Research on Demand side Reactive Power Compensation Operating Lease Mode to Adapt to the New Situation of Energy and Electricity

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Abstract. With the development of economy towards green and low-carbon, higher requirements are put forward for energy conservation and efficiency enhancement of power system. To solve the problem of high initial investment and high risk of demand side reactive power compensation, this paper proposes a demand side reactive power compensation operating lease model. Power grid companies and equipment manufacturers combine service providers to undertake different division of labor and jointly serve users. The cost-benefit model of each participant is established, Optimize service fees with the goal of maximizing the net income of both users and service providers, and solved by chaotic cat swarm algorithm, An asymmetric Nash negotiation model is established to allocate service fees between power grid companies and equipment manufacturers. Finally, an example is given to demonstrate the effectiveness of the proposed method.

Keywords: Operating, lease, Reactive compensation, Business model, Chaotic cat swarm algorithm, Asymmetric Nash Negotiation.

1. Introduction

With the development of China's economy towards green and low-carbon, in addition to meeting the needs of people's daily life and production, higher requirements have been put forward for energy conservation and efficiency enhancement of the power system [1-3]. The line loss of the distribution network accounts for a large proportion of the active power loss of the power system. Reasonable reactive power compensation on the demand side is of great significance in reducing the line loss of the distribution network, ensuring the user's electricity experience, and improving the reliability of power supply of the distribution network [4-8]. In order to promote the demand side reactive power compensation of users, each country has its own incentive scheme, so many users have a strong desire to carry out reactive power compensation. However, when some users carry out demand side reactive power compensation on their own, they encounter difficulties in capital, technology and other aspects, and need to seek external help. If the grid company can provide a service mode beneficial to all parties, it has important practical significance to promote demand side reactive power compensation.

For the demand side reactive power compensation incentive mode and high-quality power supply service, there are a lot of research at home and abroad. Paper [9] puts forward the theory of reactive power spot price. Reactive power real-time pricing model attaches importance to the operation efficiency of power market, which can promote the competition in reactive power in power market. Paper [10] proposed some compensation for the part where reactive power pricing is lower than reactive power cost. The method proposed in paper [11] takes the minimum production cost of

reactive power as the objective function, decomposes active power and reactive power, and then determines reactive power pricing once. Paper [12] puts forward the scheme and optimization strategy for adjustment by three types of users, and based on actual data, the feasibility of the scheme is verified by an example. Paper [13], based on the complete statistical information of reactive power assessment users, takes the number of substandard users and substandard reactive power as the key optimization index, weighs progressiveness and feasibility, and proposes the optimization and improvement scheme of power factor assessment index.

This paper proposes a demand side reactive power compensation operating lease model to adapt to the new situation of energy and power, describes in detail the participants and operation mode under this model, constructs a multi-objective optimization model for pricing the service charge of demand side reactive power compensation, solves the service charge of demand side reactive power management with chaotic cat swarm optimization algorithm, and then, based on the improved Nash game, we can reasonably distribute the interests among the participants.

2. Demand side reactive compensation operating lease mode

The grid has a certain assessment standard for the power factor of high-power users. When the power factor is lower than the assessment standard, a certain proportion of power rate charge shall be added; On the contrary, when the power factor is higher than the assessment standard, a certain proportion will be awarded. Therefore, many users often increase the power factor by investing reactive power compensation devices, so as to obtain benefits from electricity costs. However, due to lack of capital or technology, some users are difficult to carry out demand side reactive power compensation on their own.

At present, the operating lease mode of demand side reactive compensation is designed for the above situation. The interest of demand side reactive power management under this mode is related to three parties: users, power companies and equipment manufacturers. The tripartite relationship under the three modes is shown in Fig. 1.

