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Reactive Power Planning of Distribution Network Based on Power Load Time-sequence Characteristics

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ABSTRACT

Reactive power planning (RPP) is one of the most important tasks to reduce power loss and ensure the system voltage quality in distribution network. The traditional RPP based on the maximum load level is pool economy and low equipment utilization of the compensation capacitors. The life cycle economy of the reactive power planning scheme is one of the important factors in power markets. So the mathematical model of RPP based on the power load time-sequence characteristics is proposed with the objective function of the maximum life cycle net benefit in present value, and the model shows the benefit of power loss reduction vividly. The improved sharing niche genetic algorithm is applied to reactive power planning of distribution network, and enhances the ability of global optimization and the stability of the results. The RPP program is developed by Visual 2005C#, and the test results prove its effectiveness and applicability.

KEYWORDS

Terms-reactive power planning; Distribution network; Life cycle cost (lcc); Power load time-sequence characteristics; Fitness sharing niche genetic algorithm.

INTRODUCTION

The reactive power optimization planning focuses on selecting the best nodes for capacitor and the type as well as the capacity of the capacitor to reduce investing expenditure[1]. The reactive power planning can significantly improve the performance of the distribution network by reducing its power loss and improving its voltage profile, and avoid the blind construction of the reactive power in the distribution network reconstruction and expansion[2]. At present the distribution network reactive power planning focus on the selection of the objective function and optimization algorithms[1][7]. A few of papers considered the multiple load levels in distribution network reactive power planning. Generally, the compensation capacity is decided by the maximum load level, and the compensation capacitor grouping is decided by the others load level [8][9]. The compensation capacitor capacity are usually larger according to the maximum load level to planning the reactive power, and the planning scheme's economy is pool, the compensation capacitor's equipment utilization rate is low. The compensation capacitor capacity maybe cannot meet the need of the maximum load level according to the average load level to plan the reactive power. Due to the uncertainty of the load, the optimal reactive power planning scheme cannot be obtained by the traditional method. This paper present a distribution network RPP model based on the time-sequence power load model. The objective function of the model is the maximum life cycle net benefit in present value, and the constraint condition is to meet the various periods' reactive power load demand and voltage profile. The objective functions of the traditional distribution network RPP are the minimum power loss or the minimum expenditure to guarantee the voltage profile, and the operation and maintenance cost of the reactive power compensation equipment are not considered usually. The operation and maintenance cost of the reactive power compensation equipment account for a large proportion of the LCC. So considering the total life cycle cost in planning is important too.

RPP is a non-differential, non-linear and non-convex optimization problem. There are a lot of conventional optimization methods that have been applied to solve the RPP problem. The main problem of this method is that they can't guarantee to find the global minimum of the problem. At present, there are many methods which are used for the reactive power planning, such as classical optimization algorithm, artificial intelligence and hybrid algorithm. Among others, the genetic algorithm is used popularly[3][7]. Traditional genetic algorithm has defects such as low optimization efficiency and premature convergence and so on. Fitness sharing genetic algorithm is a very effective method which can maintain diversity, and it can solve the above problems in a certain extent. But niche radius should be set according to the experience when sharing degree is calculated, and niche radius is very important for the diversity and the reasonable distribution of the population and it directly affects the global searching ability of the algorithm. In order to overcome this defect, the niche radius is adopted as decision variables and is encoded, put in the chromosomes and optimized with the variables of the problem by fitness sharing genetic algorithm without a prior knowledge of the above parameters[10][11]. Reactive power planning example shows that this algorithm has strong global optimization ability.

THE REACTIVE POWER OPTIMIZATION MODEL OF DISTRIBUTION NETWORK

Reactive power planning in distribution network is to choose the optimal compensation points and determine the reasonable compensation capacity, to achieve the minimum active power loss or the minimum total operation cost under certain constraint conditions.

Power Load Time-sequence Model

According to the power load types, the power loads were summed up to three kinds of typical user as shown in the Figure 1. Type I: municipal power load; Type II: three shifts power load; Type III: one shift power load.

