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Medium- and Long-Term Trading Strategies for Large Electricity Retailers in China's Electricity Market

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Abstract: In the rapid promotion of China's electricity spot market, a large number of electricity retailers and large consumers participate in power trading, of which medium- and long-term power trading accounts for a large proportion. In the electricity spot market, the previous medium- and long-term transactions need to be closely combined with the current spot market transaction settlement rules. This paper analyzes the trading strategy of large retailers in the power market. In order to effectively reduce the total electricity cost, it is necessary to optimize the medium- and long-term transactions based on three aspects: electricity quantity and benchmark price decisions of medium- and long-term contracts, the daily electricity decomposition method in the day-ahead (DA) market, and the daily load curve decomposition strategy. According to load history characteristics that are extracted by the X12 method, daily electricity is decomposed from the medium- and long-term electricity quantity in the DA market. This paper introduces three methods of decomposing the daily load curve and proves that the particle swarm algorithm is the best method for effectively minimizing the cost in the DA market. Through analyzing the total electricity cost change pattern, we prove that the basic component of decision making is the relative relationship between the electricity price of medium- and long-term contracts and the equivalent kWh price of medium- and long-term electricity in the DA market, which is determined by the decomposition daily curve method. If the equivalent kilowatt-hour price obtained by the decomposition method in the DA market is greater than the electricity price of medium- and long-term contracts, the larger the electrical energy of medium- and long-term contracts, the lower the costs. Based on the above principles, electricity retailers can carry out planning for medium- and long-term transactions, as well as the decomposition and declaration of the daily electricity quantities and daily load curves.

Keywords: decomposition strategy of contract electricity quantity; decomposition strategy of daily load curve; electricity spot market; medium- and long-term trading strategy; particle swarm

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1. Introduction

Under the guidance of low-carbon, environmentally friendly, energy-saving, and emission-reduction policies, China has widely promoted electric vehicles. Additionally, the urban public transport system has also proposed the development of electric buses. In the last two years, the number of electric buses in Beijing has increased quickly. In order to cooperate with electric buses' operations, a large number of dedicated bus charging stations have been built [1]. As an electricity consumer, the charging station operator (CSO) is responsible for operating the bus charging stations. At present, CSOs have to settle the extremely high electricity bills according to the peak-to-valley electricity price of industrial and commercial energy consumers. Since the State Council of China issued "*(Several Opinions on Step Deepening Electricity System Reform (2015) No. 9)*" in 2015, China's electricity market reform has entered the deep-water area. Market transaction strategies have gradually improved, and market transaction shares have achieved rapid sustained growth. In order to reduce electricity costs through the reasonable allocation of multiple transaction forms, a large number of electricity retailers and large electricity users directly participate in electricity market transactions.

At present, the research on the participation of electric vehicles (EVs) in the electricity market mainly focuses on the following aspects: EV load peak shifting with energy storage systems (ESS), demand-side responses with EVs, and grid auxiliary services through the Vehicle-to-grid(V2G) form. In the research on electricity market transactions, [2] focuses on the proportion of various power purchase contracts under different risk aversion coefficients for electricity retailers without restrictions on medium- and long-term (MALT) electricity purchases. In [3,4], according to the operation strategy of the electricity retailers in the spot market, the researchers designed the electricity price to influence the market share and the income of the enterprise. In [5], according to the decentralized market rules in ShanXi Province, China, the optimal bid tariff and share of power purchase within the set price range were calculated. Reference [6] researched the risks of electricity purchase and sales for electricity retailers. Additionally, this paper constructed an optimization model in a multi-level market and pointed out that the mathematical mean and variance of market spread had great influence. In [7], the authors studied the decomposition method of annual electricity. In [8], taking hydro-power as an example, the authors studied the decomposition strategy of the electricity contract under different water conservancy conditions in order to optimize the contract completion rate. Reference [9] investigated the influence of wind power uncertainty on the electricity contract execution. In references [10–14], focusing on the power generation side, the researchers studied the MALT generation constraints and the MALT power decomposition strategy to ensure the fair distribution of various generation units. References [15–17] studied the inspection mechanism of the safety constraints of the power generation side and corrected the unenforceable energy contract. Electricity market trading research has focused on the pricing strategies and trading matching mechanisms of various power sources [18–20]. In the research field of electric vehicles, there are a lot of references that focused on vehicle operation optimization and load demand response, and a few focused on the operation of charging stations. The research perspective of electricity buyers, such as electricity retailers, focuses on the impact of different tariff contracts and market shares. However, it ignores the impact of electricity decomposition strategies due to the combination of the MALT trading market and spot markets. From the perspective of the power generation unit, the research on the decomposition strategy of MALT contracts mainly focuses on the contract implementation rate and the fairness of distribution. However, from the perspective of electricity retailers, few studies focus on the decomposition strategy of MALT transactions. The above research about EV mainly focuses on private EV. There is less research on the operation mode of an electric bus system, which is quite different from that of a private car.

The electricity quantity of MALT transactions of large electricity users accounts for a high proportion of electricity market transactions. Through an orderly transition with the spot market, it can stabilize the transaction risk of electricity price fluctuations in the spot market [21]. Then, it maintains healthy market competition.

This article will study the MALT trading strategies for the Beijing public transportation system (CSO) in China's electricity market. Taking Beijing CSO as an example, this article reduces electricity costs by optimizing electricity trading strategies. Based on the centralized spot market transaction rules piloted in Guangdong Province, this article analyzes the optimization trading strategies of CSOs and other buyers in the electricity spot market, mainly for MALT transactions.

This article is organized as follows. Section 1 introduces the development status of China's power market and the research status of electric vehicles and the power market. Section 2 describes the operating costs and load characteristics of the Beijing CSO. Section 3 introduces the development of China's power market and the trading and settlement rules of China's current power market. Section 4 analyzes the main factors that affect the electricity costs in the MALT market based on transaction rules. Based on historical data, Section 5 obtains a typical daily load curve, which is a declaration load curve in the day-ahead (DA) market and an important factor of the decomposition daily load curve. Section 6 obtains the characteristics of the daily electricity distribution through X12 and proposes a daily energy decomposition method of MALT electricity. Section 7 introduces the particle swarm optimization algorithm of the decomposition method of the daily load curve. In Section 8, we provide a case study based on the Beijing CSO and analyze different impact factors on electricity costs. Section 9 summarizes the research conclusions.

2. Research Background of Electric Bus Charging Stations in Beijing

Charging station operators have to settle their electricity fee in accordance with the local urban price policy. Beijing's industrial and commercial energy consumers are subject to local peak-to-valley electricity prices, the tariff curve of which is shown in Figure 1. The annual electricity consumption and electricity costs of Beijing CSO are shown in Table 1. It can be seen that electricity costs are extremely high.

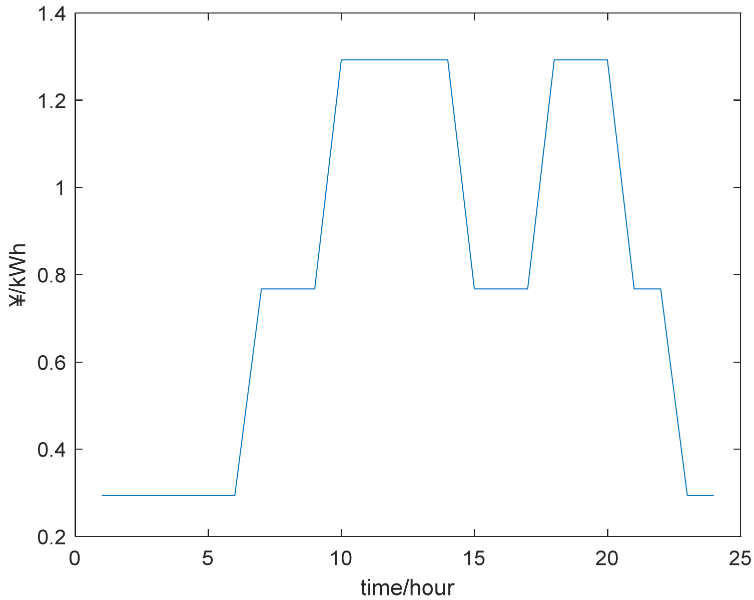

Figure 1. Peak-to-valley electricity price curve in the Beijing area.

Table 1. Operators' annual electricity consumption and electricity costs based on peak and valley electricity prices.

Year	Electricity Consumption (kWh)	Electricity Costs (100 Million RMB)
2019	2.3507×10^8	2.36234
2020	2.3591×10^8	2.37065

Figure 2 shows the monthly electric energy consumption data since 2019. It can be seen that the energy consumption in 2019 increased rapidly, and the energy consumption at the end of the year was much greater than that at the beginning of the year. Due to COVID-19, the energy consumption at the beginning of 2020 decreased significantly compared with that at the end of 2019 and returned to normal after May 2020. Considering the rapid growth in the number of charging stations, this number increased from 82 at the beginning of 2019 to 165 in 2021. The total electric bus load was relatively stable, excluding the influential factor of charging station growth. Load fluctuations were mainly affected by seasonal temperature factors. Heating energy consumption was the highest in winter. The load fluctuation trend is shown in Figure 3. It is expected that the annual power of 2021 will be much larger than the data of 2019 and 2020, so the pressure to reduce the electricity costs is extremely high.

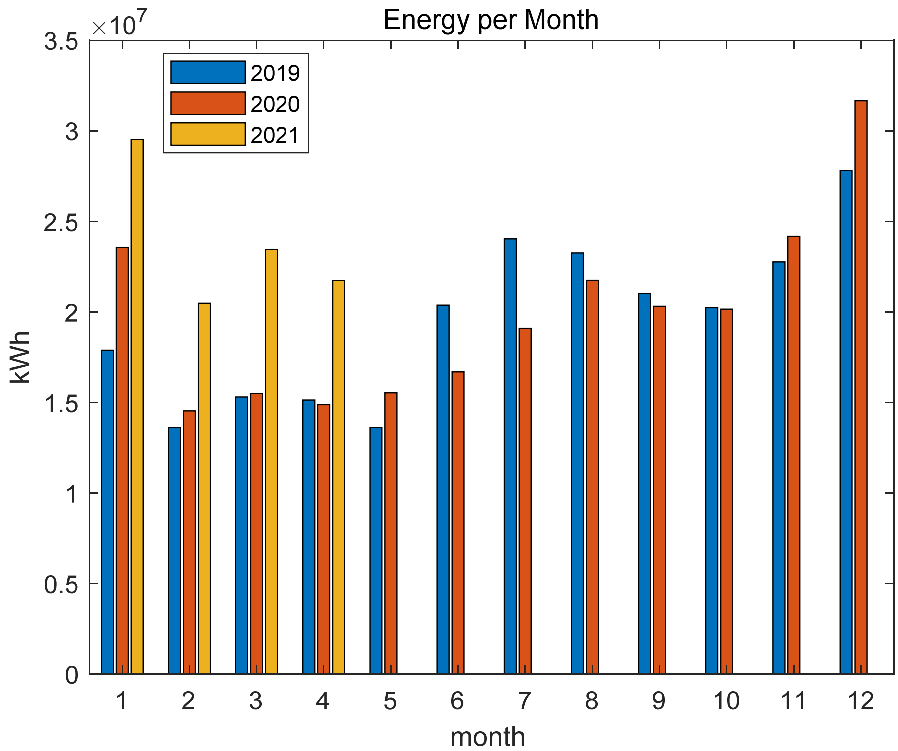

Figure 2. Monthly electricity consumption data of charging stations from 2019 to 2021.

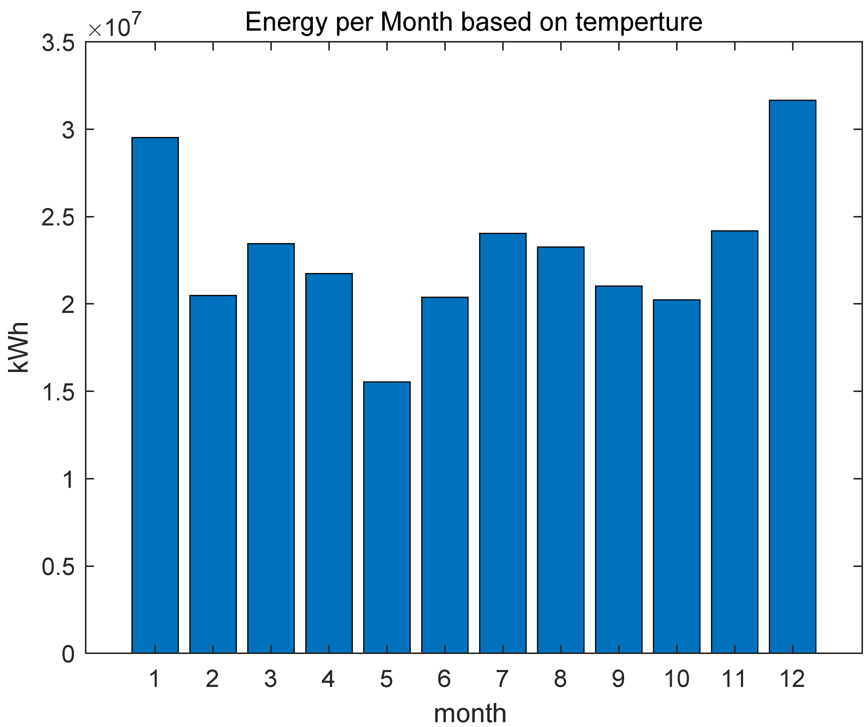

Figure 3. Annual load fluctuation trend of charging stations.

