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Research on Reactive Power Compensation System Technology of Distributed Generation Connected to Grid

Minxing Xu

Department of Electrical Engineering, North China Electric Power University (Baoding), Baoding071000, China

220191040123@ncepu.edu.cn

Abstract

According to the control characteristics of distributed power grid-connected, the distributed power supply is designed as voltage control type and reactive power compensation type. Considering its combination with the voltage and reactive power control methods of the regional power grid, it participates in the dynamic reactive power optimization dispatch of the regional power grid. A fuzzy dynamic reactive power optimization dispatching model for regional power grids is established with the comprehensive goals of reducing regional power grid losses and suppressing voltage fluctuations. The correctness and effectiveness of the above reactive power planning model and algorithm are verified by an example of reactive power planning in a distribution network with grid-connected photovoltaic power sources.

Keywords

Distributed, power supply, reactive power compensation, network access.

1. Introduction

The traditional automatic voltage control only relies on solving the voltage and reactive power optimization problem at the current moment, and does not consider the possible intermittent change trend of the power grid in the future. This control mode causes the frequent switching of reactive power equipment such as capacitors and reactors, and the system responds the problem of insufficient dynamic reactive power reserve for disturbances and faults is dealt with. With the rapid increase in the scale of new energy power generation, the scale of the microgrid that it constitutes is integrated into the distribution network is getting larger and larger. While improving the energy utilization rate, it also has a non-negligible impact on the stable operation of the power grid, such as reducing the power quality of the power grid affects the power flow distribution of the system [1]. The in-depth study of these issues is of great significance to the further development and application of new energy power generation technologies in the future. This article first briefly introduces distributed power sources and grid-connected standards, and then combines the simulation graphics to study the various effects of distributed power grids on the power grid from multiple angles, and gives some solutions accordingly.

The article uses the fuzzy evaluation function as the objective function of the dynamic reactive power optimization dispatching model of the regional power grid with distributed power generation, and uses the improved genetic algorithm combined with the optimization principle to solve the dynamic reactive power optimization dispatching strategy of the regional power grid with distributed power generation throughout the optimization cycle.

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2. Optimal configuration model of reactive power compensation device for distributed power grid-connected distribution network

2.1. Objective function

When the active load, reactive load and electric vehicle charging station capacity of the distribution network are determined, the voltage amplitude and reactive power compensation capacity of the substation are used as the control variables, and the node reactive power compensation capacity and node voltage are used as state variables [2]. The algorithm, under the constraints of the safe and economic operation of the power grid, can play the role of distributed power grid-connected operation mode to provide a certain amount of reactive power compensation for the power grid, and determine the best reactive power compensation point and the corresponding reactive power compensation capacity.

This chapter considers the effect of distributed power grid connection on reactive power compensation of the distribution network. After applying the district comprehensive active loss/reactive power sensitivity method to determine candidate reactive power compensation points, the sum of the comprehensive network loss and reactive power compensation device cost is established. Optimal configuration model of reactive power compensation devices for distribution network based on objective function. The objective function in this paper can be expressed as follows:

$$\min C = \mu_1 \beta \tau_{\max} P_{loss1} + \mu_2 \beta \tau'_{\max} P_{loss2} + \sum_{i=1}^{N_C} \alpha Q_{ci} \tag{1}$$

In the above formula, β is the electricity price; μ_1 is the charging operation coefficient, and μ_2 is the discharging operation coefficient; P_{loss1}, P_{loss2} is the network loss value during the charging and discharging operation of electric vehicles respectively; $\tau_{\max}$, $\tau'_{\max}$ is the maximum load utilization hours of the charging station as a load and a power source, respectively N_c is the number of compensation capacitors; α is the unit price of the compensation capacitor; Q_{ci} is the reactive capacity of the compensation capacitor at node *i*.

2.2. Constraints

The constraints of the optimization model proposed in this chapter include the constraints of conventional radial distribution network reactive power optimization planning and the constraints that need to be met for grid-connected distributed power generation.

(1) Tidal flow constraints

The power flow constraint adopts the polar coordinate form, namely

$$P_i - U_i \sum_{j=1}^{n} U_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \tag{2}$$

$$Q_i - U_i \sum_{j=1}^{n} U_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) = 0 \tag{3}$$

P_i and Q_i are node i active and reactive power injected respectively; j is the number of network nodes; G_{ij} , B_{ij} is the conductance and susceptance between nodes i and j respectively; θ_{ij} is the active and reactive power of each bus node load.

