Planning of distributed generation in distribution network based on improved particle swarm optimization algorithm

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Abstract. Large-scale access of distributed power can improve the current environmental pressure, at the same time, increasing the complexity and uncertainty of overall distribution system. Rational planning of distributed power can effectively improve the system voltage level. To this point, the specific impact on distribution network power quality caused by the access of typical distributed power was analyzed and from the point of improving the learning factor and the inertia weight, an improved particle swarm optimization algorithm (IPSO) was proposed which could solve distributed generation planning for distribution network to improve the local and global search performance of the algorithm. Results show that the proposed method can well reduce the system network loss and improve the economic performance of system operation with distributed generation.

1. Introduction

Distributed generation (DG) is refers to the small scale power supply system located in the side of users, including wind power, photovoltaic power generation, small hydropower and biomass power generation using renewable energy power generation unit [1]. As a useful complement to part of the centralized power supply system, distributed generation with low investment cost and installation position changing, flexible control and other obvious advantages [2], but also increase the fluctuation and network loss of distribution network, improve power dispatching control difficulty [3].

Reasonable planning of distributed generation can effectively reduce system loss and improve system voltage level. For distributed generation planning problems, the existing research were mainly from the system active-reactive power loss [4-5], economic efficiency of investment [6] and the voltage stability index [7-8] and other directions, from single objective optimization algorithm to multi-objective intelligent algorithm to improve model [9-10]. In this paper, an improved Intelligent Particle Swarm Optimization algorithm is proposed to solve the problem of distribution network planning with distributed generation.

2. Power quality evaluation of distribution network with DG

In order to study the influence of the power quality of distribution network with DG, the related voltage and network loss evaluation indexes [9] are established as follows:

- Active line-loss reduction, *ALLR*:

$$ALLR\% = \frac{\mathrm{Re}\{\mathrm{loss}\}_0 - \mathrm{Re}\{\mathrm{loss}\}_{\mathrm{DG}}}{\mathrm{Re}\{\mathrm{loss}\}_0} \times 100\% \tag{1}$$

- Reactive line-loss reduction, *RLLR*:

$$RLLR\% = \frac{\mathrm{Lm}\{\mathrm{loss}\}_0 - \mathrm{Lm}\{\mathrm{loss}\}_{\mathrm{DG}}}{\mathrm{Lm}\{\mathrm{loss}\}_0} \times 100\% \tag{2}$$

- Voltage profile improvement, *VPI*:

$$VPI = \sum_{i=1}^{N_{\mathrm{bus}}} [V_i(0)\text{-}V_i(\mathrm{DG})]^2 \tag{3}$$

In order to consider the influence of distributed generation access on power quality under different circumstances, five cases are provided for the example system to compare and analysis results (example using IEEE-33 node power distribution system, the network structure and the parameters refer to Reference [7]).

- Case A: distribution network power flow calculation without DG.
- Case B: power flow calculation of the distribution network with wind power unit connected (the wind turbine with rated capacity of 300kW connected to Node 30).
- Case C: power flow calculation of the distribution network considering photovoltaic power unit connected (the photovoltaic power unit with rated capacity of 300kW connected to Node 32).
- Case D: power flow calculation of the distribution network considering photovoltaic power unit and wind power unit connected (the wind turbine with rated capacity of 300kW connected to Node 30 and the photovoltaic power unit with rated capacity of 300kW connected to Node 32).
- Case E: power flow calculation of the distribution network considering photovoltaic power, wind power, fuel cell and biomass power unit connected (the wind turbine with rated capacity of 300kW connected to Node 30; the photovoltaic power unit with rated capacity of 300kW connected to Node 32; the fuel cell unit with rated capacity of 300kW connected to Node 18; the biomass power unit with rated capacity of 300kW connected to Node 25).

Calculate power flow of distribution network by forward and backward substitution method (F&BS), and the results are shown in Table 1. DG is equivalent to PQ node for calculation processing, the mathematical model as follows:

$$\begin{cases} P_{DG} = -P_S \\ Q_{DG} = -Q_S \end{cases} \tag{4}$$

Table 1. Relative evaluation indexes under different cases.

