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RESEARCH ARTICLE

# THE PLANING OF DISTRIBUTION GENERATION (DG) BASED ON MULTI-OBJECTIVE QUANTUM PARTICLE SWARMS OPTIMIZATION (QPSO)

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**ABSTRACT**

According to economic-technical optimization objective of distribution network to which distributed generation is added, a multi-objective model is proposed in this paper. The model contains DG construction investment and operation fee, network loss, reliability, as well as environmental factor. and then puts forward the multi-objective quantum particle swarm optimization (QSPO) algorithm, and the distributed power supply after installation position and capacity for the comprehensive planning research. The result proves that QPSO has advantages of speedy searching for the optimum and keeping the population diversity. Compared to Particle Swarms Optimization (PSO), QSPO shows high efficiency and robustness.



## INTRODUCTION

Because of the advantages of low investment, flexible power generation method and environmental compatibility, distributed generation (DG) is being paid more and more attention. That it operates with combining with the power grid can improve the economy, safety, reliability and flexibility of the system, and meet the requirement of sustainable development, and greatly reduce the environmental protection pressure. Under the promotion for clean energy development from government, the rapidly developing trend of new energy industry has increased the need of research on DG planning (Liang *et al*., 2001 and Lv *et al*., 2011) which causes a concern from increasing scholars. The referece (He *et al*., 2003) proposed that partheno genetic algorithm (PGA) was applied to the generation planning, which can greatly simplify the calculation of generation planning, and avoid premature convergence, and improve the computational efficiency. References (Kannan *et al*., 2004 and Tsukada *et al*., 2003) has used the global optimization method of particle swarm optimization when solving the generation planning problem. Although the method's stability is poor, the local extremum problem can be avoided, to a certain extent. Quantum computing is a product of quantum theory combining with information theory and computer science, which makes full use of the superposition, parallelism and entanglement properties of quantum system, and has high computing capability beyond the classical calculation and great potential in the aspect of information processing. This paper presents the quantum particle swarm optimization (QPSO) which intergrates particle swarms optimization (PSO) into the quantum evolutionary algorithm. This algorithm uses the qubit to encode the current position of particle, and searches for the best position of particle by quantum revolving gate, and performes the mutation of particle position in order to avoid the premature phenomenon by quantum non gate. Showing the QPSO algorithm by an example can greatly improve the global optimization ability and optimization efficiency of PSO algorithm.

### DG Planning Multi-Objective Mathematical Model

With optimizing the power flow and improving the power quality, reasonable DG planning can take into account economic benefit. Its objective functions include technical and economic objectives (Xu *et al*., 2010 and Wang *et al*., 2009).

### DG Construction and Operation Costs

$$C_{DG} = \sum_{i=1}^{N_{DG}} X_i \left[ \left( \frac{r(1+r)^n}{(1+r)^n - 1} \right) \cdot C_{az,i} + C_{OM,i} \right] P_{DGi}$$

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Here, the value of $X_i$ is 0 or 1. $X_i = 0$ indicates that DG is not installed in the corresponding position, and $X_i = 1$ indicates that DG is installed in the corresponding position; $n$ is the service life of equipment. $r$ is the discount rate; $C_{az,i}$ and $C_{OM,i}$ respectively mean the operation maintenance cost and safety investment cost of DG from node $i$, RMB ten thousand/(kW, h); $P_{DGi}$ means the rated capacity of DG from node $i$.

### Network Loss Cost

Accessing DG into distribution network has changed the power grid, which makes the distribution network change from passive network to active network, and affects the network loss of system. The renewable distributed-energy output is random. According to the probability model of distribution network load and distributed generation output, the annual network loss can be gained accurately. Considering unit electricity price, the annual network loss can be transformed into economic measure index.

$$C_{loss} = \sum_{g=1}^{N} P_{loss\ g} \cdot P\{C_g\} \cdot 90 \cdot C_{pu}$$

$$P_{loss\ g} = \sum_{h=l}^{T} \sum_{i=l}^{n} \sum_{\substack{j=l \\ j \neq i}}^{n} R_{ij} \cdot \left( \frac{\Delta V_{ij}}{|Z_{ij}|} \right)$$

Where, $P_{loss\,g}$ is the loss of electricity quantity of system in state g; $P\{C_g\}$ is the probability of distributed generation output in state g; $R_{ij}$ is the branch resistance on both ends; $Z_{ij}$ is branch impedance on both ends; $\Delta V_{ij}$ is the branch voltage drop on both ends; $C_{pu}$ is unit electricity price.