(2) Reactive power output constraints of electric vehicles

$$Q_{EVi} \le Q_{EV\max i} \tag{4}$$

Among them, Q_{EVi} is the reactive power of the electric vehicle, and $Q_{EV\max i}$ is the upper limit of the reactive power of the electric vehicle. The reactive power output limit of the charging station is restricted to the allowable and reasonable range when the charging station is running in the V2G mode.

(3) Node voltage amplitude constraint

$$V_{\min i} \le V_i \le V_{\max i} \tag{5}$$

V_i is the voltage value of each load node, and $V_{\min i}$ I $V_{\max i}$ are the lower and upper limits of the voltage of each node, respectively.

(4) Compensation capacity constraints

$$Q_{c\min i} \le Q_{ci} \le Q_{c\max i} \tag{6}$$

$Q_{c\max i}$, $Q_{c\min i}$ respectively, are the upper and lower limits of reactive power compensation capacity, which are usually determined by the safety and economy of power system operation.

3. Reactive power compensation device optimization configuration solution process based on genetic algorithm

Genetic algorithm is a stochastic optimization algorithm proposed by Holland in the 1970s, based on the genetic and mutation mechanism of natural organisms [3]. Genetic algorithm can use binary coding adapted to the characteristics of computer coding, searching for optimal solutions in parallel starting from within the group, has strong global optimization ability, and is a mature algorithm for solving high-dimensional, nonlinear mixed integer optimization problems. Genetic algorithms have been widely used to solve optimization problems in power systems. When using genetic algorithm to solve the problem of optimal configuration of reactive power compensation device, the specific operation method is as follows.

The first step: encode the control variable. The control variable in this paper is the corresponding reactive power compensation capacity of n candidate reactive power compensation points determined by the comprehensive active loss/reactive power sensitivity method. Using binary coding, n individuals are generated to form the original population. According to the optimization model proposed in this chapter, a population $X = [Q_c] == [Q_{c1}, Q_{c2}, ..., Q_{cn}]$ can be generated.

Step 1: Perform genetic algorithm operations. Genetic algorithm operation is the essence of genetic algorithm, including selection, crossover and mutation steps. By determining reasonable genetic algorithm parameters, the evolutionary law of heredity and mutation in nature can be effectively simulated.

The third step: calculation of fitness function. This chapter takes the reciprocal of the objective function value as the fitness function Fit, namely

$$Fit = 1/\min C = 1/(\mu_1 \beta \tau_{\max} P_{loss1} + \mu_2 \beta \tau'_{\max} P_{loss2} + \sum_{i=1}^{N_C} \alpha Q_{ci}) \tag{7}$$

After the second step of genetic operation, the power flow calculation program is called again for the new individual. According to the results of the power flow calculation, the fitness function is calculated for each individual through the above formula. The larger the fitness function value, the stronger the individual's ability to adapt to the natural environment. By comparing the fitness function values of individual individuals, the evolutionary principle of "survival of the fittest and survival of the fittest" is applied in nature to eliminate individuals with low fitness values and retain individuals with high fitness values [4]. If the fitness function value of a body has met the termination condition of the fitness function value set in this article, and tends to be stable, then proceed to the fourth step; otherwise, re-enter the second step to the genetic algorithm operation process, and continue to the third step calculate.

Step 2: Output the best solution. The results of the optimal plan include the optimal compensation capacity of the candidate reactive power compensation point, the node voltage value, and the objective function value of the planning plan. In this paper, the process of applying genetic algorithm to solve the reactive power compensation device of distribution network is shown in Figure 1.