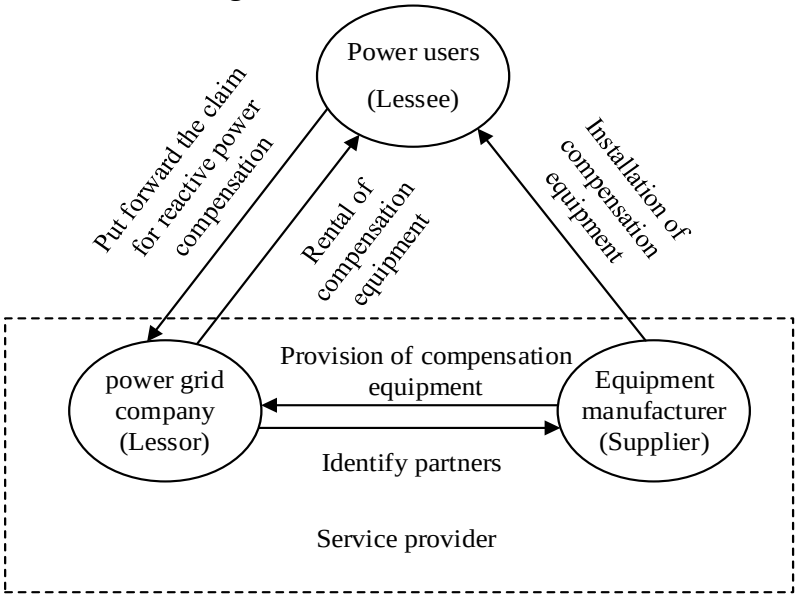


Fig. 1 Tripartite relationship under operating lease mode

The operation lease mode of reactive power compensation on the demand side is operated according to the following process:

First of all, users with demand propose to the power grid company to improve the reactive power factor, and the power grid company look for cooperative equipment manufacturers according to user needs to jointly serve users.

After the service provider and the user have agreed on a cooperation scheme, the three parties sign a lease contract. When the lease contract comes into force, the equipment manufacturer will install

and commission the compensation equipment at the user's side, and be responsible for the maintenance of the equipment to enable the stable operation of the equipment during the contract period.

During the contract period, the user shall pay a fixed service fees to the service provider on a regular basis every year, and the service provider shall distribute the service fees in proportion according to the cooperation contract.

After the lease contract is completed, the user can negotiate with the grid company on the follow-up cooperation mode according to their own needs.

3. Analysis on the pricing model of reactive power compensation service charge on the demand side

During the lease term, the user only has the right to use the compensation equipment, and the manufacturer still has the ownership of the compensation equipment; Users and equipment manufacturers will no contact directly, their are connected by the power grid company. The service provider have to consider the costs of equipment manufacturers and power grid companies at the same time, ensure that both parties can obtain ideal benefits from service fees. During the lease term, the user input costs include: service fees, operation and management costs, and its income is the reduced electricity expense after reactive power compensation. The service providers input costs includes: initial investment cost, operation and maintenance cost, failure cost and depreciation cost, and its income is service fees.

3.1. Cost benefit model of each participant

3.1.1. Cost benefit model on grid side

Under the operating lease mode, the grid side cost includes the user's electricity charge reduction and design consulting service fees. According to the current domestic electricity tariff policy, the corresponding electricity consumption cost will be different when users are at different power factors. With the increase of the power factor when users input reactive power compensation equipment, the electricity purchase cost of users will also be reduced,; The design consulting service fees refers to the labor cost generated by the design consulting service provided by the power grid according to the user's compensation demand. The specific model is:

$$C_{\mathrm{d}} = \Delta k \cdot E \cdot \pi_e + C_{\mathrm{sd}} \tag{1}$$

In the above formula, Δk is the difference of the user's corresponding electricity charge adjustment proportion before and after reactive compensation; E is annual power consumption for users; π_e is the electricity price; C_{sd} is Annual design consulting service fees.

Under the operating lease mode, the grid side revenue includes the reduction of line loss and the fees charged from the operating lease contract. The specific model is:

$$B_{\mathrm{d}} = \Delta E \cdot \pi_e + \beta \cdot F \tag{2}$$

In the above formula, ΔE is annual reduced line loss for reactive compensation; E is annual power consumption for users; π_e is the electricity price; F is annual rent specified in the contract; β is percentage of rent charged by grid side.

3.1.2. Cost benefit model of equipment manufacturers

Under the operating lease mode, the equipment manufacturer's costs include the depreciation of fixed assets and the maintenance costs of reactive power compensation devices. Depreciation of fixed assets refers to the expenses of the reactive compensation devices invested by the equipment manufacturers, which are accrued at the annual depreciation rate; The maintenance cost of reactive

power compensation device includes the maintenance cost of auxiliary parts, the cost of human resources for operation and maintenance and the cost of fault maintenance. The specific model is:

$$C_s = Q \cdot C_o \cdot \mu + C_{lab} + C_I \tag{3}$$

In the above formula, Q is rated output of purchased reactive power compensation device(kvar); C_o is unit purchase cost of reactive power compensation device(kvar/RMB); μ is annual depreciation rate; C_{lab} is annual maintenance cost of reactive power compensation device; C_I is transportation and commissioning cost of equipment.

Under the operating lease mode, the equipment manufacturer's side revenue is the rent specified in the operating lease contract. The specific model is:

$$B_s = (1-\beta) \cdot F \tag{4}$$

In the above formula, β is percentage of rent charged by grid side; F is annual rent specified in the contract.