### Reliability Economic Costs

The evaluation method about electricity outage cost adopts the weighted average between the average electricity price conversion ratio method and the electricity production ratio method. The formula is:

$$C_r = EENS \cdot (\alpha_1 K + \alpha_2 bd)$$

Where, EENS is the expectation about lack of electricity quantity; $\alpha_1$ and $\alpha_2$ are the weighting coefficient of electricity production ratio method and average electricity price conversion ratio method, respectively; K is the proportion of electricity production; b is the ratio which is obtained from unit electricity outage price divided by average price; d is the average price of electricity.

### Environmental Factors Cost

Environmental cost generally includes two aspects: 1) Environmental loss, namely consumption of environmental resources including the environmental degradation caused by water pollution and the ecological environmental damage caused by excessive consumption of natural resources; 2) Fine from the discharge of pollutants. The calculation formula is as follows:

$$C_e = \sum_{k=1}^{n} (V_{ek} \cdot Q_k + V_k) - C_{ee}$$

$V_{ek}$ is the environmental value of pollutant from item k and $Q_k$ is the emission of pollutant from item k; n means the types of pollutants; $V_k$ is the discharge fee of pollutant from item K; $C_{ee}$ is the subsidies provided by government for encouraging the development of DG.

### Constraint Condition

The constraints include equality and inequality constraints, and equality constraint is the power flow equations (Wang *et al*., 2011).

$$\begin{cases} P_{Gi} + P_{DGi} - P_{Li} - U_i \sum_{j=1}^{n} U_j (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}) = 0 \\ Q_{Gi} - Q_{DGi} - U_i \sum_{j=1}^{n} U_j (G_{ij} \sin\delta_{ij} + B_{ij} \cos\delta_{ij}) = 0 \end{cases}$$

Inequality constraints include:

1) The upper limit constraint of DG penetration power

$$\sum_{i=1}^{N_{DG}} X_i P_{DGi} \leq \eta P_l$$

Where, $P_l$ is the active load of planning level years; $\eta$ is the upper limit of proportion that DG total capacity accounts for in the total system load.

2) The upper limit constraint of DG active power

$$0 \leq P_{DGi} \leq P_{imasx}, i = 1,2,\ldots,N_{DG}$$

Where, $P_{i\max}$ is the upper limit of active power for DG from group i.

3) The voltage constraint

$$V_{\min} \leq V_{g,i} \leq V_{\max}$$

Where, $V_{\min}$ is the voltage lower bound and $V_{\max}$ is the power source upper bound.

4) The branch transmission power constraint

$$|P_i| \leq P_{i\max}$$

Where, $P_{i\max}$ is the upper limit of transmission power from branch i.

This paper comprehensively takes consideration of DG construction and operation costs, network loss cost, reliability economic cost and environmental factors cost, and achieves the overall optimization based on satisfying the various constraints on the power grid. The normalized objective function is:

$$F = w_1 \cdot C_{DG} + w_2 C_{loss} + w_3 C_r + w_4 C_e$$

Where, $w_1$, $w_2$, $w_3$ and $w_4$ express the weight which decision-makers give each sub-objective, respectively.

