The application of improved niche differential evolution algorithm in reactive power optimization of power system

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Abstract: Reactive power optimization of distribution network is a nonlinear integer programming method, which can reduce network losses by adjusting turns ratio of transformers and changing the generator terminal voltage and link capacitor compensator to change the reactive power of network. Suitable reactive power compensation can reduce the system losses and guarantee the power system to operate stably, safely and economically. Among different reactive power optimization algorithms, differential evolution algorithm is an intelligent evolutionary method with fast convergence rate and high convergence precision. This paper further introduced niche idea to the differential evolution algorithm, thereby enhancing the local search capability and broadening the search range. At the same time, the rate and precision of convergence had been also improved. At last, this paper had also made comparative analysis with several other algorithms that has relatively good results on reactive power optimization, so as to confirm the advantage of improved niche differential evolution algorithm.

Key-words: Niche theory, differential evolution algorithm, particle swarm optimization (PSO), reactive power optimization.

1. INTRODUCTION

Reactive power optimization problem of power system is a very complex nonlinear programming problem (Holland J H, 1975; Li-zhong Jin et al, 2010), which contains continuous variables and discrete variables. The optimization process is very complicated, and also the computing scale is large. With the development of intelligent heuristic optimization algorithm, differential evolution algorithm has been gradually applied to power system (Xin-bin Li et al, 2008; Li-feng Tang et al, 2011). The algorithm has the characteristics of easy understanding, parallel processing and good robustness. Also it can find the global optimal solution of problem with high probability. What's more, this computational method is more efficient than traditional evolutionary programming algorithm (Wen-chao Xu et al, 2003).

Differential evolution algorithm achieves the optimization objective by simulating natural phenomena and the swarm behavior of biological swarm in nature. There are three mainly operations: mutation, crossover and selection. It is easily implement, simple operation and local search ability. So it is suitable for reactive power optimization of power system (Tao-liang Tan et al, 2003; Qin A K et al, 2009).

2. REACTIVE POWER OPTIMIZATION MODEL

The goal of reactive power optimization is that minimize the active power loss, when the reactive power of the system is balance.To obtain the minimum needs adjusting the voltage of generator, transformer ratio and shunt capacitor in order to make the system network to meet security constraints. The mathematical model can be expressed as follows (Yang Z et al, 2008; Qin A K et al, 2005).

$$\min F=\sum_{\substack{i\in N\\ j\in I}} G_{ij}(U_i^2+U_j^2-2U_iU_j\cos\theta_{ij})+ \lambda_1\sum_{\alpha}\left(\frac{U_i-U_{i\lim}}{U_{i\max}-U_{i\min}}\right)^2+\lambda_2\sum_{\beta}\left(\frac{Q_i-Q_{i\lim}}{Q_{i\max}-Q_{i\min}}\right)^2 \tag{1}$$

Among them, F is the target function; λ1and λ2 are respectively the penalty factors in violation of voltage constraints and reactive power generation constraints; α and β are the node set in violation of node voltage constraints and reactive power generation constraints; Ui, Uimax and Uimin are the node voltage and upper and lower limit of node voltage; Uilim and Qilim are voltage and reactive power limit of the node i. The formula is defined as follows (Storn R and Price K, 1995).

$$U_{i\lim} = \begin{cases} U_{i\max}\ ,\ U_i > U_{i\max} \\ U_{i\min}\ ,\ U_i < U_{i\min} \end{cases} \quad (2)$$

$$Q_{i\lim} = \begin{cases} Q_{i\max}\ ,\ Q_i > Q_{i\max} \\ Q_{i\min}\ ,\ Q_i < Q_{i\min} \end{cases} \quad (3)$$

Equality constraints are written as follows.

$$\begin{cases} P_i - U_i \sum_{j=1}^{N} U_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \\ Q_i - U_i \sum_{j=1}^{N} U_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) = 0 \end{cases} \quad (4)$$

Inequality constraints of state variable are written as follows.

$$\begin{cases} U_{G\min} \le U_G \le U_{G\max} \\ K_{T\min} \le K_T \le K_{T\max} \\ Q_{c\min} \le Q_c \le Q_{c\max} \\ U_{L\min} \le U_L \le U_{L\max} \\ Q_{G\min} \le Q_G \le Q_{G\max} \end{cases} \quad (5)$$

In the formula, UGmin and UGmax are upper and lower limit value of the generator terminal voltage; KTmin and KTmax are upper and lower limit value of adjustable transformer tap changer; QCmin and QCmax are upper and lower limit value of the compensation capacitor switched groups; ULmin and ULmax are upper and lower limit value of load points' voltage; QGmin and QGmax are upper and lower limit value of reactive power generation (Vestertron J and Thomsen R, 2004).

3. APPLICATION

3.1 Improved differential evolution algorithm

Improvement of the basic differential evolution algorithm mainly has the following aspects (Yan-ling Wu et al, 2008; Bakare G A et al, 2007; Liang R H and Cheng C K, 2001).