Based on the demand of Beijing charging station operators and combined with electricity market transactions policy in China, this paper's research into optimization trading strategies aims to reduce its electricity costs.

3. Electricity Spot Market Trading Policy

3.1. Development of China's Electricity Market

In 2015, the Chinese government issued a policy document that requires qualifying regions to gradually establish a market-oriented power and electricity balance mechanism dominated by MALT transactions and supplemented by spot transactions. At this time, the key to China's electricity market implementation was standardizing the MALT electricity transactions. At the beginning of 2017, China's government clarified the trading rules for MALT markets. In 2019, some pilot areas represented by Guangdong Province carried out a short-term spot market trial operation. In November 2021, the sixth spot market trial operation in Guangdong was carried out for two months. According to the notice issued by China's government, in principle, the first batch of pilot areas will carry out long-term continuous trial operation of the spot market in 2022. Additionally, all electricity users participating in MALT transactions should participate in spot transactions.

Different time scales in MALT transactions include annual and above transactions, monthly transactions, and intra-month transactions. The transaction organization mode can be classified as bilateral negotiation, centralized bidding, and listing [3]. The transaction content includes contract electricity, contract electricity price, the decomposition of electricity in the day-ahead market, etc. Spot market transactions include three parts: the DA market, the real-time (RT) market, and deviation assessment.

Due to the long time period of MALT transactions, there is a huge deviation between the transaction electricity and RT power consumption. The original deviation assessment of MALT transactions cannot constrain the actual power supply and demand balance [6]. By introducing spot market transactions, the allocation optimization of power resources can ensure the real-time balance of power and trade fairness.

3.2. China's Former Electricity Market Trading Regulations

In the MALT transactions, the electricity retailers need to complete the annual MALT transaction decision and decompose the annual contract electric quantity into months, as shown in strategy 1 and strategy 2 in Figure 4. In the monthly transactions, the electricity retailers purchase electricity to supplement the insufficient part of the monthly decomposition electricity. The deviation assessment penalty shall be paid according to the deviation between the total monthly electricity purchased and the actual electricity consumed.

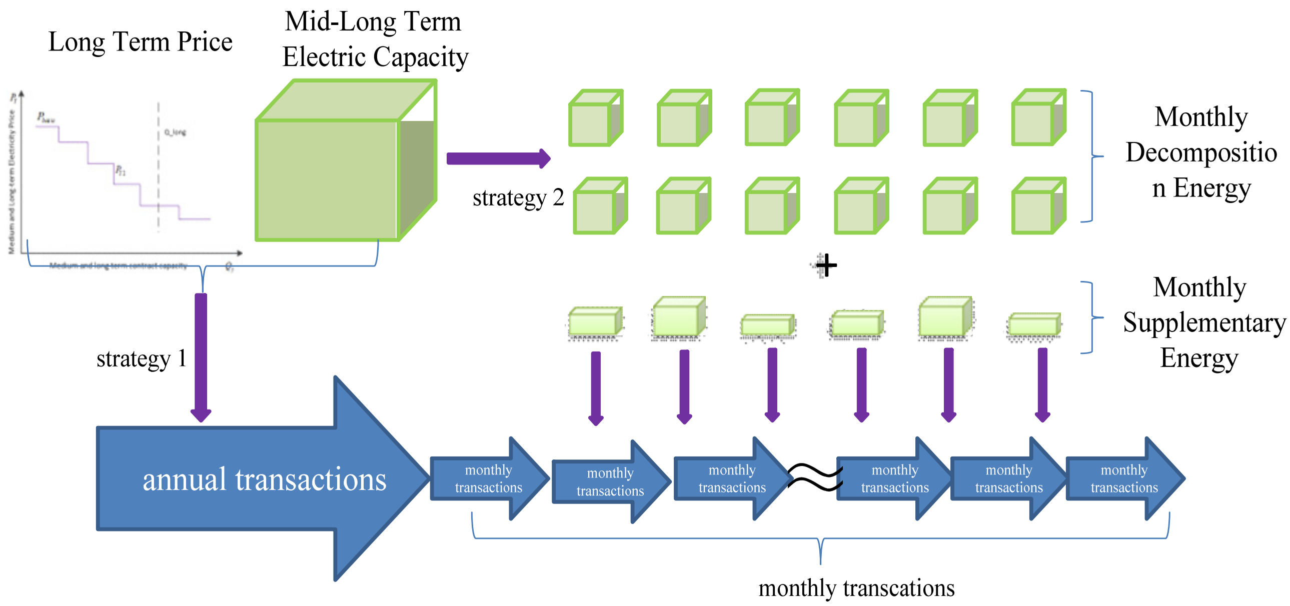

Figure 4. Medium- and long-term trading rules of the past electricity market.

In this paper, annual transactions and monthly transactions are combined in the MALT market, in which electricity retailers need to complete the transaction decisions of electricity quantity and electricity prices at the beginning of year.

3.3. China's Electric Power Spot Market Trading Rules

Under the reform of the new power system, MALT trading is the main part, and spot market trading is supplemented. Figure 5 shows the current trading procedures in China. In the DA market, the electricity retailers need to reasonably decompose the MALT electricity into daily electricity and the daily decomposition curve based on load characteristics, which is different from the decomposition of monthly electricity in Section 3.2.

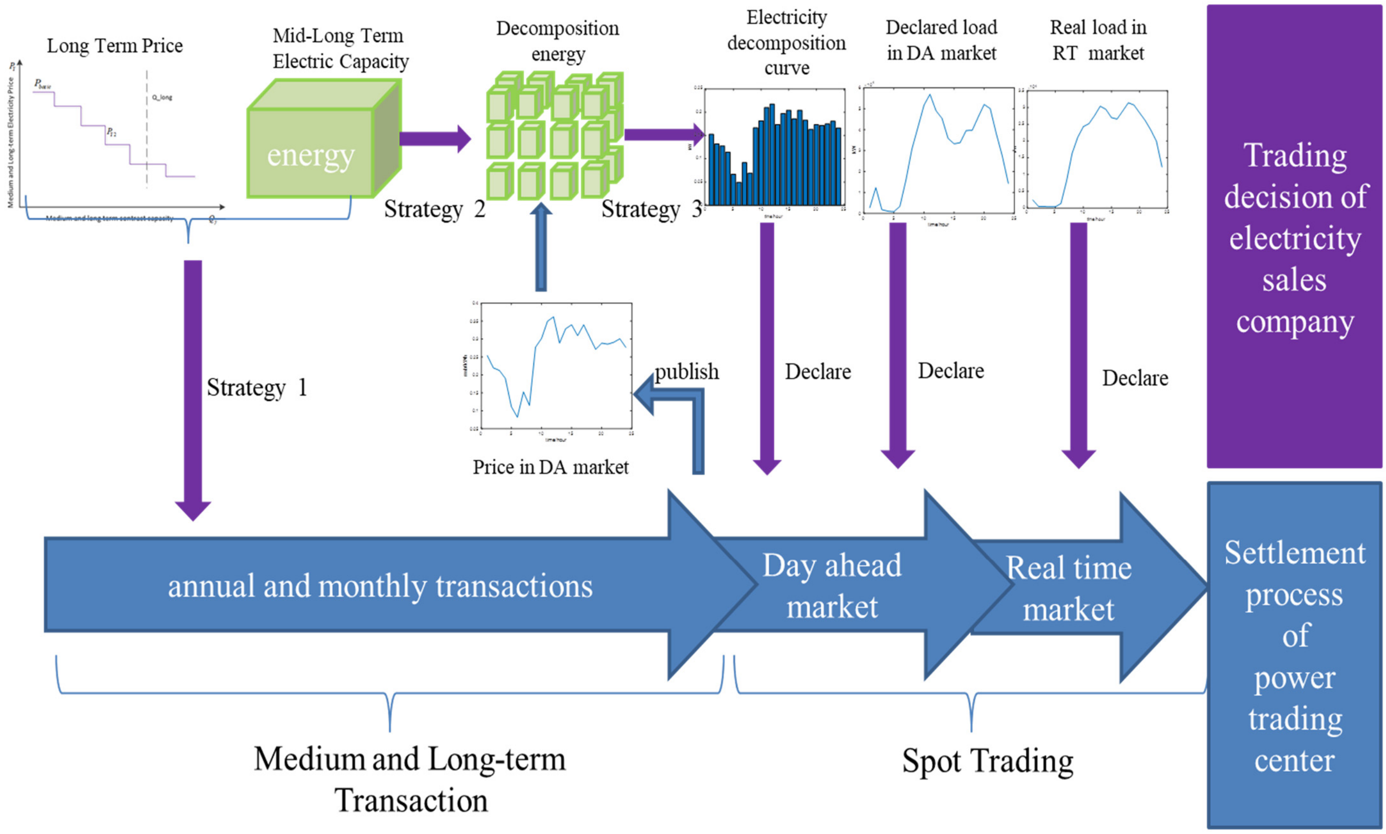

Figure 5. Transaction process of China's power market.

According to the trading rules analysis, electricity retailers need to complete the following three transaction decisions. Firstly, the electricity retailer completes the MALT transactions at the beginning of the year, of which the decision-making variables include contract electricity Q_Y and contract electricity prices P_Y, as shown in strategy 1 in Figure 5. Secondly, in order to realize the effective connection between the MALT and the spot market, the electricity retailers should reasonably decompose the MALT electricity purchases to the decomposition contract electricity Q_{y_day} of each trading day, as shown in strategy 2 in Figure 5. Thirdly, the trading center will announce the DA market price $P_{DA,t}$ before the start of the DA market. The electricity retailer needs to report the day-ahead load declaration curve $Q_{DA,t}$ and the daily load curve $Q_{y\_day,t}$ based on Q_{y_day} decomposition, as shown in strategy 3 in Figure 5. The above transaction decisions need to be declared before the start of the day-ahead market.

According to this transaction rule, the single-day electricity fee of the MALT market C_{long} is shown in Equation (1). $P_{Y,t}$ is the MALT electricity price of each time step. Q_{y_day} is daily electricity of MALT contract electricity decomposition. $Q_{y\_day,t}$ is the daily load curve based on Q_{y_day} decomposition. $P_{DA,t}$ is the DA market price.

$$C_{long} = \sum_{t=1}^{24} Q_{y\_day,t} \cdot (P_{Y,t} - P_{DA,t}) \quad (1)$$

The electricity cost in the DA market C_{DA} is shown in Equation (2). $Q_{DA,t}$ is the DA load declaration curve.

$$C_{DA} = \sum_{t=1}^{24} (Q_{DA,t} \cdot P_{DA,t}) \quad (2)$$

The electricity cost in the RT market C_{RT} is shown in Equation (3). $Q_{RT,t}$ is the actual load curve. $P_{RT,t}$ is the real-time electricity price.

$$C_{RT} = \sum_{t=1}^{24} [(Q_{RT,t} - Q_{DA,t}) \cdot P_{RT,t}] \quad (3)$$

Additionally, the deviation assessment $E_{allocation}$ is shown in Equation (4), which include two parts. The first part $C_{allocation1}$ is shown in Equation (5). When $Q_{DA,t}$ is greater than $Q_{RT,t}$, the deviation exceeds the deviation assessment range λ_0, and when $P_{RT,t}$ is higher than $P_{DA,t}$, the deviation assessment penalty needs to be paid. The second part $C_{allocation2}$ is shown in Equation (6). When $Q_{DA,t}$ is less than $Q_{RT,t}$, the deviation exceeds the deviation assessment range λ_0, and when $P_{RT,t}$ is lower than $P_{DA,t}$, the deviation assessment penalty needs to be paid.

$$E_{allocation} = C_{allocation1} + C_{allocation2} \quad (4)$$

$$C_{allocation1} = \sum_{t=1}^{24} [Q_{DA,t} - Q_{RT,t} \cdot (1 + \lambda_0)] \cdot (P_{RT,t} - P_{DA,t}) \cdot K_P], \qquad Q_{DA,t} > Q_{RT,t} \cdot (1 + \lambda_0),\ P_{RT,t} > P_{DA,t} \quad (5)$$

$$C_{allocation2} = \sum_{t=1}^{24} [Q_{RT,t} \cdot (1 - \lambda_0) - Q_{DA,t}] \cdot (P_{DA,t} - P_{RT,t}) \cdot K_P], \qquad Q_{DA,t} < Q_{RT,t} \cdot (1 - \lambda_0), P_{RT,t} < P_{DA,t} \quad (6)$$

Combining Equations (1)–(6), we can obtain the total daily electricity costs E_{day_sum}, as shown in Equation (7), and can obtain Equation (8) through consolidation.

$$E_{day\_sum} = \sum_{t=1}^{24} Q_{y\_day,t} \cdot (P_{Y,t} - P_{DA,t}) + \sum_{t=1}^{24} Q_{DA,t} \cdot P_{DA,t} + \sum_{t=1}^{24} (Q_{DA,t} - Q_{RT,t}) \cdot P_{RT,t} + E_{allocation} \quad (7)$$

$$E_{day\_sum} = Q_{y\_day} \cdot P_Y + \sum_{t=1}^{24} (Q_{DA,t} - Q_{y\_day,t}) \cdot P_{DA,t} + \sum_{t=1}^{24} (Q_{DA,t} - Q_{RT,t}) \cdot P_{RT,t} + E_{allocation} \quad (8)$$

Additionally, λ_0 is set to $\pm 5\%$, which is the deviation assessment range. K_P is set to 2, which is the deviation assessment coefficient.