3.1.3. Customer side cost-benefit model

Under the operating lease mode, the user side cost includes the annual operating cost of the reactive power compensation device, the cost of land resources occupied by the reactive power compensation device, and the payment amount specified in the operating lease contract, and its cost is converted into each year. The specific model is:

$$C_u = F + C_g \tag{5}$$

In the above formula, F is annual rent specified in the contract; C_g is annual operation cost of reactive power compensation device.

Under the operating lease mode, the user side income is the user's reduction of electricity charges. According to the current domestic electricity tariff policy, the corresponding electricity consumption cost will be different when users are at different power factors. With the increase of the power factor when users input reactive power compensation equipment, the electricity purchase cost of users will also be reduced. The specific model is:

$$B_u = \Delta k \cdot E \cdot \pi_e \tag{6}$$

In the above formula, Δk is the difference of the user's corresponding electricity charge adjustment proportion before and after reactive compensation; E is annual power consumption for users; π_e is the electricity price.

3.2. Optimization model of reactive power management service fees on demand side

Set the maximization of the total net income of users and the total net income of power grid companies and investment equipment manufacturers within the lease term as the objective function, and build a multi-objective optimization model.

3.2.1. Objective Function

The economic benefit of service providers is the rental fees charged. The higher the rental fees, the higher the overall income of power companies and equipment manufacturers; For users, the lease fee is the cost of reactive power compensation. Users expect that the lower the service fees, the better. The objective contradiction between service providers and users, this paper selects the maximization of total net income f_1 of users and the maximization of total net income f_2 of service providers during the lease term as the objective function to build a multi-objective optimization model, and the optimization variable is annual rent F. The optimization objective function is as follows:

$$\begin{cases} \max \ f_1 = B_u - C_u \\ \max \ f_2 = B_d + B_s - C_d - C_s \end{cases} \tag{7}$$

In the above formula, B_s and B_d are respectively the equipment manufacturer side income and the grid side income under the operating lease mode; C_s and C_d are respectively the equipment manufacturer side cost and the grid side cost under the operating lease mode; B_u and C_u are respectively the user side benefits and costs under the operating lease mode.

3.2.2. Constraint Condition

During the lease term, the user only has the right to use the compensation equipment, and the manufacturer still has the ownership of the compensation equipment; Users and equipment manufacturers will no contact directly, their are connected by the power grid company. When negotiating the service fees between the power grid company and the user, the overall cost and benefit of the service provider should be comprehensively considered, so that both the power grid company and the equipment manufacturer can achieve the ideal revenue goal through cooperation.

Therefore, the revenue of the service provider under the operating lease mode is not lower than the minimum expected revenue of the service provider, that is:

$$B_s + B_d - C_s - C_d \geq \Delta B_{sm} + \Delta B_{dm} \tag{8}$$

In the above formula, B_s and B_d are respectively the equipment manufacturer side income and the grid side income under the operating lease mode; C_s and C_d are respectively the equipment manufacturer side cost and the grid side cost under the operating lease mode; ΔB_{sm} and ΔB_{dm} are the lowest expected return on the equipment manufacturer side and the lowest expected return on the grid side.

At the same time, In order to make the operating lease model operate continuously, the revenue obtained by users through this model must meet the minimum expectations of users.

$$B_u - C_u \geq \Delta B_{um} \tag{9}$$

The above formula is the constraint of the annual rent on the user side under the operating lease mode. In the above formula, B_u and C_u are respectively the user side benefits and costs under the operating lease mode; ΔB_{um} is the lowest expected return on the users side.

3.2.3. Modeling and analysis of chaotic cat swarm algorithm

In this paper, chaos cat swarm algorithm is used for multi-objective optimization of demand side reactive power management high-quality service mode [14], The algorithm has the advantages of fast search speed and fast realization of global optimization. Fig. 2 shows the calculation process of the chaotic cat swarm algorithm. In this algorithm, there are two main types of cat behaviors, one is hunting, which corresponds to the tracking mode in the algorithm; The other is search, which corresponds to search mode. This algorithm fully considers the cat's tracking and searching behavior, and then constructs an optimization algorithm based on it. It can improve the optimization precision and make the algorithm converge effectively.