**Quantum Particle Swarm Algorithm**

**Quantum Encoding**

In QPSO, we directly use the probability amplitude of qubit as the current location code of particle. In consideration of the randomness of population initialization code, the coding scheme that we adopt is:

$$p_i = \begin{bmatrix} \cos(\theta_{i1})\cos(\theta_{i2})\cdots\cos(\theta_{in}) \\ \sin(\theta_{i1})\sin(\theta_{i2})\cdots\sin(\theta_{in}) \end{bmatrix}$$

Where, $\theta_{ij} = 2\pi \times rnd$ ; *rnd* is a random number in [0,1]; $i = 1,2,....,m$ ; $j = 1,2,....,n$ ; $m$ is the number of particles; $n$ is the space dimensions; Thus, each particle in the population occupies two positions in the ergodic space. They respectively correspond to the probability amplitudes of quantum state $|0>$ and $|1>$ which are:

$$P_{ic} = (\cos(\theta_{i1}), \cos(\theta_{i2}) \cdots \cos(\theta_{in}))$$

$$P_{is} = (\sin(\theta_{i1}), \sin(\theta_{i2}) \cdots \sin(\theta_{in}))$$

**Solution Space Conversion**

Initialize the particles in [-1,1], and then according to the niche theory, map the initialization solution to the solution space of optimization problem. Each probability amplitude of qubit corresponds to an optimization variable of solution space. Note qubit $j$ on particle $p_i$ as[ $\alpha_i^j$ , $\beta_i^j$ ] $^T$ , and so the corresponding solution space variables are:

$$X_{ic}^j = \frac{1}{2}\left[b_i(1+\alpha_i^j) + \alpha_i(1-\alpha_i^j)\right]$$

$$X_{is}^j = \frac{1}{2}\left[b_i(1+\beta_i^j) + \alpha_i(1-\beta_i^j)\right]$$

$\alpha_i^j$ , the probability amplitude of qubit $|0>$, corresponds to $X_{ic}^j$ ,and $\beta_i^j$ , the probability amplitude of qubit $|1>$, corresponds to $X_{is}^j$ . where, $i = 1,2,....,m$ and $i = 1,2,....,m$ . $b_i$ and $\alpha_i$ are the upper and lower limits of search range of particle $p_i$, respectively.

**Particle State Update**

In this algorithm, the particle state update learns from the basic PSO algorithm and in PSO algorithm, convert the movement speed update of particles into the revolving door corner update of quantums. Presume that the optimal location which the particle has searched currently is cosine. The following formula is:

$$p_{il} = (\cos(\theta_{il1}), \cos(\theta_{il2}) \cdots \cos(\theta_{i\ln}))$$

The optimal location that the entire population has searched for now is:

$$p_g = (\cos(\theta_{g1}), \cos(\theta_{g2}) \cdots \cos(\theta_{gn}))$$

Based on the above assumptions, the particle state update rules can be described as follows:

(1) The argument increment update of qubit on the particle $p_i$

$$\Delta\theta_{ij}(t+1) = w\Delta\theta_{ij}(t) + c_1 r_1 \Delta\theta_{ilj}(t) + c_2 r_2 \Delta\theta_{gj}(t)$$

$$\Delta\theta_l = \begin{cases} 2\pi + \theta_{ilj} - \theta_{ij} & \theta_{ilj} - \theta_{ij} < -\pi \\ \theta_{ilj} - \theta_{ij} & -\pi \le \theta_{ilj} - \theta_{ij} \le \pi \\ \theta_{ilj} - \theta_{ij} - 2\pi & \theta_{ilj} - \theta_{ij} > \pi \end{cases}$$

$$\Delta\theta_g = \begin{cases} 2\pi + \theta_{gj} - \theta_{ij} & \theta_{gj} - \theta_{ij} < -\pi \\ \theta_{gj} - \theta_{ij} & -\pi \le \theta_{gj} - \theta_{ij} \le \pi \\ \theta_{gj} - \theta_{ij} - 2\pi & \theta_{gj} - \theta_{ij} > \pi \end{cases}$$

Where, $\Delta\theta_{ij}(t+1)$ is the amount of phase shift for particle $i$ from iteration $t+1$ in dimension $j$; $\Delta\theta_{ij}(t)$ is the current phase; $\Delta\theta_{ilj}(t)$ is the history optimal phase for particle $i$ from iteration $t$ in dimension $j$; $\Delta\theta_{gj}(t)$ is the global optimal phase for particle $i$ from iteration $t$ in dimension $j$; $w$ is the inertia factor; $c_1$ and $c_2$ are the learning factors; $r_1$ and $r_2$ are random numbers in [0, 1].