4. Factors Affecting Medium- and Long-Term Transaction Costs in the Spot Market

In the former electricity market, the influential factors of the electricity purchase cost are the annual MALT electricity quantity and the electricity price elasticity coefficient of the annual MALT electricity price. The monthly electricity decomposition is completed based on the proportion of monthly electricity consumption. Supplementary monthly electricity transactions depend on the short-term forecast of monthly electricity.

In the spot market, through calculation Equation (8), there are three factors affecting the electricity costs E_{day_sum}, namely, the MALT power purchase price P_Y, the DA market price $P_{DA,t}$, the decomposition daily electricity Q_{y_day}, and the daily load curve $Q_{y\_day,t}$.

4.1. The Impact of Medium- and Long-Term Electricity Transactions and Prices on Electricity Purchase Costs

C_{long_year} is the annual electricity cost of MALT transactions. The electricity and the price of a contract are determinants of the total annual electricity cost in the MALT transactions. Since there are many types of MALT transactions, centralized bidding and listing transactions are affected by human factors and game strategies. This article ignores these factors and only considers the benchmark electricity prices of different power sources and the relative relationship between MALT electricity prices P_Y and contract electricity Q_y. The influential factors of MALT transactions are shown in Table 2.

Table 2. Comparison of power market decision-making factors.

No	Strategy Steps	Trade Types	Decision Factors of the Former Electricity Market	Decision Factors of the Current Electricity Market
1	Strategy1	Medium- and long-term transactions	Baseline price of power generation types; price elasticity coefficient	
2	Strategy2	Monthly Electricity Decomposition	Distribution of Monthly Electricity Proportion	-
3		Daily Electricity Decomposition	-	Daily Electricity Proportion Distribution
4	Strategy3	Daily Load Curve Decomposition	-	Daily Load Curve $Q_{DA,t}$;
5				The relative relationship between $P_{DA,t}$ and $P_{Y,t}$

$$C_{long\_year} = \sum_{day}\sum_{t} Q_{y\_day,t} \cdot P_{Y,t} = \sum_{day} Q_{y\_day} \cdot P_Y = Q_y \cdot P_Y \tag{9}$$

Different types of power generation units have different on-grid power prices. Figure 6 shows the nine power prices of different power generation types, among which the power prices of coal power, wind power, and photovoltaic power generation fluctuate within a certain range. Based on this situation, the electricity retailers can select the appropriate trading partner in the MALT transactions according to the energy amount and corresponding electricity price.

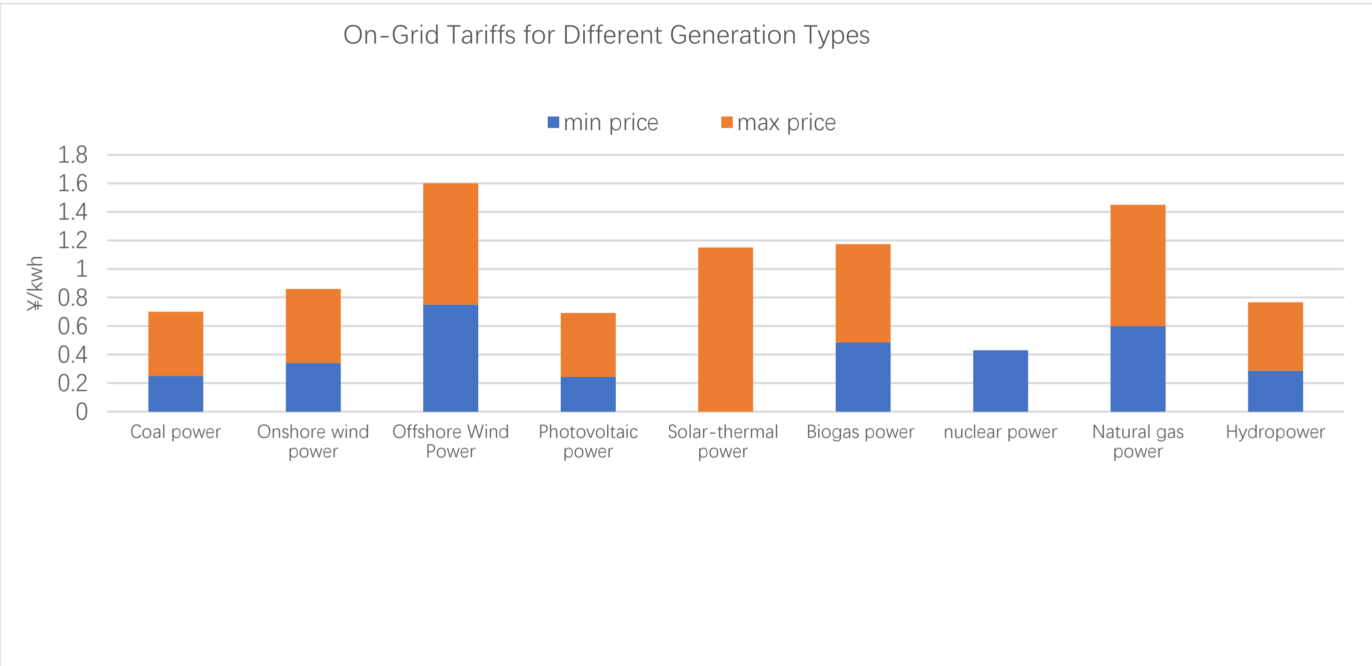

Figure 6. On-grid electricity prices of different power generation types.

The researchers studied the relationship between the electricity price elasticity coefficient and social economic development in Refs. [22,23]. The researchers studied the effects on residential load power consumption due to electricity price changes at different times in Refs. [24–26]. The demand elasticity coefficient of electricity price represents the relationship between energy demands and electricity price, as shown in Equation (10). Q is electricity. P is the electricity price. ΔQ is the electricity fluctuation, and ΔP is the electricity price fluctuation.

$$\varepsilon = \frac{dQ}{Q}\frac{P}{dP} \approx \frac{\Delta Q}{Q}\frac{P}{\Delta P} \tag{10}$$

Based on the principle of market equilibrium, in annual MALT transactions, the electricity price elasticity coefficients of power generation units and electricity retailer units are negative. Additionally, the increase in contract electricity will lead to a decrease in contract electricity prices [26,27]. The change trend of the electricity price is shown in Figure 7, in which P_{basic} is the benchmark electricity price, Q_{basic} is the corresponding minimum electricity purchase, ΔQ is the increase in electricity purchases, and ΔP is the decrease in the electricity price.

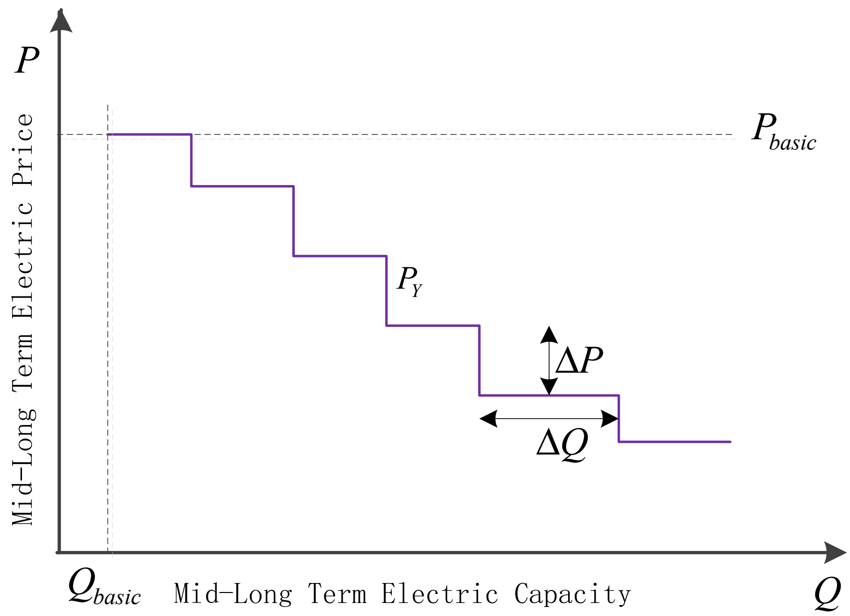

Figure 7. Relationship between electricity price and energy amount in medium-and-long term contracts.

4.2. Influence of the Decomposition of the Daily Load Curve on Electricity Costs in the Day-Ahead Market

According to the spot market trading rules, in the DA market, electricity retailers need to declare $Q_{DA,t}$ on behalf of users. Additionally, the electricity retailers need to decompose Q_Y into Q_{y_day} and further decompose Q_{y_day} into $Q_{y\_day,t}$, as strategy 2 and strategy 3 shown in Table 2.

The decomposition strategy includes two methods. The first is decomposing the daily electricity according to the average or the ratio of the peak-to-valley price curve in 24 h. The second is independently proposed by electricity retailers and takes effect after confirmation by both parties to the transaction, which is the research object in this paper.

As shown in the second term in Equation (8), C_{DA} is the electricity cost of the DA market, which can be equivalent to Equation (11). $P_{DA,t}$ fluctuates randomly. It is assumed that the predicted $P_{DA,t}$ is shown in Figure 8. $Q_{DA,t}$ depends on the load characteristics of users, which are uncontrollable. However, $Q_{y\_day,t}$ is controllable. According to the change trend of $P_{DA,t}$, it increases the distribution proportion of the power curve at a high electricity price and reduces the distribution proportion of the power curve at a low electricity price, as shown in Figure 9. The optimized decomposition method increases $P_{DA\_kWh\_day}$ which is the equivalent kWh cost (EKC) of Q_{y_day}. Therefore, based on the increase in $P_{DA\_kWh\_day}$, C_{DA} will be reduced accordingly, and the total electricity cost will also be reduced.

$$C_{DA} = \sum_{t=1}^{24} (Q_{DA,t} - Q_{y\_day,t}) \cdot P_{DA,t} = \sum_{t=1}^{24} (Q_{DA,t} \cdot P_{DA,t}) - Q_{y\_day} \cdot P_{DA\_kWh\_day} \quad (11)$$

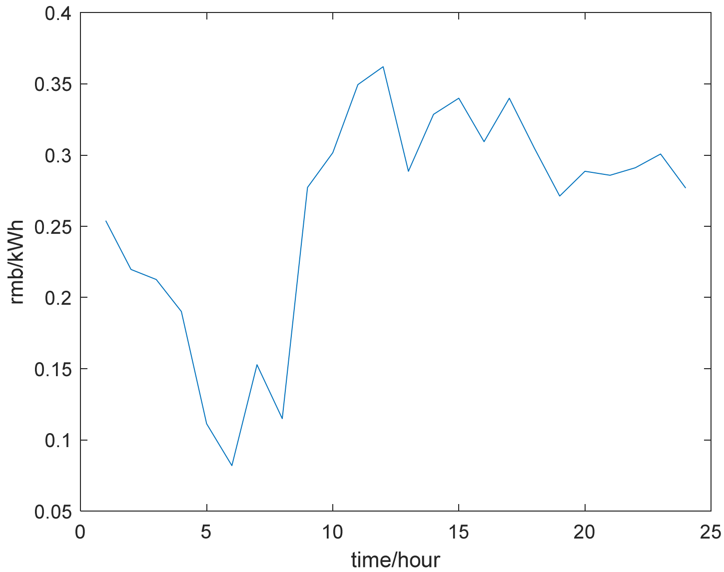

Figure 8. Forecast electricity price in the DA market.

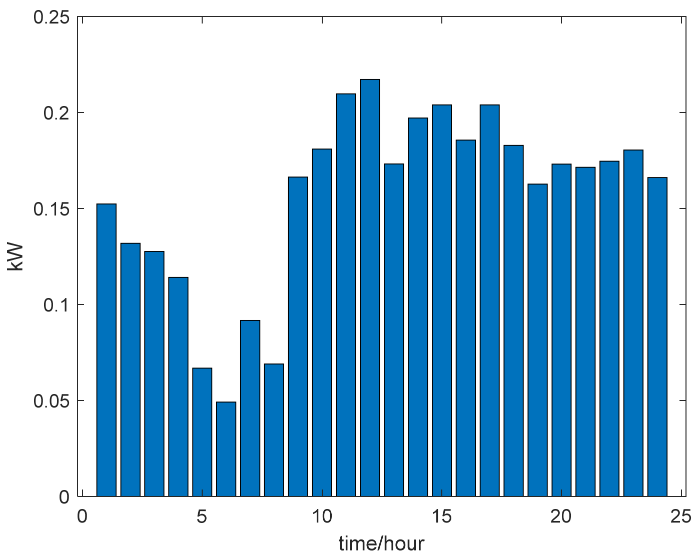

Figure 9. Decomposition load curve of daily electricity.

