Research on Optimization of NEV Power Battery Recycling Network

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Abstract. With the increasing number of new energy vehicles (NEV), the NEV industry is facing a situation of large amounts of retired power battery. In this study, first, the relevant research of the power battery recycling mode is sorted out. And this paper proposes a four-level power battery recycling network, which includes nodes such as collection warehouse, storage warehouse, transfer hub, echelon utilization enterprise, etc. Then, a Mixed-Integer Non-Linear Programming model is proposed to minimize the cost of the network.

1. Introduction
In recent years, the national government has shown sufficient attention to the power battery recycling industry. OEMs, battery manufacturers, and comprehensive utilization companies have also invested in the construction of the power battery recycling system. In addition to technologies such as power battery disassembly and recycling, the layout of the power battery recycling network is also very important. A perfect location for recycling outlets, hubs, etc. can not only improve the efficiency of the recycling network, but also save the cost of overall power battery recycling, thereby further promoting the development of the new energy vehicle industry. And this research is from the perspective of the industry, exploring reasonable power battery recycling models. Based on this, it optimizes the layout of the power battery recycling network, reduces the overall cost of the recycling network and improves its efficiency, and provides certain reference for the research on the recycling network of the power battery recycling industry.

2. Construction of Power Battery Recycling Network
Through literature research [1][2], it can be found that the power battery recycling network mainly includes three major processes, namely: power battery collection, power battery pretreatment (such as detection, classification, etc.), power battery reprocessing (such as regeneration) Utilization, disposal, etc.). Combined with the design principles of reverse logistics, the nodes required by the power battery recycling network can be obtained.

(1) Collection recycling service outlets (hereinafter referred to as collection warehouses). Refers to a dedicated site that can temporarily store used power batteries.

(2) Centralized storage recycling service outlets (hereinafter referred to as storage warehouses). Refers to a large dedicated venue that can store power batteries for a long time.
Transit hub. Refers to the premises for pretreatment, including physical dismantling, capacity/health testing, and cell classification, etc., established by OEM or OEM joint comprehensive utilization companies.

Echelon utilization enterprises. Use batteries with better capacity and health that are screened by the transit hub to manufacture energy storage equipment. The location of this logistics node is usually fixed.

Material recycling enterprises. Disassemble batteries that cannot be used in cascades, recover valuable materials in them, and dispose of worthless materials. The location of such logistics nodes is usually fixed.

Waste treatment enterprises. Measures such as solid landfill for wastes that are difficult to reuse. The location of such logistics nodes is usually fixed.

The above power battery recycling network nodes and logistics activities can be summarized as the following figure.

Figure 1. Schematic diagram of the consumer-based power battery recycling network structure

3. Construction of Power Battery Recovery Network Model

3.1. Analysis of Power Battery Recycling Network Cost

The power battery recycling network model mainly includes the construction cost of collection warehouses, storage warehouses, and transit hubs, the transportation costs between each link, the storage cost of each link, and the processing cost of each link.

3.2. A Mixed Integer Nonlinear Programming Model (MINLP) of Recycling Network

In order to achieve the goal of minimizing the total cost, the following problems need to be solved: (1) Determine the number and corresponding location of the storage warehouses so that the storage warehouses can cover all collection warehouses; (2) Based on the collection cycle, collection volume and construction Factors such as cost, logistics and transportation costs, warehousing costs, etc., determine the number of storage depots under the minimum cost of the recycling network and the location distribution; (3) Comprehensive factors, determine the number of transfer hubs and the location distribution with the minimum total cost of the recycling network, and then a mixed integer nonlinear programming model(MINLP) is constructed.

In order to facilitate reading and description, the symbols involved in the model are organized as follows.
Table 1. Symbol description

| Symbol | Description |
|--------|-------------|
| ℎ     | The collection library, ℎ ∈ ℋ |
| 𝑖     | The repository, 𝑖 ∈ 𝐼 |
| 𝑗     | The transit hub, 𝑗 ∈ 𝐽 |
| 𝑘     | Tiered utilization enterprises |
| ℓ     | Material recycling companies |
| 𝑚     | Waste disposal companies |
| 𝐵𝐶   | Construction cost |
| 𝐶𝐶   | Holding cost per unit mass of goods per unit time |
| 𝐷𝐶   | Treatment cost per unit mass power battery |
| 𝐸𝐶   | The transportation cost per unit mass per unit distance |
| 𝑄     | Freight volume |
| 𝐷     | Distance |
| 𝑃     | Storage capacity |
| 𝑇     | Storage time |
| 𝐺     | Quantity of goods collected |
| 𝑊     | Total actual working days in one year |

