Distribution System Feeder Reconfiguration Considering Optimal Dispatching Of Distributed Generators

Wanlin Guan

Electric Power Research Institute of State Grid Heilongjiang Electric Power Co,. Ltd., Harbin, Heilongjiang, 150030, China.

wanlinguan@163.com

Abstract. In view of the increasing penetration rate of distributed power in distribution network, power injection of distributed generation (DG) directly affects the result of feeder reconfiguration. In order to optimize the performance of distribution network, a distribution system feeder reconfiguration method considering optimal dispatching of DGs is proposed. Traditional quantum particle swarm optimization (QPSO) algorithm is improved to realize parallel computing of QPSO and improved integer coding quantum particle swarm optimization algorithm(ICQPSO).However, two control variables ,distribution network reconfiguration and power injection of DG, can be processed in the optimization and achieve real power loss reduction and voltage stability improvement. The dispatchable DGs are divided into four grid-connected types according to the generation mechanism and calculated accurately in power flow. Simulation results of applying the proposed comprehensive optimization algorithm to PG&E 69 -bus radial distribution system show that the proposed algorithm is effective.

1. Introduction

With the objective requirements of environmental protection and the development of new energy technology, the penetration rate of distributed generation in distribution network increases year by year[1].In the planning stage of distributed generation, reasonable installed capacity and access location can reduce network active power loss and improve grid voltage stability [2]. The illumination and wind power need be consideration for optimizing DG capacity and access location [3, 4].The location and capacity of distributed generation are determined under initial network, however, with the change of network load and network fault, the network need reconstruct. The output power of distributed generation determined in the planning stage is no longer the optimal state, so comprehensive optimization of the DG output power and feeder reconfiguration is needed.

Existing research results have considered the influence of DG on distribution network reconfiguration [5]. According to different types of DG, fuel cell, wind, photovoltaic power type DG are precise modeled in distribution network reconfiguration for improving the precision of reconfiguration [6], but the optimal dispatching of distributed generators is not considered in the reconfiguration. Ref [7] comprises a step by step heuristic algorithm based on sensitivity indexes to optimize distributed generation allocation with the reconfiguration. However, the capacity of DG is treated as a fixed value and the calculated quantity of heuristic algorithm is huge. Ref [8] considers DG as dispatched equipments during the distribution network reconfiguration optimization process,

and the injected power is regarded as optimization variables. DG injected power, network loss, and benefit distribution are changed into comprehensive costs according to tariff, and the minimum of costs is taken as the objective function to solve the reconfiguration problem. Ref [9] proposes a comprehensive optimization algorithm for DG injection power and distribution network reconfiguration based on particle swarm optimization (PSO) to achieve global optimization of distribution network.

However, the above references regard DG as the PQ node with constant active power in the reconfiguration, and wind, photovoltaic, micro gas turbine and fuel cell power type DG have not accurate modeled The DG model is simple and the reconstruction effect is not consistent with the reality. Therefore, the comprehensive optimization of DG optimization configuration and network reconfiguration with different types of DG is the research focus. This paper realizes the comprehensive optimization of the four node types of DG. In order to achieve simultaneous optimization of distribution network reconfiguration and DG injection power, the parallel optimization algorithm of quantum particle swarm optimization and integer coded quantum particle swarm optimization is proposed, and the reconstruction efficiency improves greatly.

2. Model of dispatchable DG
DG can be divided into two types, dispatchable DG and non-dispatchable DG [10].Non-dispatchable DGs usually include wind power and photovoltaic power generation. The output power of these power are random with the influence of environmental factors such as wind speed and light intensity, except for large wind farms and photovoltaic power plants which can be used for grid dispatch. Some distributed generation forms, such as hydraulic turbine, fuel cell and micro-turbine, have excellent regulating performance and can control output power through the supply of energy quantity. These DGs can be treated as dispatchable DG. According to the mechanism of DG, the dispatchable DGs are divided into the four node types as shown in Table1.

Table 1. The classification of dispatchable DG in power flow .