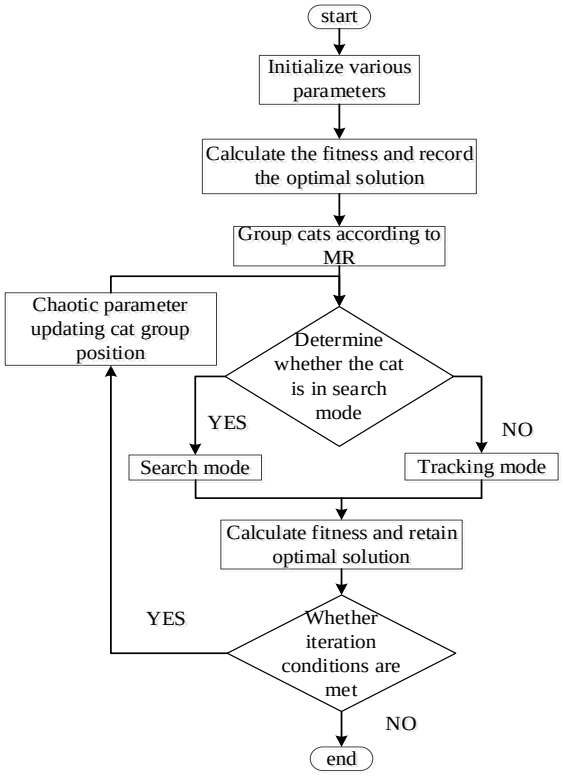


Fig.2 Chaotic cat swarm algorithm flow

First initialize the parameters, and then divide the cat group into search mode and tracking mode according to MR (mixture ratio), The cat samples are copied in the search mode, and the copied samples are stored in the memory pool SMP (shape memory polymer). In the tracking mode, the cat group updates its movement speed according to the best position in time, so as to update its position. The current position of the *x* cat is marked as $O_x=(O_{x1}, O_{x2}, \ldots, O_{xm})$, *m* is the dimension of its search space, and the best position in the cat group is O_{best}. In addition, the current speed of the *x* cat is recorded as $v_x=(v_{x1}, v_{x2}, \ldots, v_{xm})$.

Chaotic cat swarm algorithm updates the velocity and position of particles according to the following formula:

$$\begin{cases} O_x^{t+1} = O_x^t + v_x^{t+1} \\ v_x^{t+1} = v_x^t + g_{O(t)} \cdot rand[O_{best}^t - O_x^t] \\ g_{O(t)} = a + O_x^t(b-a) \\ z^t = \lambda z^t[1-z^{t-1}] \end{cases} \tag{10}$$

In the above formula, v_x^t is the speed of the *x* cat in the *t* iteration; O_x^t is the position of the *x* cat in the *t* iteration; O_{best}^t is the best position of the cat group in the process of iteration *t*; z^t is a chaotic variable, with the value between 0 and 1; λ is chaos control parameter; [*a*,*b*] is the traversal range of cat group positions.

The algorithm has fewer parameters, is more flexible, is easy to implement, and has fast convergence speed. The problem that the algorithm falls into local optimal value prematurely can be solved by using chaotic variables.

4. A model of reactive power compensation service fees allocation on demand side

How power grid companies and equipment manufacturers allocate service fees paid by users is also an important factor affecting the stability and sustainability of the operation lease model. The service fees allocation model based on improved Nash negotiation is adopted to study the service fees allocation strategy between service providers, which the aim is to maximizing the Nash product of the revenue distribution proportion of power grid companies and equipment manufacturers.

In the process of operating lease, the power power grid company has the credibility to convince users, has a large number of customer resources, and is in the leading position. Therefore, it needs to establish an asymmetric Nash negotiation model to study the distribution of service fees among service providers. The model is:

$$\begin{cases} \max \ (\beta - x_d)^{\varphi_d} \cdot (1-\beta - x_s)^{\varphi_s} \\ s.t. \begin{cases} 1-\beta \geq x_s \\ \beta \geq x_d \end{cases} \end{cases} \tag{11}$$

x_d and x_s are expectations for the minimum cooperative distribution ratio of power companies and equipment manufacturers respectively.

Risk ratio, investment size and negotiation status are three important factors affecting the allocation factors of power grid company and equipment manufacturers. The calculation method of the allocation factors is:

$$\begin{cases} \varphi_d = \sum_{n=1}^{3} \sigma_{dn} \cdot w_n \\ \varphi_s = \sum_{n=1}^{3} \sigma_{sn} \cdot w_n \end{cases} \tag{12}$$

In the above formula, σ_{dn} and σ_{sn} (n=1,2,3) are respectively the influence factors of power grid companies and equipment manufacturers on the nth (n=1,2,3) factor, and $\sigma_{dn} + \sigma_{sn} = 1$ (n=1,2,3); w_n is the weight of the nth (n=1,2,3) factor, and $w_1 + w_2 + w_3 = 1$.