\[ f(Q, D) = a\beta \]

\[ f(Q, D) = \alpha \beta \]

\[ p_1, p_2 \] The volume of traffic when the shipping discount changes

\[ q_1, q_2 \] The transport distance when the transport penalty changes

\[ R \] The maximum distance allowed for a collection to a repository

\[ M \] Any extremely large positive real number

\[ a, b, c \] The cargo volume ratio of the transit hub to the echelon utilization enterprise, the material recovery enterprise and the waste disposal enterprise \( a + b + c = 1 \)

\[ y \] Establish the minimum number of repositories

\[ z \] Establish the minimum number of transit hubs

\[ \text{MINLP} \text{ is shown as follows,} \]

\[ \text{MinTC} = \sum_{h} BC_h + \sum_{i} BC_i y_i + \sum_{j} BC_j z_j + \sum_{h} \left[ \sum_{i} W \bar{Q}_h EC_h D_h U_h f(Q_h, D_h) \right] \]

\[ + \sum_{j} \left[ Z_j \sum_{i} W \bar{Q}_j EC_j D_j f(Q_j, D_j) \right] \]

\[ + \sum_{j} \left[ Z_j \sum_{i} W \bar{Q}_j EC_j D_j f(Q_j, D_j) \right] + \sum_{j} \left[ Z_j \sum_{i} W \bar{Q}_j EC_j D_j f(Q_j, D_j) \right] + \sum_{j} \left[ Z_j \sum_{i} W \bar{Q}_j EC_j D_j f(Q_j, D_j) \right] \]

\[ \text{(1)} \]

\[ + \frac{\sum_{h} W T_h + 1}{2} G_h CC_h + \frac{\sum_{i} W T_i + 1}{2} G_h CC_i U_h + \left[ \frac{\sum_{j} W T_j + 1}{2} Q_j CC_j V_j \right] \]

\[ + \frac{\sum_{h} W T_h + 1}{2} a CC_h + \frac{\sum_{i} W T_i + 1}{2} a CC_i + \frac{\sum_{j} W T_j + 1}{2} a CC_j \]

\[ + \frac{\sum_{h} W T_h + 1}{2} b CC_h + \frac{\sum_{i} W T_i + 1}{2} b CC_i + \frac{\sum_{j} W T_j + 1}{2} b CC_j \]

\[ + \frac{\sum_{h} W T_h + 1}{2} c CC_h + \frac{\sum_{i} W T_i + 1}{2} c CC_i + \frac{\sum_{j} W T_j + 1}{2} c CC_j \]

\[ + \sum_{j} \left[ Z_j \sum_{i} W \bar{Q}_j V_i (DC_j + a DC_k + b DC_t + c DC_m) \right] \]

\[ \text{(2)} \]
The constraint,

\[ \sum U_{hi} = 1, \forall h \in H \]  
(3)

\[ \sum V_{ij} = 1, \forall i \in I \]  
(4)

\[ \sum U_{hi} \leq M Y_i, \forall h \in H, \forall i \in I \]  
(5)

\[ \sum V_{ij} \leq M Z_j, \forall i \in I, \forall j \in J \]  
(6)

\[ D_{hi} U_{hi} \leq R, \forall h \in H, \forall i \in I \]  
(7)

\[ G_h = \sum Q_{hi}, \forall h \in H, \forall i \in I \]  
(8)

\[ \sum h \frac{w}{T_h} G_h U_{hi} = \sum j \frac{w}{T_j} Q_{ij}, \forall h \in H, \forall i \in I, \forall j \in J \]  
(9)

\[ \sum i \frac{w}{T_i} Q_{ij} V_{ij} = \frac{w}{T_j} (Q_{jk} + Q_{jl} + Q_{jm}), \forall i \in I, \forall j \in J \]  
(10)

\[ y \leq \sum Y_i \]  
(11)

\[ z \leq \sum Z_j \]  
(12)

\[ T_h, T_i, T_j, T_k, T_l, T_m \in \{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16\} \]  
(13)

\[ \forall h \in H, \forall i \in I, \forall j \in J \]  
(14)

\[ Y_i, Z_j, U_{hi}, V_{ij} \in \{0,1\}, \forall h \in H, \forall i \in I, \forall j \in J \]  
(15)

4. Site Selection Optimization Based on Improved Genetic Algorithm

4.1. Selection of Algorithm

Hybrid formal nonlinear programming (MINLP) problem is used in the power battery recovery network. In fact, in the field of engineering, there are a large number of optimization decision problems related to this, which often involve nonlinear or discrete variables. For solving such problems, there are mainly two kinds of algorithms, namely deterministic algorithm and heuristic algorithm[3]. Deterministic algorithms usually decompose and simplify problems based on analytic properties, and search for global optimum based on local minimum attempt. For such an algorithm, the nodes and constraints required for the model are usually not too many. However, heuristics are usually iterative and random searching based on certain rules to get a good solution quickly, but it is impossible to judge whether the solution is optimal or not. In addition, the two types of algorithms can be combined to speed up the solution.