Classification	Model type
Direct driven synchronous wind turbines(installed energy storage systems, ESS); Micro gas turbine; Fuel cell	PQ
Photovoltaic system equipped with current inverter(ESS); Micro gas turbine; Fuel cell	PI
Fixed speed and slip controlled asynchronous wind turbines(ESS)	PQ(V)
Doubly fed wind turbines(ESS)	PV

3. Double objective formulation
Weight coefficient method is used to convert real power loss reduction and voltage stability improvement into a single double objective formulation [11].

$$\min f = aw_1 \frac{f_{ploss}}{\lambda_1 ploss_{init}} + bw_2 \frac{f_{ustab}}{\lambda_2 Ustab_{init}} \tag{1}$$

Where, *fploss* is real power loss formulation, *fustab* is voltage stability index formulation .Detailed parameters can be seen in Ref [1] written by *W.L. Guan*.

4. Distribution network reconfiguration optimization algorithm considering dispatchable DG

4.1. Improved Parallel Quantum Particle Swarm Optimization
The traditional QPSO can be used to optimize the DG injection power. However, the particle is integer loop coded in distribution network reconfiguration, as each dimension of particle is positive integer ,so

integer coded quantum particle swarm optimization (ICQPSO) is applied [12].Parallel QPSO can get network reconfiguration optimum solution and DG injection power optimization simultaneously.

The improved parallel quantum particle swarm algorithm only needs to improve the mutation strategy of the traditional QPSO algorithm. Only the modified formula (2) is needed, as follows:

$$X_{id}(t) = \begin{cases} round(P_{id}(t) \pm \beta * |mbest(t) - X_{id}(t)| * \ln(\frac{1}{u})) & 1 \le d \le LL \\ P_{id}(t) \pm \beta * |mbest(t) - X_{id}(t)| * \ln(\frac{1}{u}) & LL < d \le LL+m \end{cases} \quad (2)$$

The particles will appear go out of bounds when random search in the solution space. If particle go out of bounds, the algorithm proposed the boundary mutation operation process according to Eq (3).

$$\begin{cases} X_{id} = rand\, int(1,1,[Lb_d,Ub_d]) & \begin{matrix} X_{id} > Ub_d \\ or X_{id} < Lb_d \end{matrix} (1 \le d \le LL) \\ X_{id} = rand(1,1,[Lb_d,Ub_d]) & \begin{matrix} X_{id} > Ub_d \\ or X_{id} < Lb_d \end{matrix} (LL < d \le LL+m) \end{cases} \quad (3)$$

Where, X_{id} is d dimension of particle i; LL is the number of tie switches; m is the number of DGs. Ub_d is upper initialization of dimension d; Lb_d is lower initialization of dimension d; d=1,2,…$LL+m$, Dim, and d is the number of dimensions.

4.2. Coded form
The improved parallel QPSO algorithm is adopted in the distribution system feeder reconfiguration considering optimal dispatching of DGs. QPSO and ICQPSO is applied to the parallel optimization algorithm and realize the optimization of switch state combination and DG injection power simultaneously. The coding of particles is: $x = [S_{w}, P_{DG}]$. The continuous variable (DG injected power P_{DG}) is optimized by standard QPSO algorithm, and the discrete variable (switch state Sw) is optimized by ICQPSO algorithm.