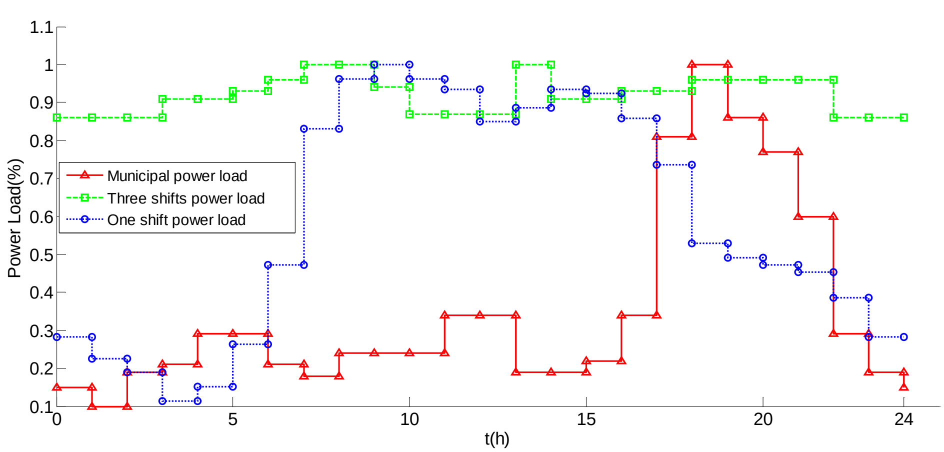

Figure 1 : Time-sequence curves of three types power load

Objective Function

Generally, the objective function is to satisfy the amplitude of voltage and reactive power generator which is not exceed the limit, and obtains the minimum power loss. In order to show the benefit of power loss reduction vividly, the objective function of maximum life cycle net benefit in present value is established. The discount rate is *r*, the design life of reactive power compensation equipment is T years, and the model of the net benefit in present value (NPV) is

$$Max \quad NPV = \sum_{i=1}^{24}(C_{P-i} - C_M - C_v)*\beta - C_I \tag{1}$$

Where $C_{p\text{-}i}$: the *i*th hour of one day (24 hours) annual benefits caused by reduction of reactive power compensation which contains the economic benefits caused by the reduction of distribution lines and transformer loss, $C_{p-i} = \sum_{j=1}^{n}(\Delta P_{Loss-i} * \lambda * \tau_{\max} / 24)$, $\Delta P_{Loss\text{-}i}$ is the reduction of the active power loss of each node in the *i*th hour of everyday, λ is electricity price, $\tau_{\max}$ is the equivalent maximum loss hours, n is the nodes number. C_I: The investment cost of the compensation device, including fix cost (the basic construction project cost and the control device cost which has nothing to do with the compensation capacity) and dynamic cost (capacitor bank cost). C_M : Annual maintenance cost which take two percent of the investment amount, $C_M = C_I * 0.08$. β : Equal split present value conversion coefficient, $\beta = \frac{(1+r)^t - 1}{r(1+r)^t}$; $C_v = k_v \sum_{i=1}^{n}(\frac{\Delta U}{U_{i\max} - U_{i\min}})^2$, k_v is voltage cross-border penalty factors $\Delta U = \begin{cases} U_i - U_{i\max} & (U_i > U_{i\max}) \\ 0 & (U_{i\min} \le U_i \le U_{i\max}) \\ U_{i\min} - U_i & (U_i < U_{i\min}) \end{cases}$.

Equality Constraint Equations

The equality constraint equations are power balance equations:

$$\begin{aligned} P_i &= U_i \sum_{j\in i} U_j (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) \\ Q_i &= U_i \sum_{j\in i} U_j (G_{ij}\sin\theta_{ij} + B_{ij}\cos\theta_{ij}) \end{aligned} \tag{2}$$

Where P_i, Q_i are injection active power and reactive power of node *i*; U_i, U_j are node voltage of node *i* and *j*; G_{ij}, B_{ij} are the conductance and the susceptance between node *i* and *j*; θ_{ij} is voltage phase angle difference between node *i* and *j*; $j \in i$ expresses all the connected nodes with node *i*.