Case	Active Loss /kW	Reactive Loss /kvar	Mean voltage /kV	Evaluation Indexes		
				ALLR(%)	*RLLR(%)*	*VPI*
Case A	201.72	134.48	12.0088	-	-	-
Case B	153.09	101.70	12.0903	24.11	24.38	0.3707
Case C	166.25	110.43	12.0664	17.58	17.88	0.1908
Case D	118.86	79.42	12.1664	41.08	40.94	1.4019
Case E	94.11	64.19	12.2268	53.35	52.27	2.4037

Table 1 shows that the evaluation indexes of different cases are not the same. The fundamental reason is that the total capacity of DG connected to the distribution network of each case are different, the system network loss decreasing and the voltage level advancing with the capacity increasing. The total capacity of Case B and C are equal, but the connected location is different, resulting in different loss and voltage indexes. To sum up, it is necessary to optimize the location and capacity of DG, so as to achieve the optimal targets of system.

The voltage distribution under different cases is shown in Figure 1. It could be known that the voltage distribution of other cases are better than that of case A, which shows that DG can effectively improve the voltage operation level of distribution network.

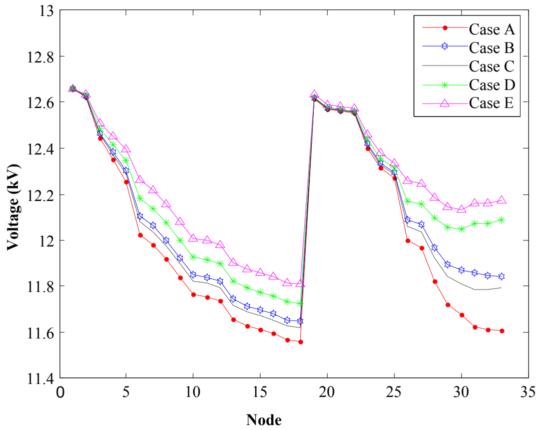

Figure 1. The voltage distribution under different cases.

3. Planning of DG in distribution network based on improved particle swarm optimization algorithm

3.1. Mathematical model of DG

The DG planning problem is a nonlinear and non-differentiable multi-objective optimization problem. The objective function can improve the voltage operation level of distribution network and minimize the active network loss of distribution network by optimizing the location and capacity of DG, and the corresponding mathematical model [11] is:

$$F = \min\left\{ P_{\mathrm{loss}} + \lambda \sum_{n=1}^{N_{\mathrm{p}}} \left| \frac{\Delta U_n}{U_{n\max} - U_{n\min}} \right|^2 \right\} \tag{5}$$

$$P_{\mathrm{loss}} = \sum_{u=1}^{NL} I_u^2 (RR_u + XX_u) \tag{6}$$

Where F is the objective function; P_{loss} is the active power loss in distribution network; I_{u} is the branch current; RR_u, XX_u are the resistance and reactance on the branch; N_{p}, NL are the node number and branch number in distribution network; λ is the penalty function coefficient of node voltage.

$$\Delta U_n = \begin{cases} U_{n\min} - U_n & U_n < U_{n\min} \\ 0 & U_{n\min} \le U_n \le U_{n\max} \\ Un - U_{n\max} & U_n > U_{n\max} \end{cases} \tag{7}$$

Where ΔU_n is the off-limit value deviation of Node n; $U_{n\min}$, $U_{n\max}$ are the minimum and maximum values of allowable voltage offset of distribution network nodes.

The equality constraint is:

$$P_{\mathrm{sub}} + \sum_{m=1}^{N_{\mathrm{DG}}} P_{\mathrm{DG}\_m} = P_{\mathrm{loss}} + \sum_{n=1}^{N_{\mathrm{p}}} P_{\mathrm{NL}\_n} \tag{8}$$

Where P_{sub} is the power of station; N_{DG} is the number of connected DG; P_{NL} is the active load in distribution network.