5. The 0ptimaling procedure
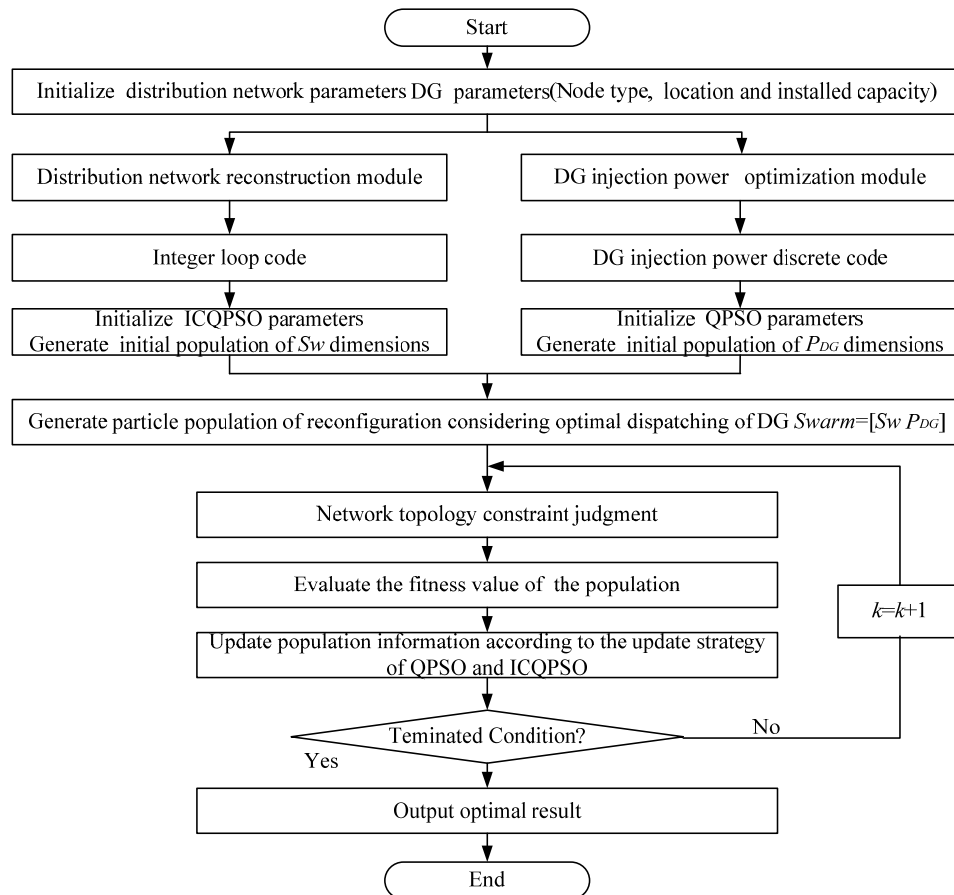
Figure 1. Optimization flow chart of distribution system feeder reconfiguration considering optimal dispatchable DGs.

6. Simulation results

The proposed method is tested on PG&E69-bus radial distribution system shown in Fig.2. The substation voltage is considered as 12.66kV (1*p.u.*). It consists of 5 tie switches and 68 sectionalizing switches. All tie and sectionalizing switches are candidate switches in reconfiguration. The numbers in the figure indicate the switch number. The total power loads are 3802.19 kW and 2694.60 kvar. Assume *Ploss* is the real power losses of network; *Ustab* is the voltage stability index .*Vmin* is lowest voltage of all buses. For initial network without DGs, normally open switches [69 70 71 72 73], and real power losses (*Ploss*) is 226.4735 kW, *Vmin* is 0.9089 *p.u.*. Particle dimension is 5, population size is 50, the number of iteration is 100, and convergence precision is set to $1e^{-6}$.

In order to verify the effect of the comprehensive optimization algorithm, six schemes have been simulated and analyzed. Description of six schemes is shown in Table 2.

Table 2. Description of six schemes

| Scheme number	Scheme description
1	Injection power of DG is zero, the network not reconfigure.
2	Injection power of DG is constant, the network not reconfigure.
3	Injection power of DG is constant, the network reconfigure.
4	First reconfigure network, then optimize DG injection power
5	First optimize DG injection power, then reconfigure network
6	Comprehensive optimization of network reconfiguration and DG injection power
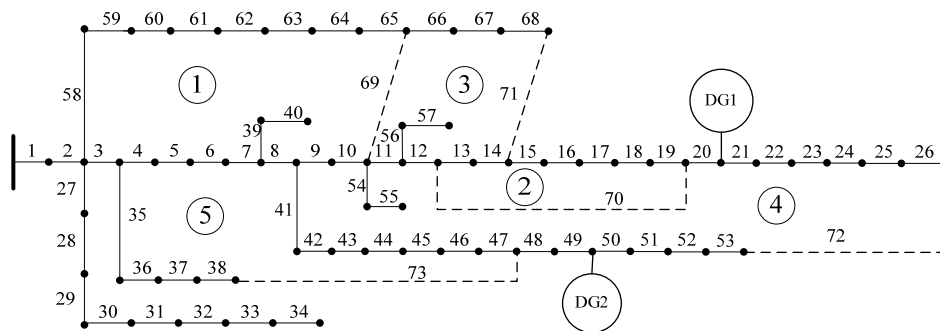
Figure 2. PG&E69-bus distribution network system