(1) The choice of difference individual

This paper Fitness Eulidean-distance Ration (FER) is added to the differential evolution algorithm, and it is used to increase the diversity of population. Fitness Eulidean-distance Ration (FER) is first introduced to Particle Swarm Optimization (PSO) algorithm for solving multimodal optimization problems. Join this mechanism makes the particles toward to the individual nbest which is nearer and fitness to it. In the Particle Swarm Optimization (PSO), each individual is the largest individual of Fitness Eulidean-distance Ration (FER), and it is one of the neighborhood individual. The calculating formula of FER as follows.

$$FER_{(j,i)} = \alpha \cdot \frac{f(p_j) - f(p_i)}{\left\| p_j - p_i \right\|} \quad (6)$$

$$\alpha = \frac{\|s\|}{f(p_g) - f(p_w)} \quad (7)$$

Among them, pi and pj respectively represent optimal individual of the i and the j individual. α is a proportional coefficient; pw is worst-fitness individual in current swarm; $\|s\|$ is the size of the search space.

$$\|s\| = \sqrt{\sum_{k=1}^{d} (x_k^u - x_k^l)^2} \quad (8)$$

In formula, x_k^u and x_k^l is the maximum and minimum values of the K dimensions search space.

Fitness Eulidean-distance Ration (FER) method is applied to differential evolution algorithm. Through the method to choice xr1 to xr5 five individuals, and the calculating formula of Fitness Eulidean-distance Ration (FER) is written as follows.

$$FER_{(j,i)} = \frac{normalize\left(f(p_j) - f(p_i) \right)}{normalize^{N}\left(\left\| p_j - p_i \right\| \right)} \quad (9)$$

Considering that α is a constant, if delete the proportion coefficient, it will have no effect on sequence of Fitness Eulidean-distance Ration (FER). Meanwhile, reduce the computational complexity and improve the efficiency of the algorithm. The denominator of Fitness Eulidean-distance Ration (FER) is normalized. At same time, in order to strengthen distance's function to keep diversity of swarm, denominator is become the n-th power of distance. The value of N adjusts according to search condition. According to the above formula, calculate every individual to all swarms' individuals of Fitness Eulidean-distance Ration (FER), and put them in order. After that, according to the roulette wheel method select xr1 to xr5 individuals in other individuals.

In the course of swarm search, there may be many individuals gathered at a peak. It will cause the waste of search, so initialize a part of worst fitness individuals for remaining elite parts continue to search the peak. The remained elite individuals don't use Fitness Eulidean-distance Ration (FER) formula any longer, but use standard differential evolution algorithm to local search ensuring the convergent precision of algorithm. In order to ensure that the swarm can continue to use Fitness Eulidean-distance Ration (FER) strategy, add the individuals had same number of elite individuals to initialized swarms. It can global search optimal solution. So the size of swarm NP is adaptively adjusted.

(2) Memory mechanism added in, algorithm will save optimal solution's position what elite individuals has searched every time. Because dynamic problems is a periodic function, it is necessary that memory mechanism join in algorithm. At same time, it can use the saved information in the process of swarm's initialization.

(3) The variation factor F is decreasing after swarm's initialization and then lineal increasing in the search process. It's helpful to splitting swarm.

The step of improved Different Evolution Algorithm Fitness Eulidean-distance Ration as follows.

Improved differential evolution algorithm based on FER is applied in the reactive power optimization of power system. Search range and precision are improved on the original algorithm. Firstly, the paper establish power system reactive power optimization model, and then compare application of reactive power optimization with the particle swarm optimization algorithm, differential evolution algorithm and niche particle swarm algorithm. To show the superiority of improved strategy .