Inequality Constraint Equation

Variables in reactive power planning can be divided into the control variables and state variables. Node voltage U and transformer ratio *T* regulated by tap changer are state variables, inequality constraint equations of control variables are:

$$\begin{cases} U_{j\min} \le U_j \le U_{j\max} (j = 1,2...n_u) \\ T_{g\min} \le T_g \le T_{g\max} (g = 1,2...n_t) \end{cases} \tag{3}$$

The control variables use mixed integer coding, in this paper the individual chromosome coding can be expressed as

$$\begin{aligned} P_i(t) &= [Q \mid U \mid T \mid \sigma] \\ &= [Q_1, Q_2, ..., Q_{n_L} \mid U_1, U_2, ...U_{n_u} \mid T_1, T_2, ...T_{n_t} \mid \sigma] \end{aligned} \tag{4}$$

Where n_L is all the possible compensation points of the system; n_u is system nodes number; n_t is nodes number of regulating transformer; σ is niche radius.

Adaptive Compensation Points Determination

Reactive compensation points are determined artificially based on the sensitivity analysis in conventional reactive power compensation algorithm. In order to get the optimal compensation scheme, the adaptive algorithm for determining compensation points is proposed. In this paper, C_Q is compensation cost decomposed into fixed investment and dynamic investment. Fixed investment including the basic construction project cost and control system cost which has nothing to do with the compensation capacity. Dynamic cost refers to the capacitor bank charges which is directly proportional to capacitor installed capacity. Fixed investment cost limits the number of compensation points can not be too much.

IMPROVED SHARING NICHE GENETIC ALGORITHM FOR REACTIVE POWER PLANNING

In 1987, Goldberg proposed a method based on sharing niche technique. The basic approach is to adjust the fitness of each individual by the sharing function of similar degree between individuals. Thus in the process of evolution in populations, operation can be selected according to the new adjusted fitness degree, the diversity of the population can be maintained, and a niche evolutionary environment can be created. An individual's sharing degree is a measure of a sharing degree of individual in the group, equal to the sum of sharing function value between the individual and all other individuals of the group. The sharing function reflects the close degree about the relationship between two individuals. When the relationship between individuals is relatively close, sharing function value is larger, and vice versa is small.

If the Hamming distance between two individuals is for $d(i, j)$, the sharing function of the individuals is

$$sh(d(i,j)) = \begin{cases} 1-(d(i,j)/\sigma)^{\alpha}, d(i,j) < \sigma \\ 0 \ , \qquad \text{others} \end{cases} \tag{5}$$

Where σ is the designated niche radius which is known or assumed; α is the parameter of controlling sharing function shape, its value is usually take 1. *N* is the individual number in the population.
The individual sharing degree is expressed as:

$$S_i = \sum_{j=1}^{N} sh(d(i,j)) \quad (i = 1,2,...N) \tag{6}$$

The fitness value of individuals after sharing is represented as:

$$f_i' = f_i / S_i \tag{7}$$

Where f is the fitness value of individual *i* before sharing.

The selection process then will use the shared individual fitness value. If the sharing degree of one species is large, the fitness value of all individuals in the species will be greatly reduced, thereby encouraging less individual species. So the value of the niche radius is very important to maintain the population diversity and distribution characteristics. By the method of adaptive adjustment of the niche radius, the fitness of individuals after sharing can be changed, the selected probability of the individual can be affected, the population diversity can be further adjusted. The basic idea of adaptive niche radius control method is taking the niche radius of fitness sharing genetic algorithm as a decision variable, then it is coded and the coding string is connected, so that it can participate in the optimization of the whole process.
The step of fitness niche genetic algorithm based on sharing function is:

Step1. Reading the initial data, initial genetic group population size (*M*), crossover probability (typical value P_c =0.9), mutation probability (typical value P_m =0.01), niche length (σ), σ is set by self-adaption.

Step2. Calculating the fitness value of the initial population by back/forward sweep method, according to each individual fitness to list in descending order and individuals to memorize (*N*, $N<M$).

Step3. For current genetic group (G_t), use one-point crossover operation, one-point mutation operation and roulette wheel selection operation to generate (G_{t+1}).

Step4. For the $N+M$ individuals (*M* in current G_{t+1}, and *N* in memorizer), compute their distance between their nearest neighbors, calculate f_i' based on equation (5) to equation (7), to decide whether they are punished or not; then sort these individuals by fitness; select the better *M* individuals as G_{t+1}, memorize the better *N* individuals.

Step4. Loop: if termination (for example, max generation has been reached, or genetic group keeps the same by and large) is satisfied, break, show output and then stop; else, back to Step2.

RESULT AND DISSCUSS

To verify the effectiveness of the method and the algorithm, the reactive power planning program is developed by Visual 2005 C# and applied into the 28 nodes distribution network reactive power planning in the reference[12]. The types of every node are shown in the TABLE 1. The Network topology is shown in Figure 2.