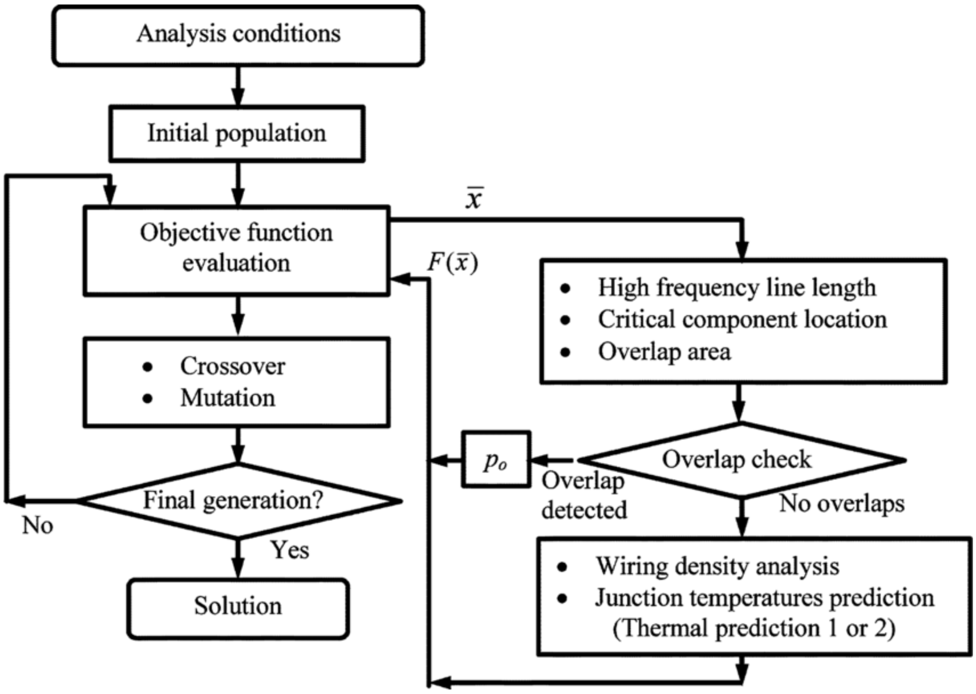

Figure 1. The flow chart of applying genetic algorithm to solve the reactive power compensation device of distribution network

4. Example analysis

In this chapter, on the basis of the IEEE54 node calculation example in Chapter 3, the distribution network planning scheme that considers the grid-connected effect of distributed power sources, the optimization configuration planning of reactive power compensation devices considering the grid-connected distributed power sources is carried out [5]. This chapter divides the area to be planned into four areas according to the optimized planning scheme combined with the geographical division method. Each area node is shown in Table 1.

Table 1. Partitioning scheme

Area number	Node number
1	51, 1, 2, 3, 9, 4, 10, 7, 5, 8, 6, 33, 39, 32, 38
2	52, 14, 46, 11, 15, 12, 16, 45, 13, 44, 43, 37, 31
3	53, 28, 36, 41, 27, 35, 40, 42, 26, 34, 47, 48, 49, 50
4	54, 30, 22, 21, 29, 23, 18, 24, 17, 19, 25, 20

Apply the district comprehensive active power loss/reactive power sensitivity method to determine the node sensitivity value in each area as shown in Table 2 to Table 5.

Table 2. Sensitivity value of each node in area 1

Node number	Active loss/reactive sensitivity value		Comprehensive sensitivity
	V1G mode	V2G mode	
51	5.8624	5.8852	3.0806
1	0.2929	1.9115	0.3561

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3	9.8579	9.7884	5.1667
9	16.3836	16.3836	8.6014
2	10.7666	10.7666	5.6525
4	17.1802	24.1402	9.8896
10	13.3023	13.3023	6.9837
7	17.9247	17.8958	9.4069
5	15.5361	15.5056	8.1526
8	11.6732	12.9481	6.2878
6	9.0322	9.0305	4.7417
33	17.9992	6.4662	8.008
39	15.0424	32.6976	10.9216
32	14.0519	14.0955	7.3827
38	16.2477	16.2474	8.53

Table 3. Sensitivity value of each node in area 2

Node number	Active loss/reactive sensitivity value		Comprehensive sensitivity
	V1G mode	V2G mode	
52	5.9286	5.9374	3.1136
14	-2.2147	-2.2147	-1.1627
11	8.225	8.2062	4.3158
46	14.2394	14.2394	7.4757
15	13.2239	13.2239	6.9425
12	28.8577	30.4042	15.3436
16	9.5214	9.5214	4.9987
45	22.6026	26.1551	12.3104
13	24.9705	16.9519	12.1072
44	7.0758	7.065	3.7134
43	14.2932	14.2928	7.5039
37	12.3051	12.3196	6.462
31	9.6208	9.6204	5.0509

Table 4. Sensitivity value of each node in area 3

Node number	Active loss/reactive sensitivity value		Comprehensive sensitivity
	V1G mode	V2G mode	
53	22.4127	22.425	11.7682
28	2.2958	2.2958	1.2053
36	3.7838	3.7838	1.9865
41	8.9651	22.709	6.4247
27	11.9792	11.9792	6.2891

35	16.6603	15.4784	8.5892
40	10.2645	10.2478	5.3868
42	19.6147	19.6102	10.2972
26	10.3637	10.3637	5.4409
34	10.0252	10.0252	5.2632
47	12.087	12.0923	6.3463
48	16.4261	16.4212	8.6231
49	14.8042	12.984	7.5447
50	8.6667	8.6667	4.55
53	22.4127	22.425	11.7682