4.3. Influence of the Electricity Quantity Difference and Electricity Price Difference on the Power Purchase Cost

The electricity difference between $Q_{y\_day,t}$ and $Q_{DA,t}$, as shown in the second term of Equation (8), determines the day-ahead market transactions. Thus, there are two situations when making decisions regarding MALT purchases. The first is that $Q_{y\_day,t}$ is less than $Q_{DA,t}$, which is necessary to purchase supplementary electricity in the DA market. The second is that $Q_{y\_day,t}$ is greater than $Q_{DA,t}$, which is necessary to sell excess electricity in the DA market. The price difference between $P_{Y,t}$ and C_{DA} determines the economy of purchase decision. Analysis of the influential factors of the daily load decomposition curve is shown in Table 2. As P_Y and $P_{Y,t}$ are locked in the transaction at the beginning of the year, the randomness fluctuation of $P_{DA,t}$ will cause electricity cost changes. Electricity retailers need to optimize $Q_{y\_day,t}$ according to $P_{DA,t}$ released by the power trading center 24 h in advance. The following four situations will occur.

- When $P_{Y,t} > P_{DA,t}$ and $Q_{y\_day,t} < Q_{DA,t}$, electricity retailers buy electricity at high prices in the MALT market and replenish the electricity gap at low prices in the DA market.
- When $P_{Y,t} < P_{DA,t}$ and $Q_{y\_day,t} < Q_{DA,t}$, electricity retailers buy electricity at low prices in the MALT market and replenish electricity at high prices in the DA market.
- When $P_{Y,t} > P_{DA,t}$ and $Q_{y\_day,t} > Q_{DA,t}$, the electricity retailers buy surplus electricity at a high price in the MALT market and need to sell it at a low price in the DA market, resulting in a loss.
- When $P_{Y,t} < P_{DA,t}$, and $Q_{y\_day,t} > Q_{DA,t}$, power retailers buy surplus electricity at a low price in the MALT market and need to sell it at a high price in the DA market, resulting in arbitrage income.

Due to the fluctuation of $P_{DA,t}$, any of the above situations may occur randomly in the DA market.

5. Method of Decomposition of Medium- and Long-Term Contract Electricity

According to the analysis of Sections 2 and 3, the electricity decomposition of MALT contracts is an important link between MALT transactions and the spot market. In the former electricity market, electricity retailers allocated annual MALT electricity according to the empirical data of the monthly electricity proportion of the load. In the spot market, electricity retailers need to obtain Q_{y_day} according to the distribution law of annual daily electricity quantity, as shown in No. 3 of Table 2.

The author investigate the electricity decomposition of the generator side in Ref. [11]. The goal of the decomposition of MALT electricity is completing the contract electricity. In [8], the MALT electric quantity is allocated to daily electricity quantity with the goal of reducing the load rate deviation of each generator unit. There are few studies on electricity decomposition on the consumption side. The MALT electricity decomposition of electricity retailers should be based on the proportion of daily power consumption. By searching and investigating load forecasting methods, this paper proposes a method of extracting load characteristics from load forecasting to carry out daily power decomposition.

Through research into MALT load forecasting, we can analyze the relationship between demand development and various factors and establish a mathematical model. Related research methods include regression analysis, the differential autoregressive moving average method, artificial intelligence, and the X12-ARIMA seasonal decomposition method [28–31]. In [32], the authors used the X12 seasonal adjustment method to decompose the change trend of electricity data. The X12 seasonal adjustment method can effectively decompose the trend component series, the seasonal periodic component series, and the random component series in time series data. There are two types of X12 decomposition models: the addition model and the multiplication model. The additive model is suitable for models with relatively stable seasonal cycles and the multiplicative model is suitable for models with obvious changes in the seasonal cycles.

Since the total electricity consumption of the charging station is relatively stable, the MALT electricity transaction is not equal to the annual electricity consumption. Thus, the electricity decomposition can ignore the random fluctuation of actual electricity consumption. It decomposes MALT contract electricity based on daily electricity characteristics through the historical electricity consumption data analysis. As shown in Equation (12), bus charging station operations are suitable for the multiplication model, affected by factors such as different seasons, working days, and holidays. Q_{day} represents the historical daily electricity data; Q_T is the trend component sequence; Q_C is the seasonal cycle component sequence; and Q_I is the random component sequence.

$$Q_{day} = Q_T \cdot Q_C \cdot Q_I \tag{12}$$

According to Equation (12), the decomposition of Q_{year} is based on the trend component series Q_T and periodic component series Q_C of daily electricity consumed. The random component Q_I is ignored. The calculation formula of Q_{y_day} decomposition is shown in Equation (13).

$$Q_{y\_day} = Q_{year} \cdot Q_T \cdot Q_C \tag{13}$$

6. Generation Method of the Declared Load Curve Based on Historical Data in the DA Market

According to the spot market trading rules, electricity retailers need to declare $Q_{DA,t}$ based on the characteristics of the daily load curve. According to the analysis in the Section 3, $Q_{DA,t}$ will affect the decomposition of daily electricity, as shown in No. 4 of Table 2. An accurate $Q_{DA,t}$ value can effectively avoid the deviation assessment in the RT market.

Therefore, it is very important for electricity retailers to analyze and understand the daily load characteristics of their agent users. Based on a large number of historical load curves, this section adopts the principal component analysis (PCA) method to remove random interference factors and obtains representative load curves and scene probabilities through clustering.

6.1. Disturbance Data Processing

The first step is to exclude the influence of random components and extract load curve features from historical data. This section adopts principal component analysis (PCA) [33–35], which can separate the commonness and difference from data vectors and retain the main information of the data.

N is the number of samples of historical data. The data number of each sample of the load is p. The variable $X_{N\times p}$ is the matrix of samples of historical data, as shown in Equation (14). The principal component Y is obtained through the orthogonal transformation matrix $U_{p\times p}$, as shown in Equation (15). The variance λ_j of Y represents the dispersion degree of the sample points on the principal component of j. β_j is the corresponding contribution rate, as shown in Equation (16). Y_{main} is the principal component with a 95% contribution rate. In Equation (17), X_{main} represents the load data that remove the disturbance and retain the main variation.

$$X_{N\times p} = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,p} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,p} \\ \cdots & \cdots & \cdots & \cdots \\ x_{N,1} & x_{N,2} & \cdots & x_{N,p} \end{bmatrix} \tag{14}$$

$$Y = [y_1, y_2, \cdots, y_p] = X_{N\times p} U_{p\times p} = X_{N\times p} \begin{bmatrix} u_{11}, u_{12}, \cdots, u_{1p} \\ \cdots \\ u_{p1}, u_{p2}, \cdots, u_{pp} \end{bmatrix} \tag{15}$$

$$\beta_j = \frac{\lambda_j}{\sum\limits_{i=1}^{p} \lambda_i} \qquad (j = 1, 2, \cdots, p) \tag{16}$$

$$X_{main} = U^T Y_{main} \tag{17}$$

6.2. Typical Scenarios for Load Declaration Curves

Aiming at the periodicity and uncertainty of the load, the representative time series scenes are extracted form historical data, which can reflect the load characteristics [36,37]. The annual load of a charging station varies with the season, changes on weekdays, weekends, and holidays due to operational demand differences, and fluctuates over the day due to peak and valley demands, as shown in Figure 10.

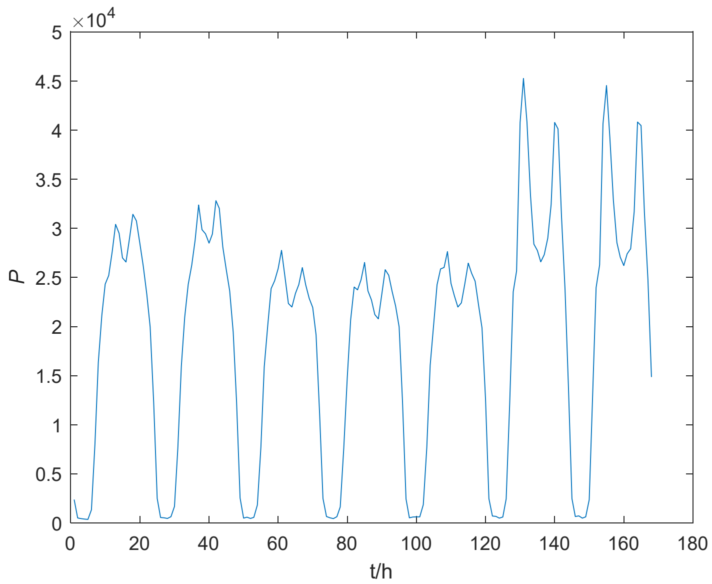

Figure 10. Multi-day load data of charging stations.

Through the scene reduction method, small scene sets are obtained from sequential scenes with a large amount of original data. These can represent the characteristics of the original scene to the greatest extent [38]. Clustering algorithms are widely used in scene reduction. In this paper, the k-means clustering method is used to classify the original scene [39].

The original time series scene S contains N historical data X_{main}. k scene sets are classified, $S_1, S_2, \cdots S_k$, through the k-means clustering method, in which S_i represents all scenes belonging to category i. In Equation (18), these data are the load data belonging to the scene. The average of S_i is the typical load curve of this scenario, as shown in Equation (19). The corresponding scenario probability is shown in Equation (20).

$$\left\{X_{main}^1, X_{main}^2, \cdots, X_{main}^n\right\} \in S_i \tag{18}$$

$$P_i = \sum_{m=1}^{n} X_{main}^m \Big/ n \tag{19}$$

$$pro_i = n/N \tag{20}$$

$P_1, \cdots P_i, \cdots P_k$ represent the typical scene load curve of the charging station, which are equivalent to $Q_{DA,t}$. $pro_1, \cdots pro_i, \cdots pro_k$ represent the corresponding scene probability.

7. Load Curve Decomposition Method

In the DA market, the electricity retailers decompose Q_{y_day} obtained in Section 5 to obtain $Q_{y\_day,t}$ based on $Q_{DA,t}$ obtained in Section 6, as shown in strategy 3 in Table 2.

According to the fluctuation curve of the $P_{DA,t}$, this section adopts the particle swarm optimization (PSO) method to reasonably decompose Q_{y_day} into $Q_{y\_day,t}$, which will be reported to the trading center before the DA market transaction starting. This method can effectively reduce the electricity cost in the DA market.

7.1. Optimization Objective of Load Curve Decomposition

At present, there are few studies on the decomposition of the daily load curve on the electricity consumption side. Referring to the research on the power generation side's power decomposition in the literature [7,9,10,40], the aim of the decomposition of the daily load curve is to reduce the difference in the load rate of the power generation side units with the constraint of the randomness of new energy and the natural conditions of cascade hydropower.

Since this paper seeks to reduce the electricity cost of electricity retailers, the optimization objective function provides the minimization of electricity cost in the DA market, as shown in Equation (21), which complete the decomposition of the daily load curve $Q_{y\_day,t}$.

$$\min C_{DA} = \sum_{t=1}^{24} \left[Q_{DA,t} - Q_{y\_day,t} \right] \cdot P_{DA,t} \tag{21}$$

Based on different typical scenarios mentioned in Section 6.2, Equation (22) is the combined objective function formula of Equation (21). $P_{i,t}$ is the typical load curve in scenario i. pro_i is the probability of the occurrence of this scenario. $Q_{y\_day,t}$ is the optimization target. $P_{DA,t}$ is announced by the trading center, as a known quantity.

$$\min C_{DA} = \sum_{i}^{k} [pro_i \cdot (\sum_{t=1}^{24} (P_{i,t} - Q_{y\_day,t}) \cdot P_{DA,t})] \tag{22}$$

7.2. Constraints

Electricity retailers are different from power generation enterprises. Their main constraint conditions include the total consumption constraint, the maximum power constraint, and the electricity cost constraint.

$$\sum_{t=1}^{24} Q_{y\_day,t} \cdot \Delta t = Q_{y\_day} \tag{23}$$

Δt is the time step of settlement in the DA market. The integral $Q_{y\_day,t}$ with respect to Δt is equal to Q_{y_day}.

$$0 < Q_{y\_day,t} < \min\Big(\max(P_{i,t}), Q_{y\_day}\Big) \qquad (t = 1, 2, \cdots, 24) \tag{24}$$

The load curve power $Q_{y\_day,t}$ should be less than the declaration load $P_{i,t}$ and Q_{y_day} at any time.

$$\begin{cases} C_{DA} < C_{DA\_MEAN} \\ C_{DA} < C_{DA\_PEAK} \end{cases} \tag{25}$$

C_{DA} is the optimized electricity cost obtained by the decomposition method of the particle swarm in the DA market. C_{DA_MEAN} is the electricity cost of the DA market obtained by the decomposition method of the average distribution in 24 h. C_{DA_PEAK} is the electricity cost of the DA market obtained by the decomposition method of the distribution ratio based on the peak-to-valley price. C_{DA} should be less than C_{DA_MEAN} and C_{DA_PEAK}.