The inequality constraint is:

$$\begin{cases} U_{n\min} \le U_n \le U_{n\max} \\ I_j \le I_{j\max} \\ P_{\mathrm{DG}\min}(n) \le P_{\mathrm{DG}}(n) \le P_{\mathrm{DG}\max}(n) \\ Q_{\mathrm{DG}\min}(n) \le Q_{\mathrm{DG}}(n) \le Q_{\mathrm{DG}\max}(n) \end{cases} \tag{9}$$

Where I_{jmax} is the maximum current allowed passing through Branch j; $P_{\mathrm{DGmin}}(n)$ and $P_{\mathrm{DGmax}}(n)$ are the minimum and maximum values of the active power of DG connected to Node n; $Q_{\mathrm{DGmin}}(n)$ and $Q_{\mathrm{DGmax}}(n)$ are the minimum and maximum values of the reactive power of DG connected to Node n; U_n is the voltage state value of Node n.

3.2. Improved particle swarm optimization algorithm

Particle swarm optimization algorithm (PSO) is mainly used to deal with nonlinear and non-differentiable complex mathematical optimization problems. The variation of particle velocity is related to the variation of particle position, and the velocity and position update formula is [10]:

$$v_{ik}(t+1)=\omega v_{ik}(t)+c_1r_1[p_{ik}(t)-x_{ik}(t)]+c_2r_2[g_{ik}(t)-x_{ik}(t)] \tag{10}$$

$$x_{ik}(t+1)=x_{ik}(t)+v_{ik}(t+1) \tag{11}$$

Where $v_{ik}(t)$, $x_{ik}(t)$ are the velocity and position of the k-th dimension in the t-th iteration of Particle i; $p_{ik}(t)$ is the individual extreme point location of the k-th dimension in the t-th iteration of Particle i; g(t) is the global extremum point location in the t-th iteration; ω is the inertia weight; c_1, c_2 are the learning factors; r_1, r_2 are the uniformly distributed random numbers in Interval [0,1].

Aiming at the defects in convergence speed and precision of PSO, from the point of improving the learning factor and the inertia weight, an improved particle swarm optimization algorithm (IPSO) is proposed. The concrete improvement process is as follows:

The selection of inertia weight ω has an important influence on the convergence performance of the algorithm, and the larger weight is beneficial to improve the global search ability, the smaller weight will enhance the local search ability. Therefore, in order to balance the global search ability and local search ability, the self-adaptive weight method is used to improve the weight of PSO, as follows:

$$\omega=\begin{cases}\omega_{\min}-\dfrac{(\omega_{\max}-\omega_{\min})\times(f-f_{\min})}{(f_{\mathrm{avg}}-f_{\min})} & \\ \qquad f\le f_{\mathrm{avg}} & \\ \omega_{\max} \qquad f>f_{\mathrm{avg}} & \end{cases} \tag{12}$$

Where $\omega_{\max,}$ $\omega_{\min}$ are the Maximum and minimum values of weight; f is the particle current objective function; f_{avg}, $f_{\min}$ are the average target value and minimum target value of all present particles.

The learning factor in PSO is generally fixed constant, and the value is generally equal to 2.To improve this point, the asynchronous learning factor is used to update the particle process which will enhance the global search ability. The corresponding change formulas are:

$$c_1=c_{1,\mathrm{ini}}+\frac{c_{1,\mathrm{fin}}-c_{1,\mathrm{ini}}}{t_{\max}}\times t \tag{13}$$

$$c_2=c_{2,\mathrm{ini}}+\frac{c_{2,\mathrm{fin}}-c_{2,\mathrm{ini}}}{t_{\max}}\times t \tag{14}$$

Where: $c_{1,\mathrm{ini}}$, $c_{2,\mathrm{ini}}$ are the initial values of c_1 and c_2; $c_{1,\mathrm{fin}}$, $c_{2,\mathrm{fin}}$ are the final values of c_1 and c_2.
The basic steps of IPSO are as follows:

- Randomly initialize the position and velocity of particles in a population.
- Evaluate the fitness of each particle, and let the current position and the adaptation value store in the local optimal solution of each particle, then store the local optimal solution in the global optimal solution.
- Update the velocity and position of particles by Formula (10) and (11).
- Update the weight coefficient by Formula (12).
- Update the learning factors by Formula (13) and (14).
- For each particle, compare its adapt value with its experienced best position. If preferably, then take the adapt value as the current best position. Compare all the current local and global optimal values, and update the global optimal value.

- Determine whether to meet the iterative termination condition, if stop iteration and output results, otherwise, go to step 3 to continue to iterate until reaching the maximum iterations.

The planning process of DG in distribution network based on IPSO is shown as Figure 2.