(2) The qubits probability amplitude update based on quantum revolving door

$$\begin{bmatrix}\cos(\theta_{ij}(t+1))\\ \sin(\theta_{ij}(t+1))\end{bmatrix}=\begin{bmatrix}\cos(\theta_{ij}(t)+\Delta\theta_{ij}(t+1))\\ \sin(\theta_{ij}(t)+\Delta\theta_{ij}(t+1))\end{bmatrix}$$

$$=\begin{bmatrix}\cos(\Delta\theta_{ij}(t+1)) & -\sin(\Delta\theta_{ij}(t+1))\\ \sin(\Delta\theta_{ij}(t+1)) & \cos(\Delta\theta_{ij}(t+1))\end{bmatrix}\begin{bmatrix}\cos(\theta_{ij}(t))\\ \sin(\theta_{ij}(t))\end{bmatrix}$$

Where, $\cos(\Delta\theta_{ij}(t+1))$ and $\sin(\Delta\theta_{ij}(t+1))$ are the probability amplitudes for particle $i$ from iteration $t+1$ in dimension $j$.

### Mutation Treatment

The main reason why the PSO algorithm is easy to fall into local optimum lies in the loss of population diversity in the process of search. In the QPSO algorithm, that mutation operation is performed by the quantum non gate can significantly increase the diversity of population, and effectively avoid the premature phenomenon. The operation process is shown in the following formula:

$$\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix}\begin{bmatrix}\cos(\theta_{ij})\\ \sin(\theta_{ij})\end{bmatrix}=\begin{bmatrix}\cos(\frac{\pi}{2}-\theta_{ij})\\ \sin(\frac{\pi}{2}-\theta_{ij})\end{bmatrix}$$

### Realization of Quantum Particles Swarm Optimization Algorithm

According to the above algorithm, the realization process of algorithm is shown in Figure 1.

### Example Analysis

This paper regards a north area with rich wind and light resources as an example. In this area, annual wind speed, light radiation record as well as specific parameters of DG are known. Use the standard IEEE16-node-three-feeder system, and the source voltage is 10.5 kV, and the total load of entire network is 28.7 + j7.75 MVA. Put QPSO algorithm into programming calculation, and analyze the results. Algorithm parameters selection: population size takes 50, and inertial factor range varies from 0.4 to 0.8, and mutation probability takes 0.04, and learning factor takes 2.0, and the number of iterations takes 150.Through using matlab7.0 to program and calculate algorithm, the running results are shown in Table 1. In order to reflect the contribution of DG on environment and in view of the higher cost for adding DG in current market situation, we reduce the weight of DG construction operation cost and increase the environmental factors weight. The results are shown in Table 2. Compared with PSO, use the network loss single objective function to optimize the location and capacity of DG, and the results are shown in Table 3. Figure 2 is the best fitness comparison between QPSO and PSO. As can be seen from the figure, in the early iteration, The QPSO algorithm has a fast convergence speed which is less than the PSO algorithm iterations over 30 times to achieve the same calculation accuracy. In the later iteration, the optimal results found by QPSO algorithm are superior to ones found by PSO algorithm. After 90 iterations, the population diversity of PSO algorithm loss serious, but QPSO algorithm remains good. Therefore, with using the encoding mechanism and mutation strategy of qubits probability amplitude, the search capabilities and optimization efficiency of QPSO algorithm are superior to PSO algorithm.