7.3. Solution Algorithm

This paper refers to research into dispatching power distribution in power generation plants to select an optimization algorithm. The research into electricity dispatching of power distribution focuses on the fairness of power distribution of multiple generators, the completion of contract power, and the utilization balance of generators. These problems are mostly solved by quadratic programming or the particle swarm algorithm [12,13]. This paper studies the decomposition of the daily electricity of electricity retailers; considering the number of price data in the spot market, it uses the particle swarm algorithm to decompose the load curve, which represents the optimized particles. Optimization of the electricity cost is achieved in the DA market according to the flowchart in Figure 11.

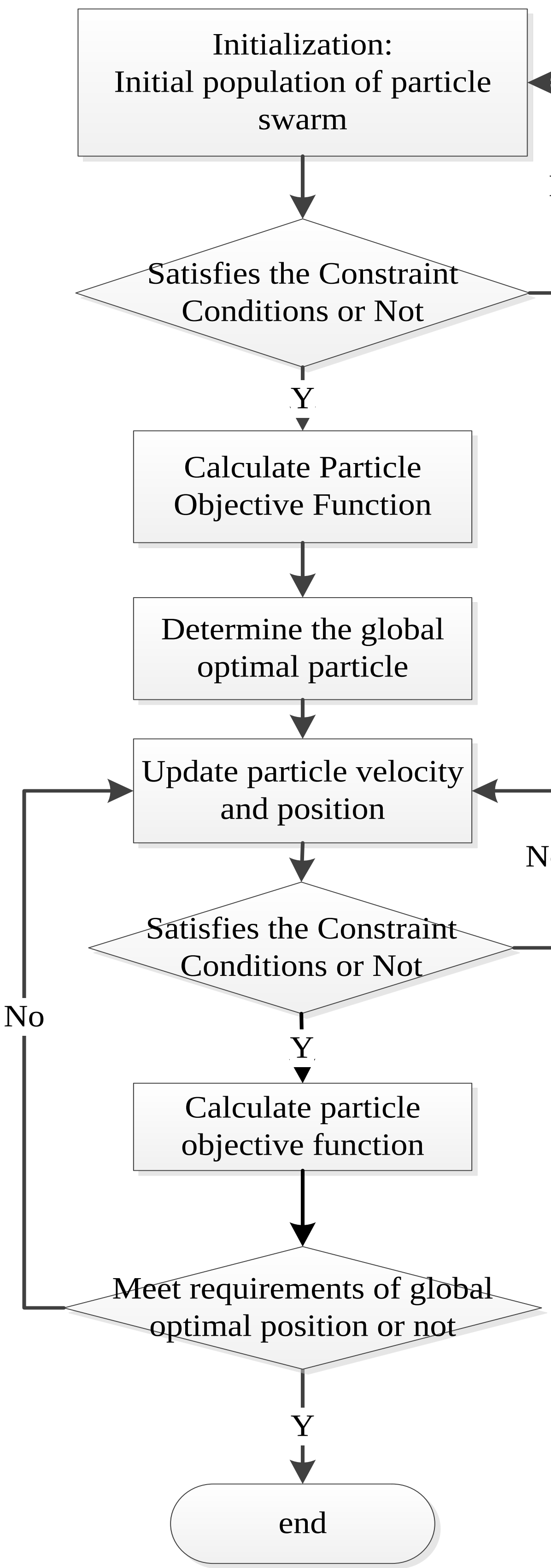

Figure 11. Algorithm flow chart.

8. Case Study

8.1. Contract Electricity Price for Medium- and Long-Term Transactions

According to historical data, the energy consumption of the built bus charging stations is stable. The power consumption of the CSO depends on the annual development of urban public transportation. In 2021, the annual electricity consumption of electric bus charging station operators was about 250 million kWh in Beijing.

In this paper, we assume the deviation of annual purchased electricity consumption to be ±40%. Thus, Q_Y is between 150 million kWh and 350 million kWh. Taking into account the price changes of different types of power sources, this study assumes that the benchmark electricity price P_{basic} is as follows.

$$P_{basic} = [0.25 \quad 0.3 \quad 0.35 \quad 0.4 \quad 0.45 \quad 0.5 \quad 0.55 \quad 0.6] \tag{26}$$

The minimum electricity quantity Q_{basic} in the medium- and long-term contract is 150 million kWh. The increase step of electricity quantity ΔQ is 50 million kWh. The corresponding electricity price step ΔP is −5%. Thus, the corresponding P_Y values are shown in Table 3.

Table 3. Medium- and long-term transaction prices with different benchmark prices.

Benchmark Price Q_Y(kWh) (RMB/kWh)	0.25	0.3	0.35	0.4	0.45	0.5
0~1.5	0.25	0.3	0.35	0.4	0.45	0.5
1.5~2	0.2375	0.285	0.3325	0.38	0.4275	0.475
2~2.5	0.225	0.27	0.315	0.36	0.405	0.45
2.5~3	0.2125	0.255	0.2975	0.34	0.3825	0.425
3~3.5	0.2	0.24	0.28	0.32	0.36	0.4

8.2. Decomposition Method of Medium- and Long-Term Contract Electricity for the Load of Bus Charging Station Operators

According to the historical electricity data P_{data} of Beijing electric bus charging station operators, the electricity consumption varies with the seasons. The highest electricity consumption is in winter. Additionally, it fluctuates periodically at a frequency of seven days, as shown in Figure 12.

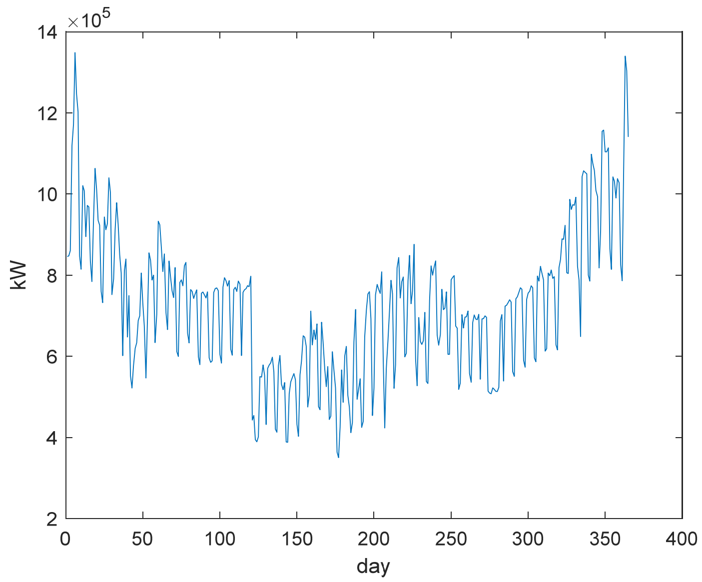

Figure 12. Daily electricity consumption data of charging station operators.

The trend component and periodic component are extracted from daily electricity data P_{data} according to the X12 method. $X12_T$ is the ratio of the trend component in daily electricity to the annual electricity, and $X12_S$ is the ratio of the periodic component to the trend component in daily electricity, as shown in Figure 13. According to the MALT contract electricity Q_Y given in Section 8.1, the decomposition of Q_Y is shown in Figure 13, which can be expressed as $Q_{y\_day} = Q_Y \cdot X12_T \cdot X12_S$.

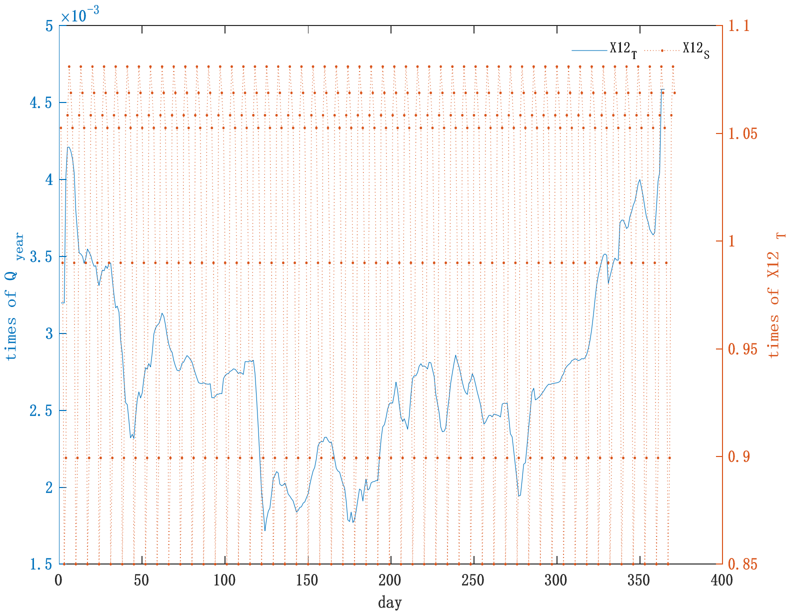

Figure 13. Proportion of trend components and periodic components.

When Q_Y is 250 million kWh, Q_{y_day} is as shown in Figure 14. In Figure 14a, it shows 84 daily electricity types, and in Figure 14b, it shows the occurrence numbers of each decomposed daily electricity types.

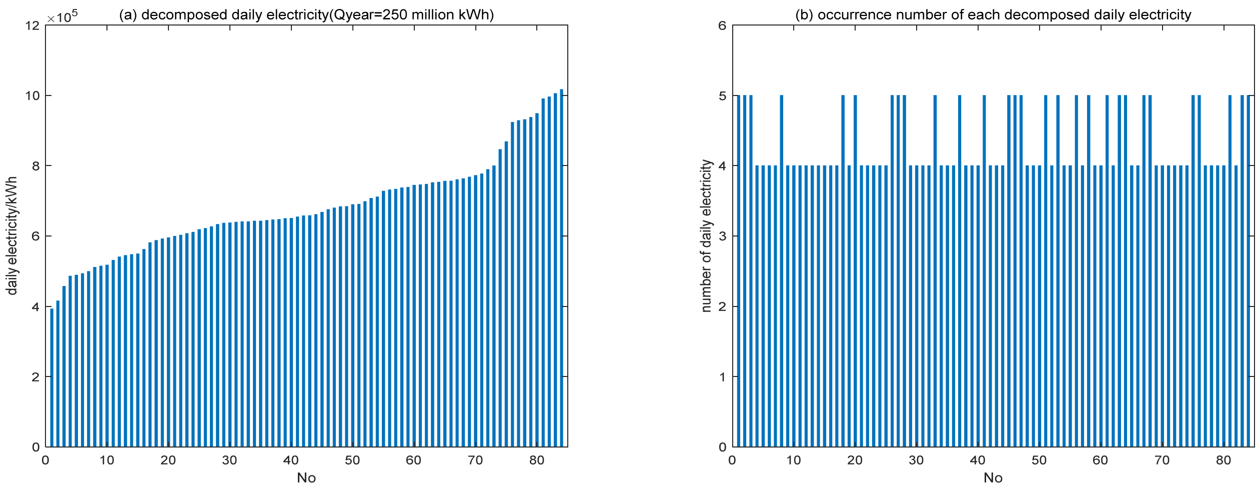

Figure 14. Daily electricity types and the occurrence numbers of different types.

8.3. Generation of the Load Curve Declaration of the Bus Charging Station in the DA Market

At present, the deviation assessment of Guangdong power market is 5%. According to the PCA method in Section 6.1, P_{data_PCA} represents the first four principal components extracted from the annual daily power data P_{data}, and the influence of random disturbance signals within 5% is excluded, as shown in Figure 15. This retains the main characteristics of load data P_{data}.

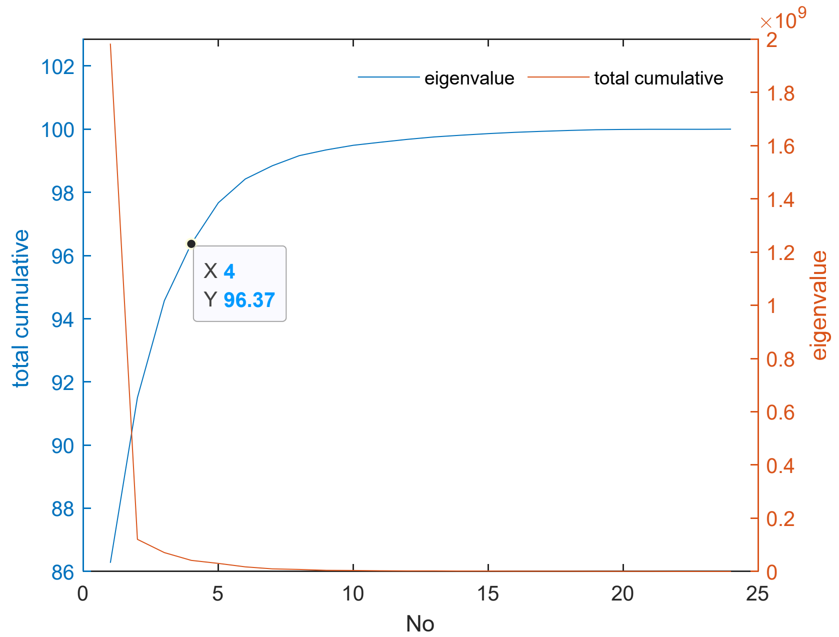

Figure 15. Principal component eigenvalues and cumulative contribution rate of load data.

