An improved gravitational search algorithm for distributed generation optimization

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Abstract: In order to optimize allocation and sizing of distributed generation, this paper puts forward an improved gravitational search algorithm based on particle swarm optimization. For the sake of preventing the gravitational search algorithm from falling into local optimum, mutation is added to the formula of position, and only Kbest particles are searched. The objective function to be optimized is the minimization of the power losses, and the IEEE-33 bus system is adopted to test the efficiency of the improved algorithm. The results indicate that the improved gravitational search algorithm has better convergence accuracy than the basic gravitational search algorithm, and that the voltage of the system can be improved.

1. Introduction
Distributed generation (DG) is a small power system, and it is used for especial users. The capacity of DG is usually less than 50MW. With the development of DG, more and more DGs are connected to the distribution system. If the allocation and sizing of DG are unreasonable, the DG will have a lot of bad influences on the distribution system. So the optimization of DG is of great significance. Many optimization algorithms have been proposed for the optimization of DG. In [3], the authors proposed the AGSO-BAS hybrid algorithm, and the optimization characteristics of AGSO-BAS and AGSO were compared to prove the efficiency of the AGSO-BAS. In [8], the authors proposed a modified cat swarm optimization, and chaos theory was used in the improved algorithm.

2. Materials and methods
2.1. Objective function
The objective function which is to minimize the power losses of distribution system can be calculated as follow:

\[ P_{loss} = \sum_{b=1}^{N} r_b |I_b|^2 \]  

Where \( I_b \) and \( r_b \) are the current and resistance of line \( b \), \( P_{loss} \) is the power losses of the system, \( N \) is the number of buses.

2.2. Constraint
The maximum penetration of DG is 25% of the total active loads, it can be expressed as follow:
\[
\sum_{i=1}^{N} P_{dg-i} \leq 0.25 P_{load}
\] (2)

Where \(P_{load}\) is the total active loads of the system, \(P_{dg-i}\) is the active power of DG at bus \(i\).

2.3. Particle swarm optimization

Particle swarm optimization (PSO) is an optimization algorithm that simulates the predation of birds [7]. It is often used to solve the problems of nonlinear optimization. The algorithm initializes a number of particles randomly, and each particle has position and velocity. The position of particle \(i\) can be defined as follow [7]:

\[
x_i = [x_1^i, x_2^i, x_3^i,..., x_D^i]
\] (3)

Where \(D\) represents the number of unknown numbers. By comparing the fitness value, the individual best and the global best at current iteration are obtained. By constantly updating the position, the best solution is found. The velocity and position of particle \(i\) at the \(t\)th iteration are calculated respectively as follows [7]:

\[
V_i^d(t+1) = V_i^d(t) + c_1 \times rand \times (p_i^d - x_i^d(t)) + c_2 \times rand \times (g_{best}^d - x_i^d(t))
\] (4)

\[
x_i^d(t+1) = x_i^d(t) + v_i^d(t+1)
\] (5)

Where \(c_1\) and \(c_2\) are the individual factor and global factor respectively, \(p_i^d\) and \(g_{best}^d\) represent the position of individual best and the position of global best respectively, \(t\) represents the \(t\)th iteration [5].

2.4. Gravitational search algorithm

The gravitational search algorithm (GSA) has drawn more and more attentions at home and abroad in recent years. The initialization of each particle is the same with PSO. The movement of each particle is based on the total gravitational force of other particles, and the better the particle is, the greater the gravitational force is. So the particles move toward the best particle. The total gravitational force acting on particle \(i\) from other particles at the \(t\)th iteration can be calculated as follow [2]:

\[
F_i^d(t) = \sum_{j=1,j\neq i}^{P} rand \times G_i \times \frac{M_j(t) \times M_i(t)}{||x_j^d(t) - x_i^d(t)||^2} \times (x_j^d(t) - x_i^d(t)) + \varepsilon
\] (6)

Where \(G_i\) and \(a\) are constant numbers, \(\varepsilon\) is a very small number, \(T\) represents the maximum number of iterations, \(P\) represents the total number of particles [5]. The mass of particle \(i\) is calculated as follows [2]:

\[
m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)}
\] (7)

\[
M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{P} m_j(t)}
\] (8)

Where \(fit_i(t)\) is the fitness value, \(M_i(t)\) is the mass of particle \(i\). In this paper, \(best(t)\) represents the minimum and \(worst(t)\) represents the maximum [4].