In order to verify the effectiveness of the proposed comprehensive optimization algorithm for different types of DG, The 20 and 50 nodes of the system are respectively connected to photovoltaic power generation with energy storage system (PI node type DG, as DG1) and asynchronous wind generator (PQ (V) node type DG, as DG2).

The rated current of DG1 is 50A, and the parameters of DG2 are shown in Ref [11].The capacity upper and lower limit of access to DG are set to 2400kW and 150kW respectively. The integrated optimization are carried out with the active loss static voltage stability index double target. The results of the six schemes are shown in Table 3. Fig.3 shows the comparison of voltage magnitude for Schemes 1–6.

Table 3. Comprehensive optimization results of 69node system

Scheme	Open Switches	Output active power of DG1(kW)	Output active power of DG2(kW)	Fitness value	*Ploss*(kW)	*Ustab*	*Vmin*(p.u.)
1	[69 70 71 72 73]	0	0	1	226.4735	0.1257	0.9089
2	[69 70 71 72 73]	300	300	0.8304	167.2237	0.1160	0.9226
3	[69 70 12 50 44]	300	300	0.6107	76.4082	0.1111	0.9465
4	[69 70 14 50 44]	516	1800	0.4899	92.1984	0.0720	0.9539
5	[8 14 71 12 41]	414.2	1800	0.5640	90.7290	0.0914	0.9541
6	[10 15 13 12 44]	602.5	1866.7	0.2821	63.9363	0.0354	0.9788
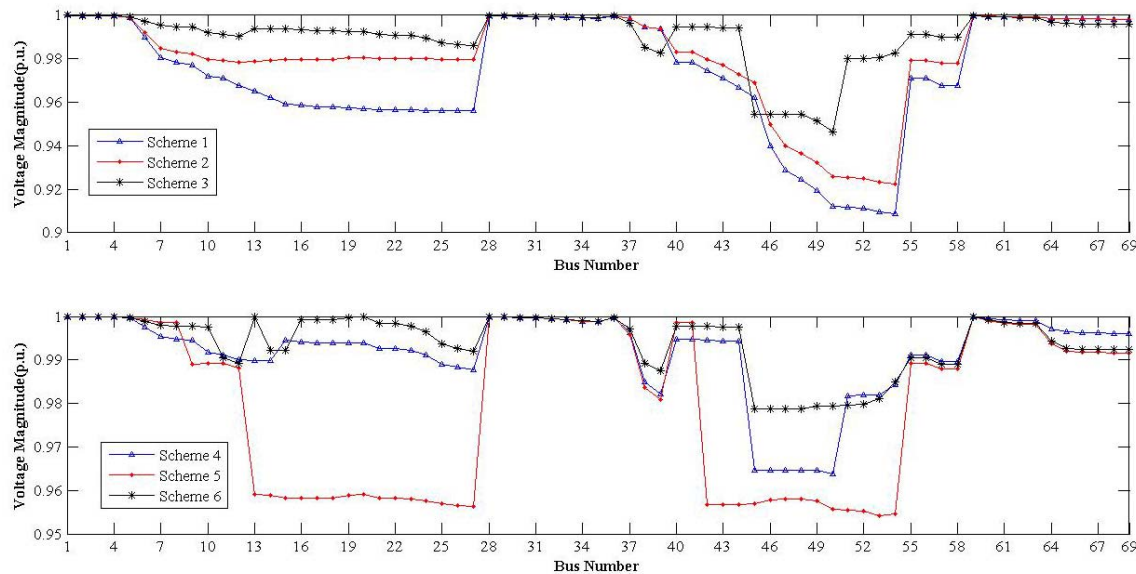
Figure 3. Comparison of voltage magnitude for Schemes 1–6.