This process obtains 38 groups of typical load scenarios and the corresponding scenario probabilities through clustering 365 daily load data points by k-means clustering. The typical load scenarios are used as the daily declaration load in the DA market.

8.4. Analysis of Operator's Electricity Cost under the Medium- and Long-Term Trading Strategy

8.4.1. Analysis of Electricity Costs in Medium- and Long-Term Transactions

The influential factors of MALT electricity charges are the benchmark electricity price and electricity price elasticity coefficient. According to Q_Y in Section 7.1, the corresponding electricity cost of the MALT transaction is shown in Figure 16. The electricity cost increases with the increase in the quantity of purchased electricity. When the increase in the electricity quantity leads to a decrease in the electricity contract step price, the cost of electricity will decrease.

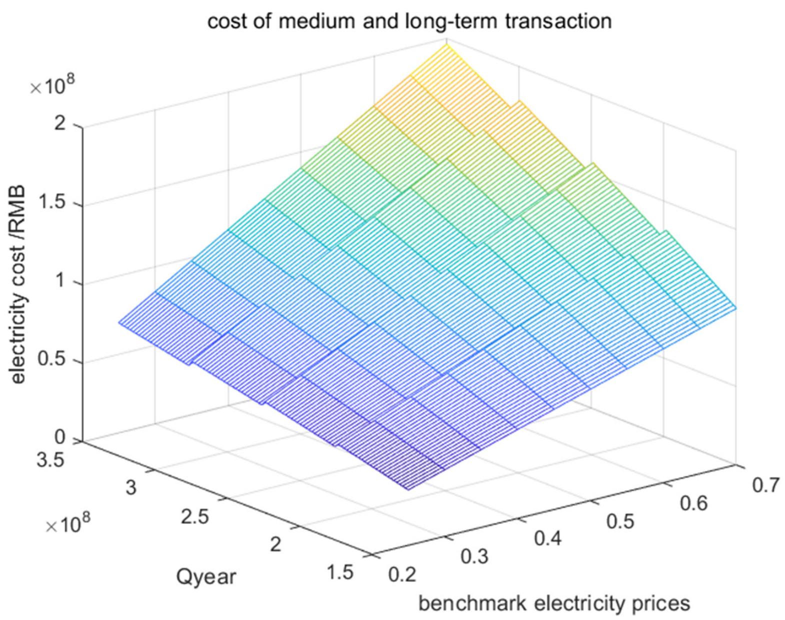

Figure 16. Medium- and long-term electricity costs with different electricity quantities and benchmark prices.

8.4.2. Analysis of the Electricity Cost in the DA Market

In this paper, the prediction error of the daily declared load is ignored. According to the analysis in Section 3.2, the influential factors of C_{DA} are $P_{DA,t}$ and $Q_{y\_day,t}$. $P_{DA,t}$ is shown in Figure 17, in which Figure 17a is the trial operation price curve of Guangdong Province. In order to analyze the impact of different price ranges, the price in Figure 17b is 1.5 times that in Figure 17a. The price in Figure 17c is 2.5 times that in Figure 17a. And the average kilowatt-hour price of three different price is shown in Table 4.

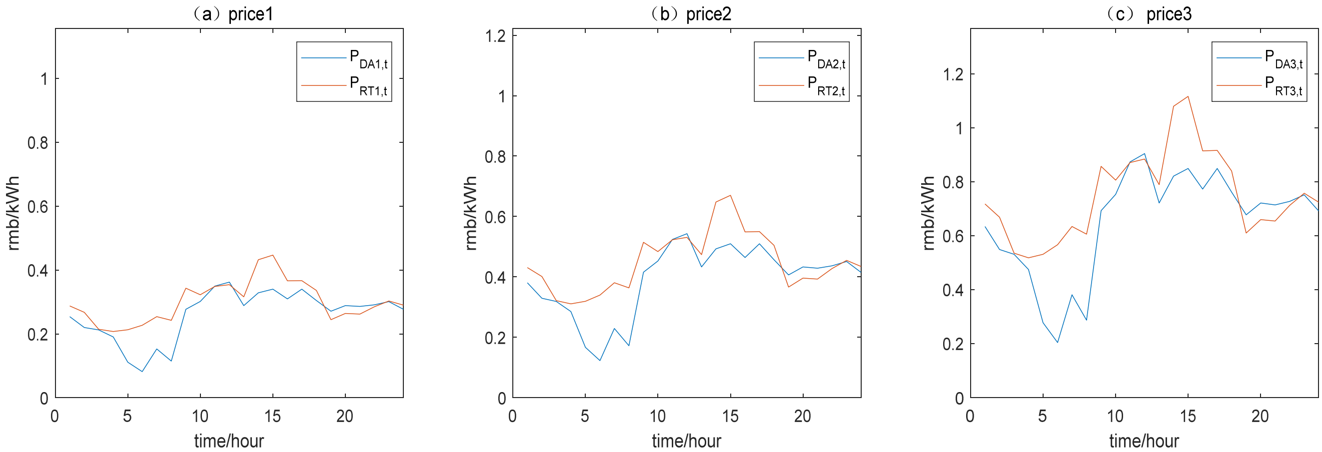

Figure 17. Day-ahead and real-time electricity prices in different ranges.

Table 4. Average kilowatt-hour price based on three DA prices.

	Price1	Price2	Price3
Average kilowatt-hour DA price	0.261	0.391	0.651

Influence of the DA Electricity Price on the DA Electricity Cost

In Figure 18, C_{DA} based on the 24-h average decomposition is shown. Q_{y_day} is obtained through X12 decomposition method, as shown in Figure 14. Based on different DA prices, each DA electricity cost will change. However, when Q_{y_day} is less than the actual electricity consumption, it is necessary to supplement electricity in the DA market. Additionally, C_{DA} is positive. When Q_{y_day} is greater than the actual electricity consumption, the excess electricity needs to be sold in the DA market. Additionally, C_{DA} is negative. Therefore, the overall C_{DA} decreases with the increase in Q_{y_day}, and the downward trend remains unchanged.

Impact of the Decomposition Strategy on the Day-Ahead Electricity Cost

There are three electricity decomposition strategies: the decomposition strategy of the average distribution in 24 h, the decomposition strategy of the peak-to-valley price proportion distribution, and the decomposition strategy of the particle swarm method.

The variable dimension of PSO is 24 based on the time step in the DA market. The swarm sizes is 300, and the number of iterations is 3000. The convergence criterion is specified in Section 7.2, which can obtain the minimum of all iteration results below C_{DA_PEAK} and C_{DA_MEAN}. The software code was debugged by MATLAB 2019. The hardware used was a Dell workstation. The consumption used in the decomposition of the average distribution was 2.632837 s. The consumption used in the decomposition of the proportion distribution was 2.681714 s. The consumption used in the decomposition of PSO was 319.725981 s.

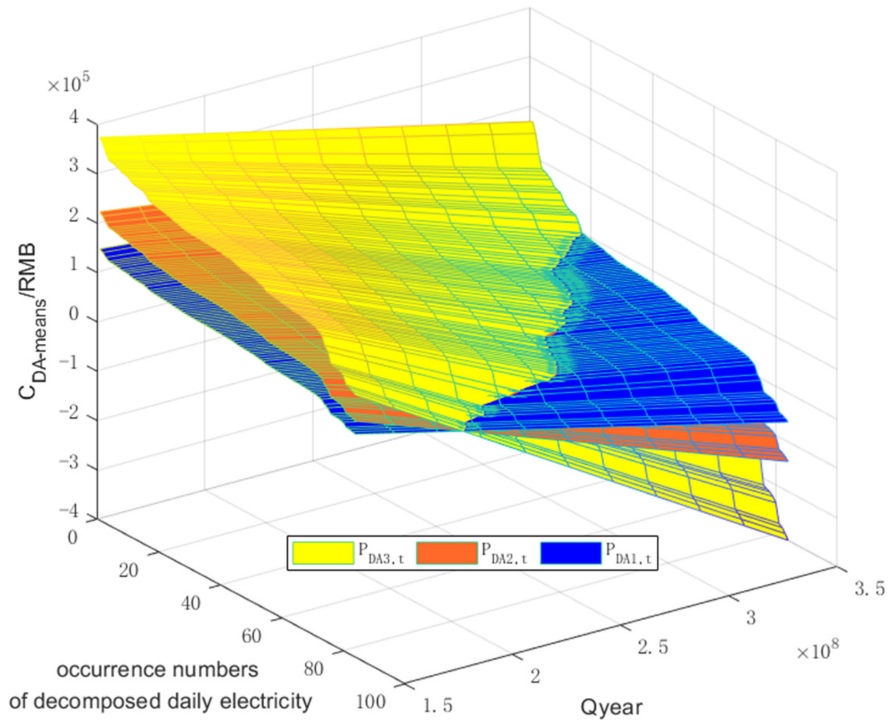

Figure 18. Electricity cost in the DA market based on 24-h average decomposition.

In Figure 19, the decomposition results with the three decomposition strategies are shown. The purpose of decomposition optimization is to increase the cost proportion of $Q_{y\_day,t}$ in the DA market, which is subtracted in Equation (11). Therefore, the higher the equivalent kWh cost (EKC) of $Q_{y\_day,t}$, the lower C_{DA} is. In Table 5, the EKC of three different decomposition methods is given. Additionally, it can be seen that the EKC of PSO is the highest.

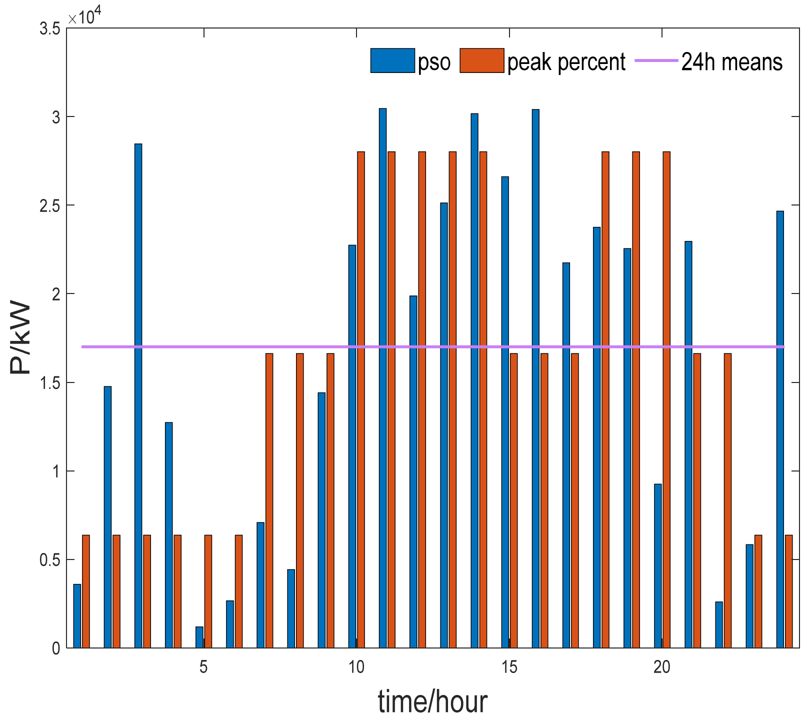

Figure 19. Three decomposition strategies of the load curve in the DA market.

Table 5. Average kilowatt-hour price based on three DA prices.

	Price1 (¥/kWh)	Price2 (¥/kWh)	Price3 (¥/kWh)
Average kilowatt-hour DA price	0.261	0.391	0.651
EKC of average distribution in 24 h	0.261	0.391	0.651
EKC of peak-valley proportion distribution	0.283	0.4245	0.7075
EKC of PSO decomposition	0.2868~0.2887	0.4282~0.4349	0.7168~0.7250

In Figure 20, when Q_Y is 250 million kWh, the corresponding electricity costs C_{DA_means}, C_{DA_peak} and C_{DA_pso} based on Price1 are shown, in which C_{DA_means} of all decomposed daily electricity types is the highest and C_{DA_pso} of all decomposed daily electricity types is the lowest. Based on Price2 and Price3, C_{DA_pso} is the lowest cost. Therefore, the decomposition strategy of PSO can obtain the lowest C_{DA} under random $P_{DA,t}$ with any decomposed daily electricity.