TABLE 1 : Node type of the distribution network

node number	node type	node number	node type	node number	node type
1	I	11	II	21	III
2	I	12	III	22	II
3	I	13	I	23	III
4	II	14	II	24	I
5	II	15	III	25	II
6	I	16	III	26	III
7	I	17	II	27	II
8	II	18	II	28	III
9	III	19	I		
10	III	20	III		

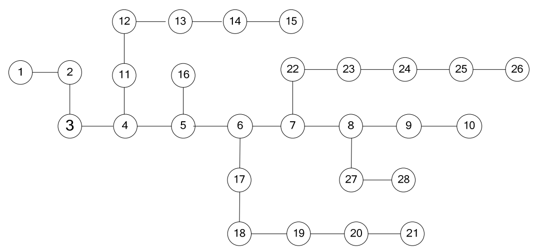

Figure 2 : Structure of IEEE-28-node net

The voltage of calculation example is 10kV. The network node 1 is the balance node. The remaining nodes are PQ node. Compensation equipment life cycle is 10 years. Electricity price is 0.42 Yuan/kWh. Fixed investment cost of reactive power compensation is 8000 Yuan/point. Capacitor price is 50 Yuan/kVar. $\tau_{\max}$ is 5000 hours. The population size is 200, the maximum number of iterations is 50.

Because the genetic algorithm is a probability search and the calculated values in different seed of random number are different, so the point compensation scheme based on sensitivity method usually chooses a better search results, or the average of multiple search results. The planning result based on the maximum load level is shown in TABLE 2.

TABLE 2 : Cost-Benefit Analysis of power loss reduction in the maximum/average power load level

Compensa-tion points	Compensa-tion apacity (kvar)	C_I (Yuan)	C_M (Yuan)	The maximum/average power loss before compensating (kW)	The maximum/average power loss after compensating (kW)	NPV (Yuan)
8	210	18500	1480	86.47/33.50	39.92/17.18	553575/ 145441
12	200	18000	1440			
19	130	14500	1160			
24	150	15500	1240			

It is apparent in the TABLE 2 that the power loss has a markedly change before and after reactive power compensation. The active power loss of the system is reduced from 89.47 kW to 39.92 kW. The lowest amplitude of voltage of the node 26 of the distribution network is improved from 8.923kV to 9.361kV. The power loss reduction and energy saving benefit of the compensation scheme in the life cycle is 553575 Yuan, the economic benefits is remarkable. But in fact, the power load can not keep in the maximum load level. According to the load points' classification in TABLE 1 and the time-sequence day load curve in Fif.1, the distribution network average power load (24 hours) is 33.50kW before compensating. According to the compensation scheme based on the maximum load level, compensating suitable capacitors on others' load level, the distribution network actual average power load (24 hours) is 17.18kW as shown in TABLE 2.

Using the Time-sequence distribution network reactive power planning method, the IEEE 28 nodes distribution network reactive power planning result is shown in Tab.3. The planning scheme can guarantee that each node can satisfy the requirements of voltage quality index in different load level and maximize the revenue of the energy loss reduction and energy saving, though the loss reduction is not the largest (18.01>17.18kW).

TABLE 3 : Cost-Benefit Analysis of power loss reduction in the time-sequence power load model

Compensa-tion points	Compensa-tion apacity (kvar)	C_I (Yuan)	C_M (Yuan)	The average power loss before compensating (kW)	The average power loss after compensating (kW)	NPV (Yuan)
7	290	22500	1800	33.50	18.01	161304
12	130	14500	1160			

CONCLUSIONS

In this paper, the reactive power planning method considering the time sequence characteristic of the power load was presented, and the improved sharing niche genetic algorithm was used to solve the model. The contributions of this work are summarized as follows:

1.The compensation capacitor capacity is usually larger according to the maximum load level to planning the reactive power, and the planning scheme's economy is pool, the compensation capacitor's equipment utilization rate is low.

2.The planning result is more close to the actual considering the time-sequence characteristic of the power load, and maximize the life cycle revenue of the energy loss reduction and energy saving.

3.The improved sharing niche adaptive genetic algorithm is applied to reactive power optimization of distribution network, and the calculation results is stability and practical.

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