5. Example analysis

The average monthly active power consumption of a chemical plant is 387021 thousand kwh, the comprehensive electricity charge is 0.493 RMB/kwh, and the power factor is 0.8. It is considered to increase the power factor to 0.95 through reactive compensation. After calculation, the reactive power compensation capacity that users need to install is 2300kvar, and the market unit price of Static Var Generator is 700 RMB/kvar. According to the expected 8-year lease period, the power grid company will report the demand to the power grid company, and find a suitable equipment manufacturer to jointly provide leasing services for users.

The adjustment proportion of industrial users' electric charge is shown in Table 1, and the reactive equivalent is 0.15 kw/kvar [15]. According to the analysis in Table 1, after adopting reactive power compensation, the electric charge will be directly reduced by 1.3144 million RMB per year, and the network loss will be reduced by 1.4695 million RMB per year.

Table 1. Implementation table of electricity charge adjustment proportion

power factor	Reduce electricity charge (%)	power factor	Increased electricity charge (%)	power factor	Increased electricity charge (%)
0.90	0.00	0.89	0.50	0.76	7.00
0.91	0.15	0.88	1.00	0.75	7.50
0.92	0.30	0.87	1.50	0.74	8.00
0.93	0.45	0.86	2.00	0.73	8.50
0.94	0.60	0.85	2.50	0.72	9.00
0.95~1.00	0.75	0.84	3.00	0.71	9.50
		0.83	3.50	0.70	10.00
		0.82	4.00	0.69	11.00
		0.81	4.50	0.68	12.00
		0.80	5.00	0.67	13.00
		0.79	5.50	0.66	14.00
		0.78	6.00	0.65	15.00
		0.77	6.50		
		If the power factor is below 0.65, the electricity charge will increase by 2% for every 0.01 decrease			

Assume that the user's annual operation cost is 2000 RMB, the SVG's annual maintenance cost is 5% of the purchase cost, the transportation debugging cost is 8% of the purchase cost, and the annual design consulting service fees is 2000 RMB. Chaotic cat swarm algorithm is used to solve the above model, and the annual service fees is 351700 RMB.

Based on the result of annual service charge, solve the asymmetric Nash model shown in (11), and the values of each influence factor are shown in Table 2:

Table 2. Values of Each Impact Factor

Power power grid company	σ_{d1}	σ_{d2}	σ_{d3}
	0.73	0.01	0.38
Equipment manufacturer	σ_{s1}	σ_{s2}	σ_{s3}
	0.27	0.99	0.62

The weights of the three factors are: 0.35, 0.5, 0.15, find that φ_d =0.3175, φ_s =0.6825. The above values are solved in (14), and the result is: β =0.0524. The annual service fees charged by the power grid company is 18500 RMB, and the annual service fee charged by the equipment manufacturer is 333200 RMB.

As shown in Table 3, the demand side reactive compensation operating lease model proposed in this paper is compared with the traditional user direct purchase model in various aspects. It can be seen that the operating lease model effectively reduces the initial investment pressure of users, and at the same time, it can obtain high-quality services jointly provided by equipment manufacturers and power grid companies. After the lease period, the income of equipment manufacturers is higher than that of direct sales of equipment, which ensures the interests of the three parties.

Table 3. Comparative Analysis of Different Business Modes

Business Modes	Initial investment of users	Investment during equipment operation	User net income during equipment operation	Manufacturer's income during equipment operation	Total revenue of manufacturers	Net income of power grid company
Direct purchase	1738800 RMB	82500 RMB per year	1231900 RMB per year	0	1738800 RMB	155100 RMB per year
Operating lease	351700 RMB	351700 RMB per year	962700 RMB per year	333200 RMB per year	2665600 RMB	173600 RMB per year

6. Conclusion

This paper proposes a demand side reactive power compensation operating lease model to adapt to the new situation of energy and electricity. Power grid companies and equipment manufacturers combine service providers to undertake different division of labor and jointly serve users. In order to maximize the profits of users and service providers, this paper establishes a cost-benefit model for each participant, and optimizes the service fees. The chaotic cat swarm algorithm is used to solve the problem, The asymmetric Nash negotiation model is used to allocate the service fees among the service providers. Finally, an example proves that the method in this paper can achieve the balance point of multiple interests, and ultimately achieve a all-win situation for all three parties. It effectively avoids the problems of large investment in the user direct purchase mode; the model proposed in this paper can improve economic benefits and the service system of grid companies. Moreover, the business volume of equipment manufacturers will increase and the benefits of equipment manufacturers will be greater after the end of the entire lease cycle. This method has certain theoretical value and practical significance for the further promotion of demand side reactive power compensation.

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