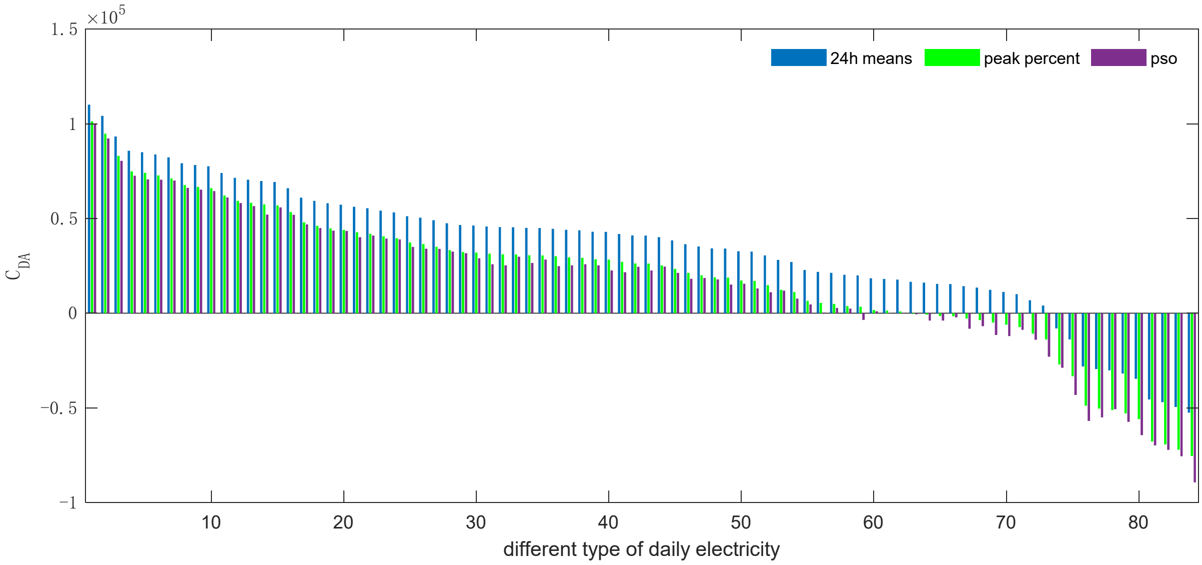

Figure 20. Electricity costs C_{DA_peak} C_{DA_pso} and C_{DA_means} in the DA market.

8.4.3. Electricity Cost and Deviation Assessment Cost in the RT Market

The main influential factor of C_{RT} is the deviation between $Q_{RT,t}$ and $Q_{DA,t}$. Based on the method described in Sections 6.1 and 8.3, the typical scene's load based on PCA is $Q_{DA,t}$. C_{RT} is calculated based on the load history data P_{data} and $P_1 \sim P_K$ of a typical load scenario. C_{RT_PCA} is calculated based on a typical load P_{data_PCA} with PCA and $P_1 \sim P_K$ of a typical load scenario. As shown in Figure 21, C_{RT} and C_{RT_PCA} are basically consistent. Thus, the main features of the original data P_{data} are effectively retained in a typical load X_{main} of principal component extraction.

This paper mainly analyzes the impact of the transaction strategy. Thus, the calculation uses historical data and ignores the impact of load forecast errors. According to the 5% deviation assessment range and two times the deviation assessment coefficient specified by the Guangdong power market, the annual deviation assessment was calculated according to three spot prices in Figure 16, as shown in Table 6.

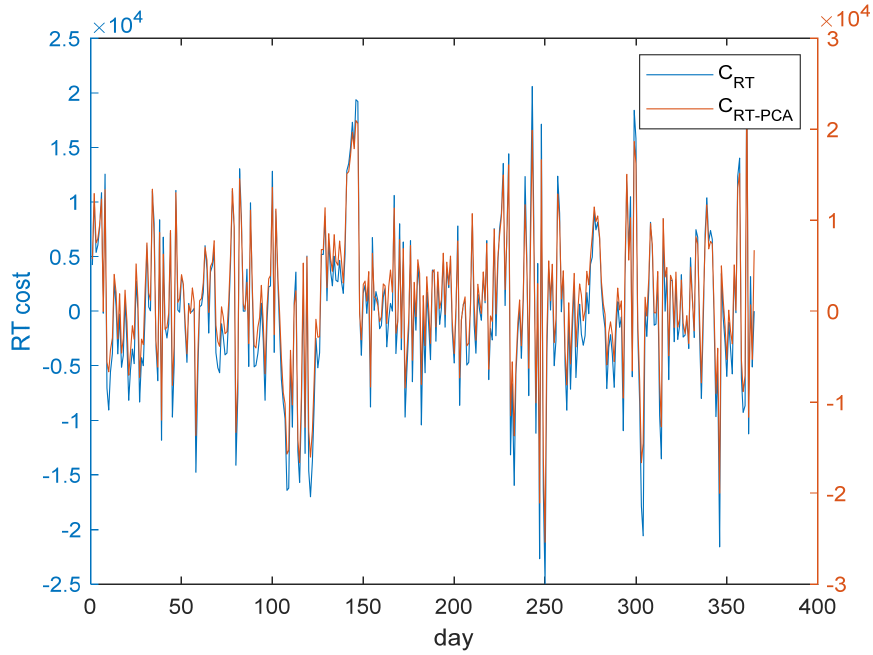

Figure 21. Electricity cost of the original load data and electricity cost of a typical load of the principal component extraction in the RT market.

Table 6. Annual deviation assessment with three spot prices.

	Price1	Price2	Price3
Annual deviation assessment (RMB)	434,677	652,015.6	1,086,692.7

8.4.4. Analysis of the Influential Factors of the Transaction Strategy on Electricity Costs

Influence of Medium- and Long-Term Electricity Quantity on Electricity Costs

According to historical data analysis, the annual electricity consumption of Beijing's electric bus charging station system is 264.5 million kWh. Additionally, the annual electricity cost is RMB 264.9 million according to the peak and valley electricity price in Beijing. If the operator participates in the electricity market transaction, the MALT transaction electricity cost can be greatly reduced.

It is assumed that the $P_{DA,t}$ of the whole year is similar to the trial price in which the EKC range of the average distribution decomposition is less than 0.3/kWh. The change in the total electricity cost corresponding to the change in Q_Y is shown in Figure 22. As shown in Table 3, if the medium- and long-term benchmark electricity price is higher than RMB 0.4/kWh, P_Y is always higher than EKC with the increase in Q_Y, which leads to an increase in the total electricity cost. If the medium- and long-term benchmark electricity price is lower than RMB 0.4/kWh, P_Y may be lower than EKC with the increase in Q_Y, which leads to a decrease in the total electricity cost.

Influence of the DA Electricity Price on Electricity Costs in the Spot Market

Taking the benchmark price of RMB 0.5/kWh as an example, based on the three electricity prices type in Figure 16, the annual electricity costs corresponding to the three decomposition strategies are calculated, as shown in Figure 23. Based on Price1, which is the lowest DA price, the total electricity cost will increase with an increase in Q_Y, as shown in Figure 23a. Based on Price3, which is the highest DA price, the total electricity cost will decrease with an increase in Q_Y, as shown in Figure 23c. Based on Price2, the change trend of the total electricity cost varies according to different stages of Q_Y and P_Y, as shown in Figure 23b.

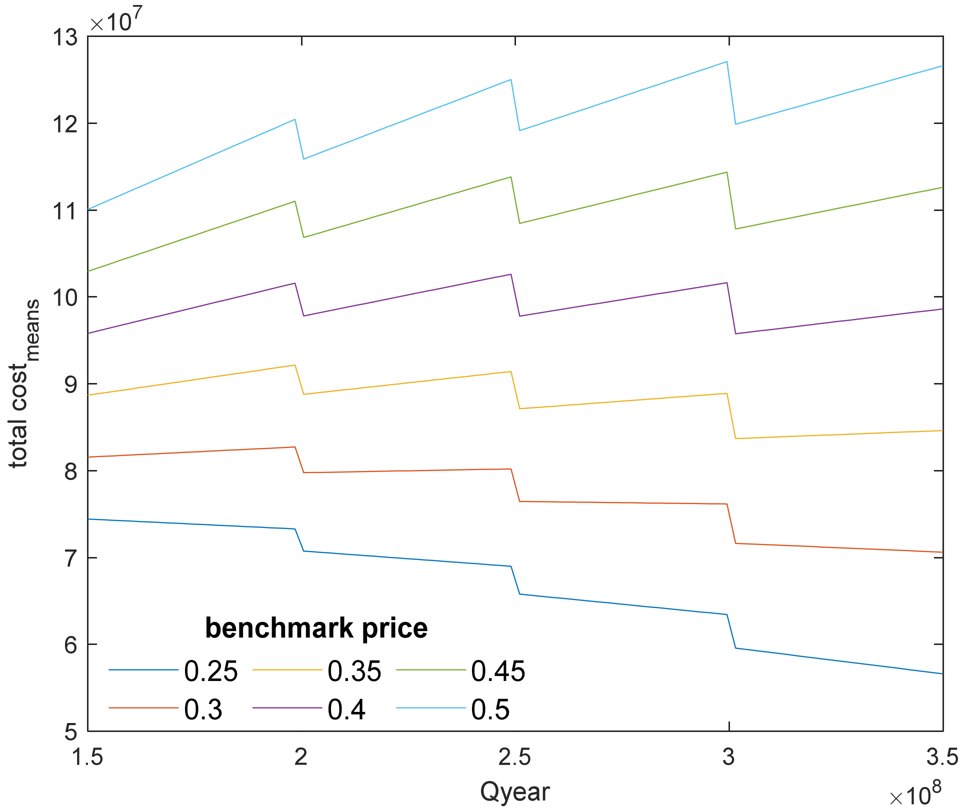

Figure 22. Trend of the total electricity cost under different medium- to-long-term benchmark electricity prices.

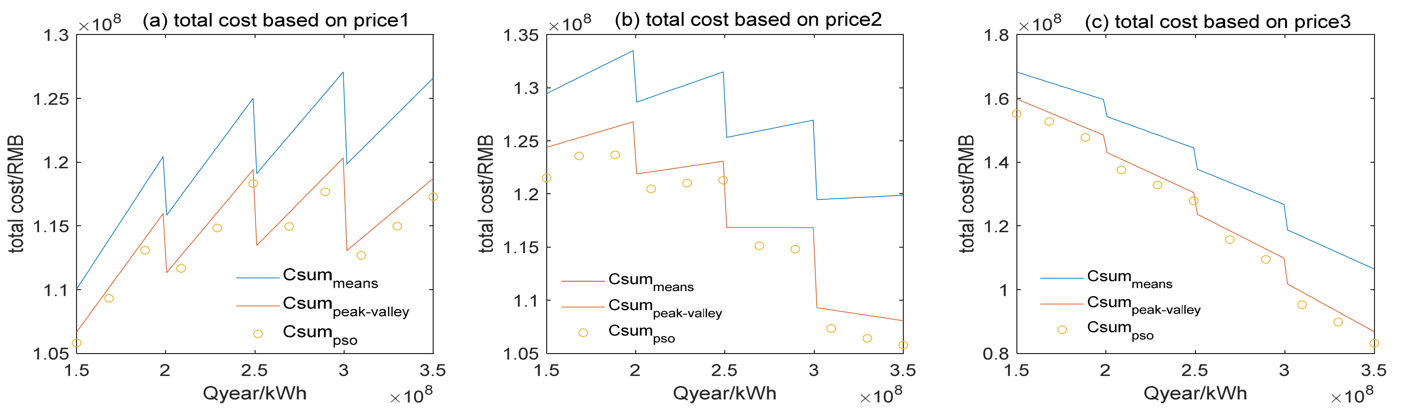

Figure 23. The influence on the total electricity cost with different medium- and long-term electricity quantities based on three spot market electricity prices.

In Figure 23, the difference in three price types is due to the difference between $P_{DA\_kWh\_day}$ and P_Y. Q_Y does not affect the $P_{DA\_kWh\_day}$ of different decomposition methods, but the increase in Q_Y leads to a decrease in P_Y. The relationship between the $P_{DA\_kWh\_day}$ of the PSO decomposition based on Price2 and P_Y is shown in Figure 24. When this $P_{DA\_kWh\_day}$ is greater than P_Y, Q_Y is higher, and the total cost is lower. When this $P_{DA\_kWh\_day}$ is lower than P_Y, Q_Y is higher, and the total cost is higher.

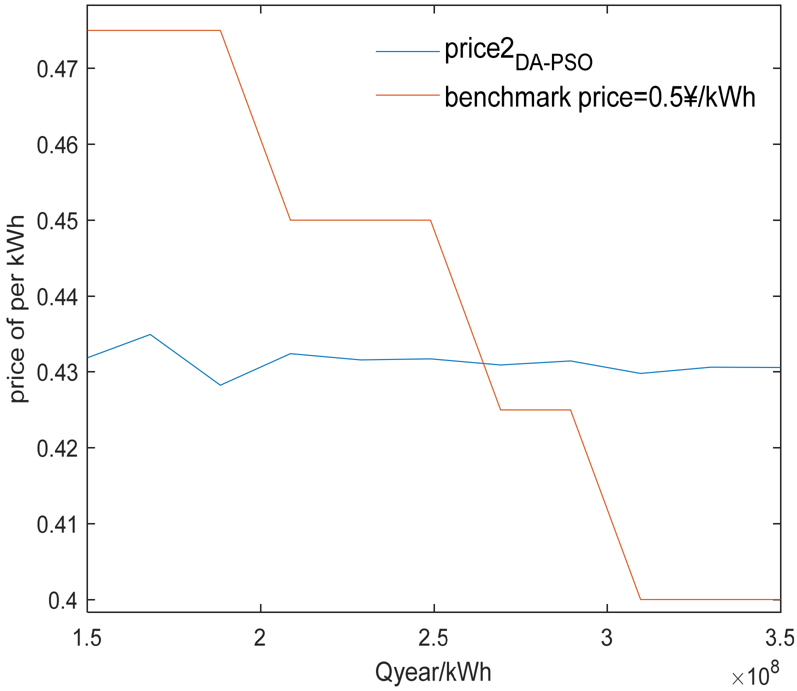

Figure 24. The relative relationship between the EKC of PSO decomposition based on Price2 and the long-term contract electricity price.