**Table 1. The optimization results of comprehensive objective function 1**

| Access DG location | Access DG Type | Access DG capacity | Access DG operating costs | Network loss cost | Reliability economic costs | Environmental factors cost | Compreh-ensive objective function values |
|---|---|---|---|---|---|---|---|
| 7 | Fan | 1.1 MW | | | | | |
| 10 | Gas turbine | 4.05 MW | $1.15*10^3$ ten thousand, RMB | 6.49 ten thousand, RMB | 6.64 ten thousand, RMB | 3.91 ten thousand, RMB | 291.76 ten thousand, RMB |
| 15 | Photovolt-aic cells | 0.6 MW | | | | | |
| 16 | Fan | 1.1 MW | | | | | |

**Table 2. The optimization results of comprehensive objective function 2**

| Access DG location | Access DG Type | Access DG capacity | Access DG operating costs | Network loss cost | Reliability economic costs | Environmental factors cost | Compreh-ensive objective function values |
|---|---|---|---|---|---|---|---|
| 7 | Fan | 1.1 MW | | | | | |
| 10 | Gas turbine | 4.05 MW | $1.67*10^3$ ten thousand, RMB | 7.94 ten thousand, RMB | 10.31 ten thousand, RMB | 4.64 ten thousand, RMB | 252.691 ten thousand, RMB |
| 11 | Photovolt-aic cells | 0.6 MW | | | | | |
| 15 | Fan | 2.2 MW | | | | | |

**Table 3. The comparison of optimization results between QPSO and PSO**

| Algorit-hm | Optimal position | Access DG Type | Optimal capacity | Optimal network loss | Average network loss | Number of converge-nce | Average number |
|---|---|---|---|---|---|---|---|
| QPSO | 8 | Fan | 2.2MW | 1098.9MW | 1142.5MW | 50 | 52.48 |
| | 10 | Gas turbine | 4.05MW | | | | |
| PSO | 10 | Gas turbine | 4.05MW | 1256.7MW | 1374.8MW | 43 | 89.64 |
| | 15 | Fan | 1.1MW | | | | |
| | 16 | Photovolt-aic cells | 0.82MW | | | | |