Since the model in this paper is to solve the problem of location optimization of collection library and transit hub in a region, the node size involved is relatively large. Compared with deterministic algorithm, heuristic algorithm is more suitable for this type of calculation, and genetic algorithm is selected in this paper.
4.2. Improved Genetic Algorithm

The design of genetic algorithms usually includes individual coding, initial population generation, individual selection, crossover, mutation and so on. This paper proposes an improved genetic algorithm design for the optimization of power battery recovery network\[4\][5], which mainly includes the following stages and the improved contents:

1. Individual coding and initial population generation

Binary encoding is adopted in this study, namely, a row of 0-1 values are used to represent decision variables. The initial population is randomly generated in the optimization of power battery recovery network. In addition, the size of the population must be determined when the initial population is generated.

\[ F(x) = \frac{M}{f(x)} \]  \hspace{1cm} (16)

Since the objective function in this paper is always positive, we ensure that the fitness function of this form is always positive. In addition, by determining the magnitude of M based on the cardinality of the objective function, the fitness function can be controlled within a reasonable range of change. So improved algorithm will adopt this function.

2. Determination of fitness function values

a) Adjustment of fitness function values

The improved genetic algorithm in this paper adopts the variable-ratio method of Sigma Scaling, and the calculation method of fitness Scaling is as follows:

if \( \sigma = 0 \) then

\[ F(x) = 1 \]  \hspace{1cm} (17)

Else

\[ F_n(x) = \frac{[F(x) - \bar{F}(x)]}{2\sigma} \]  \hspace{1cm} (18)

\( F(x) \) is the original fitness function, \( \sigma \) is the standard deviation between individuals in the population, \( \bar{F}(x) \) is the average value of the fitness function of the population, and \( F_n(x) \) is the fitness function value after Sigma Scaling.

c) The determination of the penalty function

\[ f(x) = f(x) + pv \]  \hspace{1cm} (19)
Where $p$ is the penalty factor and $v$ is the number of violations.

Through the design of penalty function above, when the individual does not fall in the solution space, the objective function value will be enlarged, that is, the fitness function value will be reduced, and the elimination of individuals not in the solution space can be accelerated.

(3) The determination of selection operator

The selection operator also follows the natural survival of the fittest, which is mainly based on the value of fitness function and adopts a certain method to select individuals, and the selected individuals will carry out a series of operations. In general, when an individual has a greater fitness function, genes are more likely to be passed on to offspring.

A reasonable operator should be able to play the characteristics of random selection, but also be able to focus on the dominant individual, so as to achieve a balance between fast convergence and global optimization. SUS (Stochastic Universal Sampling) is adopted to improve the genetic algorithm.

(4) The determination of crossover operator

There are many ways of crossing, such as uniform crossing, single point crossing, two point crossing, multiple point crossing, arithmetic crossing and so on. In this paper, uniform crossover is adopted, and its schematic diagram is shown in Figure 3.

![Figure 3. Schematic diagram of uniform crossing principle (binary coding)](image)

(5) Determination of mutation operator

There are also many methods of mutation operator, such as basic bit variation, uniform variation, non-uniform variation and so on. In this study, a mutation operator that changes with algebra is designed for iteration characteristics, as shown in Equation (20).

$$P = P - \frac{n}{N}(P_{\text{max}} - P_{\text{min}})$$  \hspace{1cm} (20)

Where, $P$ is the variation probability of the $n$ generation, $N$ is the maximum algebra, $P_{\text{max}}$ is the maximum variation probability, which is set as 0.1 in this paper, and $P_{\text{min}}$ is the minimum variation probability, which is set as 0.015 in this paper.

(6) The population of each generation is evaluated according to the established fitness function. When the algorithm termination criteria are met, the operation is stopped.

5. Conclusions

Based on the characteristics of the power battery recycling more wide coverage, level, and combined with related policies and regulations, proposed the innovation includes collection, storage, transit hub, library pilot enterprise node level 4 power battery recycling network, and based on this mathematical model is constructed, formed a mixed nonlinear programming model, then a improved genetic algorithm for the model design.

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