3.2 Operation step

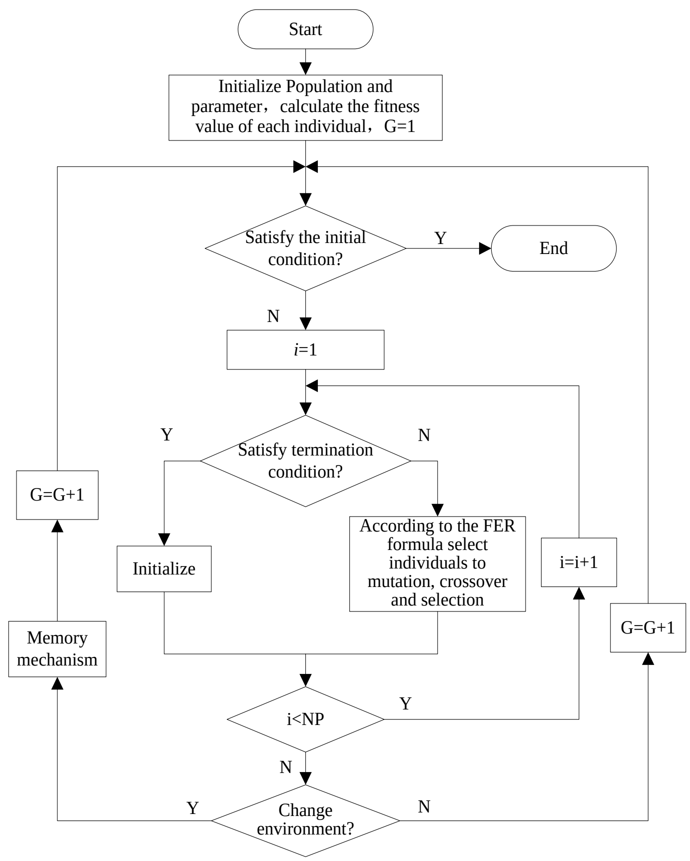

Figure 1. The step of Different Evolution Algorithm FER

3.3 Application procedure

(1) Initialize parameters

At first, initialize swarm size M, max iteration and cross rate. And then initialize output power of PV point, system load and phase angle of system nodes.

(2) Power flow calculation

Set the maximum iteration in the biggest received error and the error of the Newton-Raphson method. Then use Newton-Raphson method to power flow calculation.

(3) Variation

Through the calculation of Fitness Eulidean-distance Ration (FER) select individual of traction variation, in the meantime, linear adjust the mutation factor F. At time of extending the search scope, increase the search precision and convergence speed. After the Fitness Eulidean-distance

Ration (FER) search process, it will form a number of small swarms, in the swarm. Deepen the local search in the guidance of locally optimal particle.

(4) Crossover and selection

After Variation, it is the vector V_i^{k+1}. Interlaced operate it and the original vector to obtain the test vector. Then select the better fitness between the original vector and test vector, and keep it in a swarm.

(5) Verification of termination criterion

If the present iteration k is not equal to the maximum iteration, then turn to step B and recalculate. If the present iteration k is equal to the maximum iteration, then terminate and Write the power system loss after optimization. It can also set a convergence precision as the condition of iteration stop, stopping search when it reaches a precision. The combination of the two can save search time wonderfully.

4. THE EXAMPLE ANALYYSIS

In order to verify the advantage of differential evolution algorithm based on Fitness Eulidean-distance Ration (FER), this paper solve optimization problems in power system respectively using particle swarm optimization, Differential Evolution (DE), Niche Particle Swarm Optimization (NPSO) and Fitness Eulidean-distance Ration Differential Evolution (FERDE). (The results see Tab 1)

Table 1. Comparison of different optimization results

Test system	Algorithm	Optimal network loss	Worst network loss	Average network loss	standard deviation
IEEE57	PSO	0.0648	0.0695	0.0662	0.0089
	DE	0.0645	0.0668	0.0656	0.0073
	NPSO	0.0640	0.0642	0.0640	0.00586
	FERDE	0.00634	0.00782	0.00692	7.32e-006
IEEE30	PSO	0.06064	0.06265	0.06471	0.0009
	DE	0.06042	0.06138	0.06345	0.0003
	NPSO	0.05963	0.06081	0.06000	0.0001
	FERDE	0.00517	0.00611	0.00581	2.48e-007
IEEE14	PSO	0.05392	0.06142	0.06001	0.00004
	DE	0.05134	0.05724	0.05532	0.00007
	NPSO	0.04927	0.05421	0.05271	0.00003
	FERDE	0.00073	0.00095	0.00084	0

By comparing the worst network loss can be seen that Fitness Eulidean-distance Ration Differential Evolution (FERDE) gets the minimum network loss in the four algorithms through calculation of three systems: IEEE 14, IEEE 30 and IEEE 57. And the worst loss and average loss of Fitness Eulidean-distance Ration Differential Evolution (FERDE) algorithm in independent experiment is the least one among the four algorithms.

In the stability optimization, for the reactive power optimization of three systems IEEE 14, IEEE 30 and IEEE 57, Fitness Eulidean-distance Ration Differential Evolution (FERDE) algorithm can obtain the minimum standard deviation of network loss and optimized stability of best algorithm.

To sum up, when the Fitness Eulidean-distance Ration Differential Evolution (FERDE) separately solve reactive power optimization of three systems, obtain a better optimal performance than the Differential Evolution (DE), Particle Swarm Optimization(PSO) algorithm, and Niche Particle Swarm Optimization (NPSO) algorithm. And result shows the FERDE is successfully applied in search process of reactive power optimization.

5. CONCLUSION

Reactive power optimization can improve the security of electric power system and reduce the network loss of power system effectively. This paper studies differential evolution algorithm based on Fitness Eulidean-distance Ration and improves basic differential evolution algorithm. It improves the convergence speed and solution's quality of basic differential evolution algorithm. So it is a good algorithm to solve the problem of reactive power optimization, reducing power system network loss in the precondition of security and reliability of the power systems. Therefore it is well worth researchers delving.

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