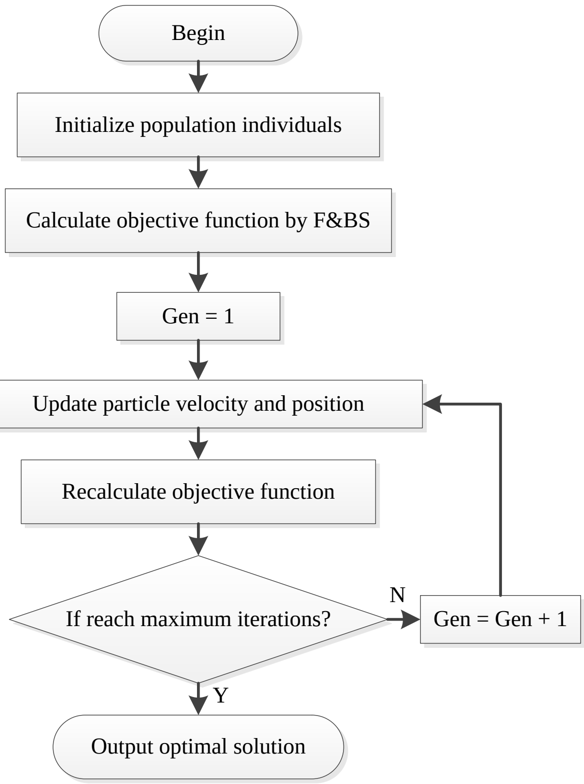

Figure 2. The planning process of DG in distribution network based on IPSO.

The concrete steps of the planning process of DG in distribution network based on IPSO are as follows:

- Input network initial data.
- Initialize algorithm particles, using real coded way to determine the location and capacity of DG, and calculate the corresponding objective function.
- Update the velocity and position of particles.
- Recalculate the objective function value of the updated particles, and compare with the optimal solution retained last time, then select the optimal solution and save it.
- Determine whether the maximum iteration number is reached, if stop iteration and output results, otherwise, continue to iterate until reaching the maximum iteration.

4. Example analysis

An example using IEEE-33 node power distribution system was given, which stipulated that the total capacity of DG did not exceed 40% of the total active load, and the corresponding power factor was 0.85.The IPSO parameters were set as: The initial particle number was 80; the particle dimension was 2; the maximum iterations was 300; the maximum inertia weight was 0.9 and the minimum was 0.4; the maximum of learning factor was 2.1, and the minimum was 0.8. The best configuration results were obtained as shown in Table 2.

Results show that DG reasonable connected to distribution network, can effectively reduce the network loss. On the other hand, with the results of the improved particle swarm optimization algorithm in [12], the system network loss index is relatively better by IPSO in this paper in the case of accessing the same capacity DG, which shows that this method has better convergence precision.

Table 2. Optimal planning example results.

Method	Capacity of DG /kW(location)	Active Loss /kW	Reactive Loss /kvar
F&BS	-	201.72	134.4792
Reference [12]	846.6(13);1151.5(30)	88.7488	61.2889
PSO	203.9(10);621.4(13);1172.8(31)	87.0565	59.8628
IPSO	257.9(9);600.2(13);1140(30)	86.1738	59.1095

In order to accurately evaluate the system voltage level after optimization, the system voltage operation by different methods was given in Figure 3. The minimum system voltage appeared at Node 18 when not optimized, the value of which was 11.5608kV. After optimization by IPSO, the minimum system voltage appeared at Node 18, and the value was 12.3089kV. Therefore, the voltage level of the optimized system is obviously improved compared with the un-optimized planning, in which the overall voltage operation level of IPSO in this paper is better.

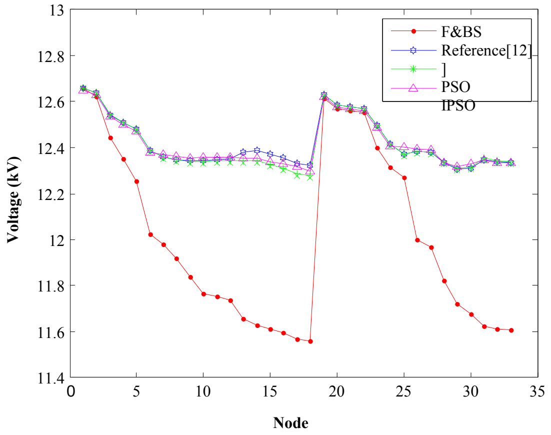

Figure 3. The system voltage distribution by different methods.