The voltage magnitude of all schemes meets the constraint conditions. Scheme 6 optimizes the distribution network reconstruction and DG injection power comprehensively and the active power loss is all lower than scheme 4 and 5, *Vmin* is also the lowest in all schemes.

As can be seen from Fig.3, access of DG and distribution network reconfiguration can improve the voltage magnitude level to different degrees. The optimization results of scheme 6 are better than scheme 1-5, and obtain the minimum *Ploss* and maximum voltage improvement. The distribution network reconfiguration and DG injection power optimization are interrelated. Comprehensive optimization is more effective than the independent optimization.

The above simulation examples show the correctness of the proposed algorithm for distribution network reconfiguration and DG injection power integrated optimization, which can be applied to the comprehensive optimization reconfiguration of various types of dispatchable DGs.

7. Conclusion

A distribution system feeder reconfiguration method considering optimal dispatching of distributed generators is proposed in this paper. Traditional quantum particle swarm optimization (QPSO) algorithm is improved to realize parallel computing of QPSO and ICQPSO. Distribution network reconfiguration and power injection of DG can be parallel optimized and adopt real power loss and voltage stability double objective formulation. Dispatchable DGs are divided into PQ/PQ (V)/PI/PV type according to the generation mechanism .This method is applied to the IEEE69 node system, and six schemes are optimized. The simulation results verify the effectiveness of the proposed method.

References

[1]   P.M. De Oliveira-De Jesus;C. Henggeler Antunes. A detailed network model for distribution systems with high penetration of renewable generation sources, Electric Power Systems Research.2018, Vol 161: 152-166

[2]   D.Q. Hung, N Mithulananthan, K.Y. Lee. Optimal placement of dispatchable and nondispatchable renewable DG units in distribution networks for minimizing energy loss. International Journal of Electrical Power & Energy Systems, 2014, 55: 179-186

[3]   M.H. Moradi, M Abedini. A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. International Journal of Electrical Power & Energy Systems, 2012, 34 (1): 66-74

[4]   A.A. Abou EI-Ela, S.M. Allam. Maximal optimal benefits of distributed generation using genetic algorithms. Electric Power Systems Research, 2010, 80 (7): 869-877

[5]   Y.K. Wu, C.Y. Lee, L.C. Liu, et al. Study of reconfiguration for the distribution system with distributed generators. IEEE Transactions on Power Delivery, 2010, 25 (3): 1678-1685

[6]   T Niknam, A.K. Fard, A Seifi. Distribution feeder reconfiguration considering fuel cell/wind/photovoltaic power plants. Renewable Energy, 2012, 37 (1): 213-225

[7]   J.S. Rosseti Gustavo, J. de Oliveira Edimar, W. de Oliveira Leonardo, et al. Optimal allocation of distributed generation with reconfiguration in electric distribution systems. Electric Power Systems Research, 2013, 103: 178-183.

[8]   D Bian, Z.N. WEI, X.Q. HUANG,et al. Distributed network reconfiguration model including distributed generation in the electricity market.Power System Protection and Control, 2013, 41(11): 117-123.

[9]   J.J. ZHAO, X LI, Y PENG, et al. A Comprehensive Optimization Algorithm for Injection Power of Distributed Generation and Distribution Network Reconfiguration Based on Particle Swarm Optimization.Power System Technology, 2009, 33 (17): 162-166.

[10]   A Rahiminejad, D Faramarzi, S.H. Hosseinian, et al. An effective approach for optimal placement of non-dispatchable renewable distributed generation [J].Journal of Renewable and Sustainable Energy,2017, **9**, 015303: 1-15

[11]   W.L.GUAN, N GUO, C.L.YU, et al. Optimal placement and sizing of wind/solar based DG sources in distribution system. [J]. IOP Conf. Series: Materials Science and Engineering, 2017, 207: 1–9.

[12]   W.L. Guan, Y.H. Tan, H.X. Zhang, et al. Distribution system feeder reconfiguration considering different model of DG sources. International Journal of Electrical Power & Energy Systems. 2015; 68: 210-221.