The acceleration, velocity and position of particle \(i\) are calculated respectively as follows [2]:

\[
a_i^d(t) = \frac{F_i^d(t)}{M_i(t)}
\] (9)
\begin{align*}
v_i^d(t+1) &= rand_i \times v_i^d(t) + a_i^d(t) \\
x_i^d(t+1) &= x_i^d(t) + v_i^d(t+1)
\end{align*}

2.5. The improved gravitational search algorithm

Although GSA can deal with multi-objective optimization problems, it will fall into local optimum. This paper puts forward an improved algorithm called IGSA to improve the convergence accuracy of the algorithm. At first, a group of solutions is found by particle swarm optimization algorithm, and then these solutions are optimized by gravitational search algorithm. Finally, the optimal solution is found. Figure 1 is the flow chart of the IGSA [6]. For the sake of preventing the algorithm from falling into local optimum, formula (11) is changed as follow [2]:

\begin{equation}
x_i^d(t+1) = x_i^d(t) \times (1+0.5 \times \text{rand}) + v_i^d(t+1)
\end{equation}

Only $K_{best}$ particles act on particle $i$ at the $t$th iteration, and $K_{best}$ is ranged from N to 5 according to iteration. $K_{best}$ is calculated as follow [1]:

\begin{equation}
K_{best} = N \times \frac{5+(1-\frac{t}{T}) \times (100-5)}{100}
\end{equation}

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**Figure 1** Flow chart of IGSA.

2.6. The settings of relevant parameters

The IEEE-33 bus system which is shown in figure 2 is used in this paper [9]. The total active loads and
reactive loads of the system is 3715kw and 2300kvar respectively, and the rated voltage of the system is 12.66kV. It was assumed that the unit capacity and the power factor of DG was 20 kw and 0.9 respectively. DG could be installed from bus 2 to bus 33. The power flow was calculated by forward-backward sweep method. In the improved algorithm, \( a \) was set to 20, \( c_i \) and \( c_j \) were set to 1.5 [7], \( T \) was set to 200, \( G_0 \) was set to 100 [2]. The algorithms were carried out by MATLAB.

3 . Results & discussion

The simulation results are shown in table 1. The power losses without DG are about 202.6 kw, while the power losses optimized by GSA are reduced to 93.5kw, and the power losses optimized by the IGSA are reduced to 85.6 kw. On the other hand, the results conform that DG is suitable to be installed near to the end line [10].

In figure 3, the optimization characteristics of the IGSA and GSA were compared. In the picture, the GSA fall into the local optimum soon, but the IGSA can jump out of the local optimum, and reaches the lower power losses. The result indicates that the IGSA has better convergence accuracy than the GSA.

In figure 4, the lowest voltage of the IEEE-33 bus system is 0.913 p. u. at bus 18 without DG. By using the IGSA, the lowest voltage reaches 0.954 p. u., which meets the requirement of voltage quality.
Table 1  Simulation results of the algorithms.

| Parameters          | Results                                      |
|---------------------|----------------------------------------------|
|                     | No DG | GSA  | IGSA             |
| Allocation          | -     | 11,14,15,17,32 | 14,17, 30,31,32,33 |
| Size (KW)           | -     | 20,100,240,20,440 | 180,180,120,140,220,60 |
| Power loss (KW)     | 202.6 | 93.5 | 85.6             |
| Minimum voltage (p. u.) | 0.913 | 0.95 | 0.954             |
| Average voltage (p. u.) | 0.948 | 0.967 | 0.969             |

4. Conclusions
This paper puts forward an IGSA for the optimization of DG. The objective function to be optimized is the minimization of the power losses, and this paper only considers the DG whose output power is stable. The IEEE-33 bus system was adopted to test the efficiency of the algorithm. The results indicate that the IGSA is effective, and that the power losses can be reduced by using the IGSA.

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