situation, this paper considers that the self-learning phase should be placed before students learn with each other, so as to improve the learning effect of students. Let students learn by themselves through the following strategies. In the formula, \( \text{Guass}(0,1) \) is a Gauss random number.

\[
x^{i+1} = x^i \times (1 + \text{Guass}(0,1))
\]  

(11)

3. SOLUTION PROCEDURE

Taking the centralized location of vehicles in each region as the central point of the region and the distance and driving cost as the objective function, the ITLBO algorithm is used to plan the charging station of EV under the constraints. By calculating, the optimal charging station position of the objective function is output.

Process:
(1) Input the coordinates of each region;
(2) Enter the number of different kinds of vehicles in each area;
(3) Input the power consumption per kilometer of different types of vehicles;
(4) Input the constraints of charging station’s coordinates;
(5) Input the constraints of charging piles’ number;
(6) Input the number of iterations, students, variable dimensions, runtime;
(8) Calculating the coordinates of charging station position by ITLBO algorithm;
(9) Calculating the number of charging station’s charging piles of electric vehicles;
(10) Output the coordinate of charging station and the quantity of charging piles.

The flow chart is as follows:

```
Input data
The coordinates of each region
The number of different kinds of vehicles in each area
The power consumption per kilometer of different types of vehicles
The constraints of charging station’s coordinates
The constraints of charging stations’ coordinates and charging piles’ number
Input data
Process:
ITLBO algorithm
Output data
The coordinate of charging station
The number of charging piles
```

Figure 1. Calculation process

4. SIMULATION EXAMPLES

Taking the urban planning area established in this paper as an example, the planning area can be divided into 30 sub-regions and total area is 25 km². Each region has three kinds of vehicles with
different power consumption of 100 kilometers. Their power consumption of 100 kilometers is 11.5, 15.2 and 19 respectively. The number of each vehicle in the planning area is a random number in [30,200]. One charging pile can flush ten vehicles in an hour. The ratio of the given number of charging piles to the number of vehicles in the area is 0.03. The coordinate distribution of 30 parts is shown as follows (The units of ordinate and abscissa in the figure are kilometers.):

![Figure 2. Distribution of 30 regions](image)

The number of three kinds of vehicles in each of the 30 sub-regions is random distribution. The number of vehicles in each sub-region is shown as follows:

![Figure 3. Number of three kinds of vehicles in each area](image)

Set the number of student is 10, and the maximum number of iterations is 1500, the dimension of variables is 2, 4, 6, 8, and the number of runtime is 5. Through ITLBO, the coordinates, coverage and the number of charging piles of charging stations are calculated when the number of charging stations is 1, 2, 3 and 4. The results are as Table 1.

| Number of charging station | Coordinate | Coverage sub-area | Number of charging pile |
|---------------------------|------------|-------------------|------------------------|
| 1                         | (1.9505,2.0467) | 30                | 303                    |
| 2                         | (0.9673,1.2031), (3.2302,3.6632) | 18, 12           | 168, 134              |
| 3                         | (1.1259,0.9704), (4.0155,3.0285), (1.2951,4.3999) | 15, 10, 5     | 152, 99, 55           |
| 4                         | (2.3566,0.4908), (0.8409,1.1881), (4.0219,3.1334), (1.6053,4.4708) | 6, 10, 9      | 55, 104, 91, 52      |
There are 30 sub-regions in the whole target area. When the number of charging stations is 1, 2, 3 and 4, the coverage area is shown in the following figures.
To compare the algorithms, TLBO and ITLBO are used to solve the charging station planning problem proposed in this paper, and the convergence curves of the two algorithms are shown in the figures.

Compared with TLBO, it can be found that ITLBO has more stable results, while TLBO results fluctuate greatly, so ITLBO has better results and stability.
5. Conclusion
The paper establishes a planning area model, and the planning area is divided into several sub-areas, then takes distance and driving cost as the objective function from the user's point of view. When the user chooses, the proportion of the two factors is determined by the remaining electricity, so as to plan the location of the electric vehicle charging station. TLBO algorithm is improved by self-adapting change of TF teaching factor and adding self-learning stage. The construction location, number, coverage and quantity of charging piles in charging station are calculated by ITLBO. The comparison between the two algorithms shows that ITLBO is better and more stable than TLBO. However, the convergence speed of the ITLBO is not ideal. Therefore, the convergence speed of ITLBO algorithm should be improved in the future research. And the planning of charging station should be considered.

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