Influence of Generation Unit Selection on the Total Electricity Cost

Due to the volatility and randomness of the electricity price in the spot market, this paper presents different EKCs of PSO decomposition corresponding to three DA price curves type, as shown in Figure 25. According to the benchmark price of the power generation unit introduced in Section 4.1, the benchmark price of photovoltaic power generation is RMB 0.25/kWh. Additionally, the benchmark price of coal-fired power is RMB 0.5/kWh.

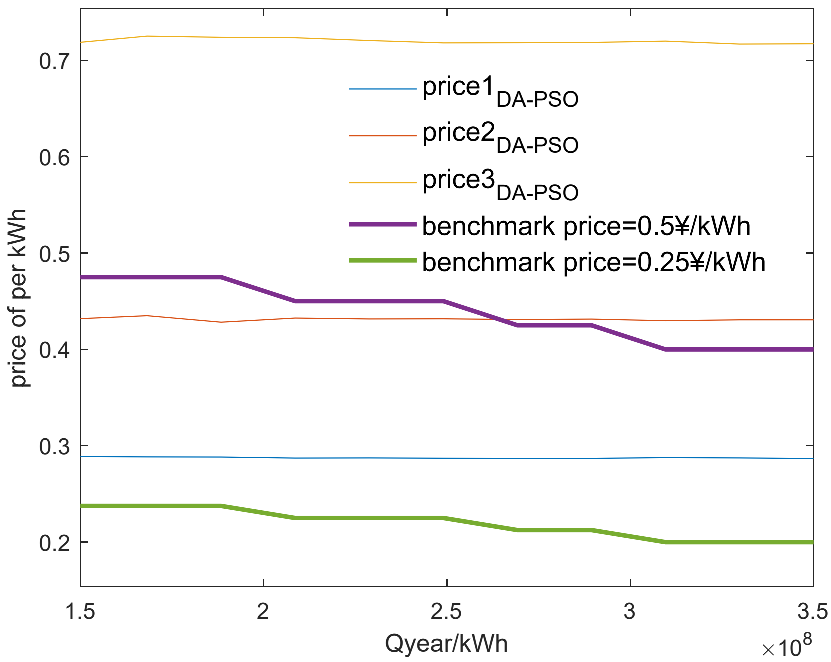

Figure 25. Itemized electricity cost and total electricity cost (medium- and long-term benchmark electricity price: RMB 0.25/kWh).

As shown in Figure 25, if the bus charge station operator signs a medium- or long-term contract with a photovoltaic power station, the EKC is higher than P_Y. The greater the Q_Y, the lower the cost. If the bus charge station operator signs a medium- or long-term contract with a coal-fired power plant and the DA price range is similar to Price2, when Q_Y is less than 260 million kWh, the EKC is lower than P_Y. Thus, the total electricity cost will be reduced by reducing Q_Y.

8.4.5. Comprehensive Influence of Various Factors on the Total Electricity Cost

MALT trading decisions involve many factors. In Section 8.4, we analyze the influential factors of the total electricity cost from the selection of the MALT benchmark electricity price, the selection of MALT contract electricity quantities, DA market electricity price change, and different decomposition strategies.

Electricity retailers need to forecast the fluctuation range of the DA price in the spot market when selecting medium- and long procurement power sources and determining contract quantities, as shown in Figure 26. If the DA price range is similar to Price3, it is indicated that the DA price in the spot market will be high, and the benchmark price of each power source is relatively low in MALT transactions. The larger the Q_Y, the lower the total electricity cost. If the DA price range is similar to Price1 and Price2, in the range where P_Y is lower than the EKC of PSO decomposition, an increase in Q_Y can reduce the cost. In the range where P_Y is higher than the EKC of PSO decomposition, a reduction in Q_Y is beneficial to reducing the electricity cost.

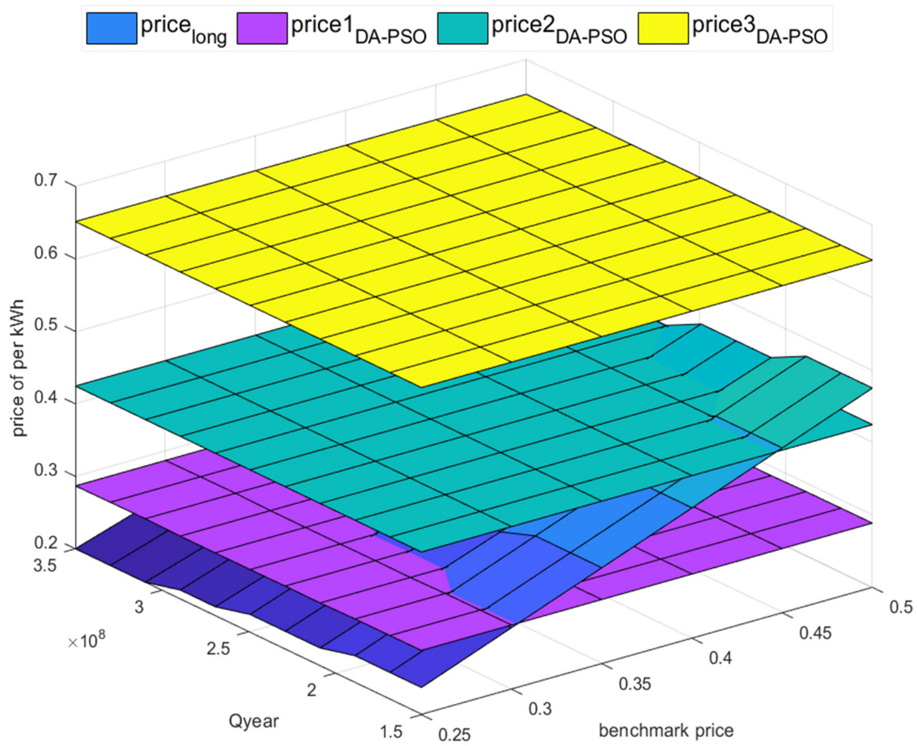

Figure 26. Relationship between the EKC of PSO decomposition and the long-term electricity price based on different DA prices in spot markets.

According to the comparison of the three decomposition strategies, it can be clearly concluded that the PSO decomposition method can effectively reduce the cost of electricity. As shown in Figure 27, the EKC of PSO decomposition is higher than the other two decomposition methods, which can reduce the electricity cost in the DA market. Thus, the PSO decomposition method is the optimal option for electricity retailers.

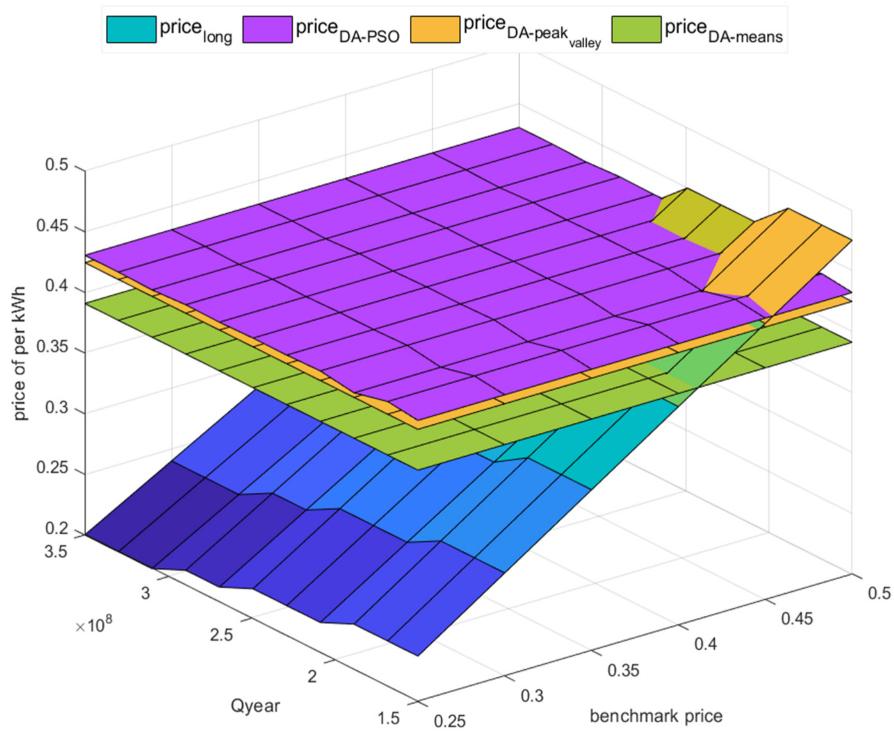

Figure 27. The relationship between the EKC of the three decomposition strategies and the medium- and long-term electricity prices.

9. Conclusions

Based on the analysis of the rules of China's power spot market, in order to guide electricity retailers to participate in the electricity market, which combines the medium- and long-term market and the spot market, this article investigates transaction decision-making strategies for the three influential factors, which are the medium- and long-term electricity quantity and the medium- and long-term contract price, the decomposition strategy of daily electricity, and the decomposition strategy of the daily load curve. In order to obtain the lowest electricity price in medium- and long-term transactions, it is necessary to determine the electricity quantity and benchmark price, considering the influence of the price elasticity coefficient. The X12 method can effectively extract the annual electricity fluctuation characteristics. The decomposition strategy of daily electricity based on X12 is the most reasonable method that combines the medium- and long-term market and the spot market. In the decomposition strategy of the daily load curve, this article introduces three decomposition methods, among which the particle swarm optimization method is the best way to increase the equivalent per kilowatt-hour cost in the DA market. Through the analysis of all impact factors, it can be seen that the three decision-making strategies comprehensively affect the relative relationship between the electricity price of medium- and long-term contracts and the equivalent per kilowatt-hours price in the DA market. Electricity retailers should choose the purchase object based on the range of equivalent per kilowatt-hours price in the DA market. If the price range of equivalent per kilowatt-hours of the whole year is higher than the electricity price of medium- and long-term contracts, retailers should increase the electricity quantity of medium- and long-term contracts.

Through the above research, taking Beijing's electric bus charging station operator as the studied case, CSOs decomposed daily electricity based on the X12 method, obtained the declaration of the load curve based on PCA and typical scenarios, and completed decision making on the electricity quantity and power type of medium- and long-term transactions based on the equivalent price per kilowatt-hours through the PSO method. The case analysis proves that the complete strategy steps in the paper can help electricity retailers to achieve a lower electricity cost.

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Abbreviations

CSO	Charging station operator
EV	Electric vehicle
PCA	Principal component analysis
MALT	Medium- and Long-Term
DA	Day-ahead
RT	Real-time
EKC	equivalent kWh cost
Q_Y	Contract electricity of medium- and long-term market transactions
Q_{y_day}	Daily energy that is decomposed from medium- and long-term contract
$Q_{y\_day,t}$	electricity in day-ahead market
P_Y	Load curve that is decomposed from Q_{y_day} in the day-ahead market
$P_{Y,t}$	Contract price of medium- and long-term market transactions
$Q_{DA,t}$	Medium- and long-term electricity price of each time step of P_Y
$Q_{RT,t}$	Day-ahead market declaration load
$P_{DA,t}$	Real-time load
$P_{RT,t}$	Real-time market electricity price
λ_0	Deviation assessment range
K_P	Deviation assessment coefficient
C_{long}	Daily electricity fee for medium- and long-term transactions
C_{long_year}	Annual purchase cost of medium- and long-term transactions
C_{DA}	Electricity fee in the day-ahead market
C_{RT}	Electricity fee in the real-time market based on real load data
C_{RT_PCA}	Electricity fee in the real-time market based on load data through PCA
$E_{allocation}$	Deviation assessment cost
E_{day_sum}	Total daily power purchase cost
P_{basic}	Benchmark electricity price
Q_{basic}	Corresponding minimum electricity purchase
ΔQ	Increase in electricity purchased
ΔP	Decrease in electricity price
Q_T	Trend component sequence
Q_C	Seasonal cycle component sequence
Q_I	Random component sequence
$X_{N \times p}$	Sample matrix of the load of historical data
Y	Principal component
λ_j	Variance of principal component Y
β_j	Contribution rate
Y_{main}	Principal component with a 95% contribution rate
X_{main}	Load data that remove the disturbance and retain the main variation
S_i	Scenes belonging to category i, which contains historical data X_{main}
P_i	Typical scene load curve of scenes S_i

pro_i	Scene probability of scenes S_i
$P_{i,t}$	Typical load curve of each time step of P_i
C_{DA_MEAN}	Electricity cost of the DA market based on the decomposition method of the average distribution in 24 h
C_{DA_PEAK}	Electricity cost of the DA market based on the decomposition method of the distribution ratio based on the peak-to-valley price.
C_{DA_pso}	Electricity cost of the DA market based on the decomposition method of the decomposition strategy of the particle swarm method
$P_{DA\_kWh\_day}$	Equivalent per kilowatt-hour cost in the DA market
$X12_T$	Ratio of the trend component in daily electricity to the annual electricity
$X12_S$	Ratio of the periodic component to the trend component in daily electricity
Δt	Time step of the daily settlement day

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