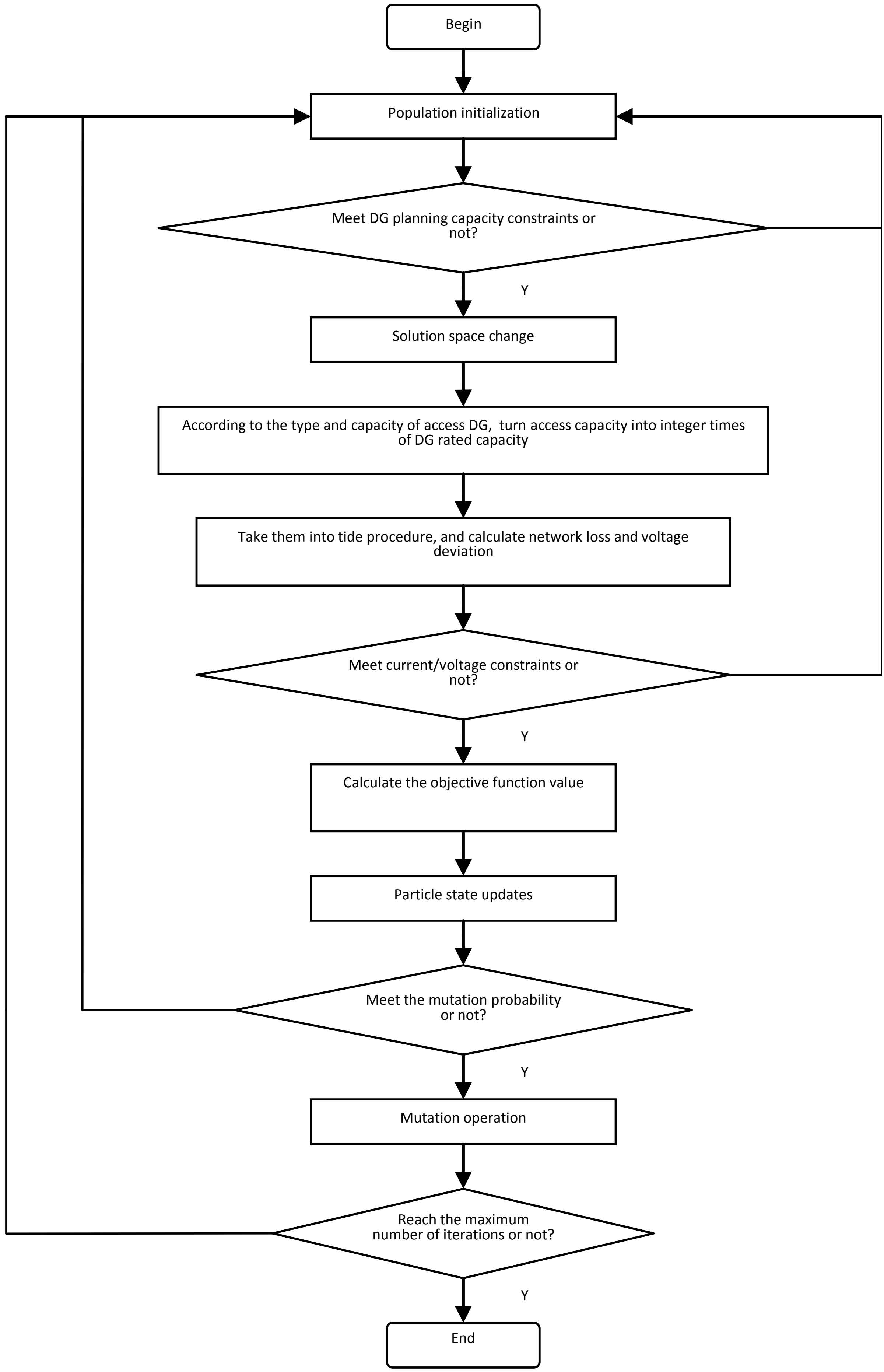


**Figure 1. Algorithm flow chart**

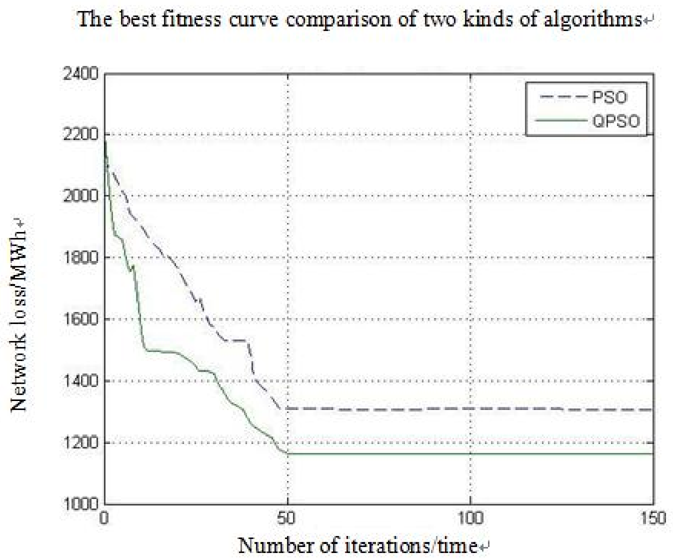


**Figure 2. The best fitness comparison between QPSO and PSO**

**Summary**

This paper has comprehensively considered the technical and economic planning problems of distribution network with accessing DG, and in other words, with taking reducing the DG investment, DG operation cost and system network loss as a objective and taking into account environmental factors, DG programming model has been established. And it has also proposed the quantum particle swarm optimization (QPSO) algorithm, and integrated the PSO algorithm into the quantum evolutionary algorithm, and used the qubit to encode the current position of particle, and used the quantum revolving gate to search the optimal position of particle, and used quantum non gate to realize the mutation of particle position to avoid the premature phenomenon. Thus, the global optimization ability and optimization efficiency of PSO are improved greatly. Meantime, the case analysis has verified that the performance of QPSO is more superior to the ordinary optimization algorithm, and the QPSO is more suitable for the power system planning field with higher real-time and accuracy requirements. This paper has only considered the three kinds of DG: fan, photovoltaic cells and micro gas turbine, and did not consider the biomass power generation and the fuel cell. And each node can only access a type of DG, therefore, it is necessary that the subjects about distribution network accessed through multi-type and mixed combination should be studied more deeply.

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