The convergence curve distribution of different algorithms was shown in Figure 4.

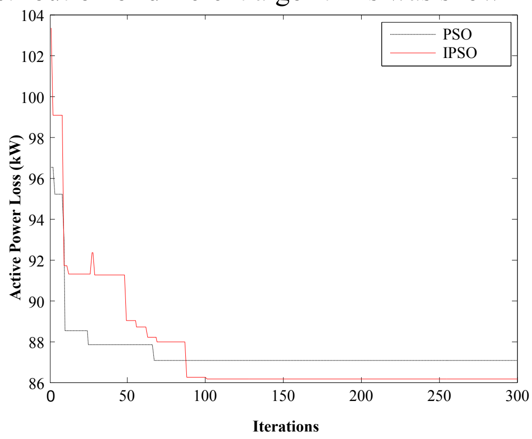

Figure 4. The convergence curve distribution of different algorithms.

As shown in Figure 4, compared with PSO, IPSO has better convergence accuracy, but at the expense of increasing iterations.

5. Conclusions

This paper has analyzed the effect of the distribution network power quality with DG, and put forward an improved particle swarm optimization algorithm in aspects of the inertia weight and the learning factor for DG in distribution network planning problems. Results show that the proposed method could well reduce the system network loss and improve the economic performance of system operation with DG. On the other hand, compared with the results of the existing research and PSO, the voltage level and the network loss were improved by IPSO in the same conditions, which show that IPSO has better convergence accuracy, but the convergence performance is slightly decreased.

References

[1] Ding M, Wang W S, Wang X L, Song Y T and Chen D Z 2014 A review on the effect of large-scale PV generation on power systems *Proceedings of the CSEE* **34** 1-14

[2] Hung D Q, Mithulananthan N and Bansal R C 2014 An optimal investment planning framework for multiple distributed generation units in industrial distribution systems *Applied Energy* **124** 62-72

[3] Keane A, et al. 2013 State-of-the-art techniques and challenges ahead for distributed generation planning and optimization *IEEE Transactions on Power Systems* **28** 1493-1502

[4] Yu L, Zhang X, Liu Y, Li Y and Wang Q G 2017 An adjustment method of distribution network reactive power compensation partition balance with distributed power sources *Power System Protection and Control* **45** 58-64

[5] Fu Y J, Wang F and Tan Y H 2017 Reactive power optimization of distribution network containing distributed generation based on Pareto optimal *Proceedings of the CSU-EPSA* **29** 18-23

[6] Li J, Yan H, Zhang Y F, Zhang Y Q, Jin H F, Hao S P and Lu G Y 2017 Comparison of locating and sizing methods of DGs between in micro-grids and in distribution network *Power System Protection and Control* **45** 147-54

[7] Wang B, Xiao J, Zhou J, Zhou H, Liu Y L and Zu G Q 2017 Dispatchable region of distributed generators and microgrids in distribution systems *Power System Technology* **41** 363-70

[8] Dent C, Ochoa L F and Harrison G P 2010 Network distributed generation capacity analysis using OPF with voltage step constraints *IEEE Trans. on Power Systems* **25** 296-304

[9] Aman M M, Jasmon G B, Bakar A and Mokhlis H 2014 A new approach for optimum simultaneous multi-DG distributed generation units placement and sizing based on maximization of system load-ability using HPSO(hybrid particle swarm optimization algorithm) *Energy* **66** 202-15

[10] Kayal P and Chanda C K 2013 Placement of wind and solar based DGs in distribution system for power loss minimization and voltage stability improvement *Electrical Power and Energy Systems* **53** 795-808

[11] Zeng M, Shu T, Shi H, Li B, Ouyang S J and Xue W L 2015 An active distribution network planning taking interest of distributed genco into account *Power System Technology* **39** 1379-1383

[12] Wang X W and Qiu X Y 2009 Distributed generation planning in distribution system based on modified particle swarm optimization algorithm *Power System Protection and Control* **37** 16-20