Table 5. Sensitivity value of each node in area 4

Node number	Active loss/reactive sensitivity value		Comprehensive sensitivity
	V1G mode	V2G mode	
54	19.2146	19.2357	10.0903
30	1.7066	1.7066	0.896
22	2.1412	2.2032	1.1319
21	4.8316	4.8316	2.5366
29	11.133	11.133	5.8448
23	16.7313	21.087	9.3284
18	18.802	18.802	9.8711
24	11.605	11.5984	6.0918
17	13.3338	13.3338	7.0002
19	17.5056	0.7053	7.0904
25	10.017	10.016	5.2588
20	10.4258	10.4258	5.4735

By comparing the sensitivity values when considering only V1G and considering V2G operation mode, the reasonable reactive power compensation candidate points in each area can be determined as shown in Table 6 below.

Table 6. Partitioned reactive power compensation candidate nodes

Area number	Reactive power compensation candidate node number	
	Consider only V1G	Consider V2G
1	7, 33	39, 4
2	12, 13	12, 45
3	35, 42	42, 48
4	18, 19	23, 18

In this paper, MATLAB software is used for programming and genetic algorithm is used to solve the optimal configuration solution of reactive power compensation device. The genetic

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algorithm parameters are selected as follows: select the roulette method that is relatively easy to implement, crossover probability proc=0.75, gene mutation rate pmut=0.05, chromosome length len=10, population number num=30, genetic frequency N=5. Other simulation parameters are: electricity price c_i = 0.5 yuan/kWh, single capacitor group capacity is 100kvar, unit price is 20 yuan/kvar, charging station power factor $\cos\varphi = 0.9$. The four regional balance nodes are 51, 52, 53 and 54 respectively. The reactive power compensation candidate nodes considering V2G and V1G only are shown in Table 6. The calculation results are shown in Table 7 and Table 8.

Table 7. Reactive power compensation scheme considering only V1G

Area	Objective function value (Yuan)	Best individual	Compensation node	Compensation capacity (Mvar)
A1	616270	0110100111	7	1.3
			33	0.7
A2	211680	0011001110	12	0.6
			13	1.4
A3	56454	00110000011	35	1.2
			42	0.3
A4	122590	0111001000	18	1.4
			19	0.8
Total	100694			

Table 8. Reactive power compensation scheme considering V2G

Area	Objective function value (Yuan)	Best individual	Compensation node	Compensation capacity (Mvar)
A1	616160	110010001	4	1.2
			39	1.7
A2	214670	110100111	12	1.3
			45	0.7
A3	29892	0001000010	42	0.2
			48	0.2
A4	93807	0000100110	23	0.1
			18	0.6
Total	954529			

Figures 2 and 3 are the reactive power compensation schemes when considering the electric vehicle charging station V1G and the charging station V2G, respectively.

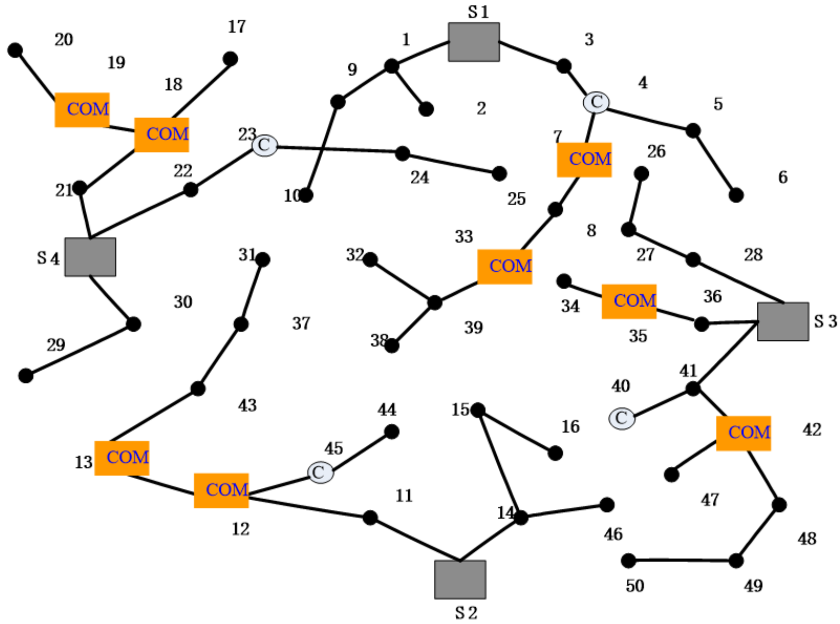

Figure 2. Reactive power compensation optimization scheme when only considering grid connection

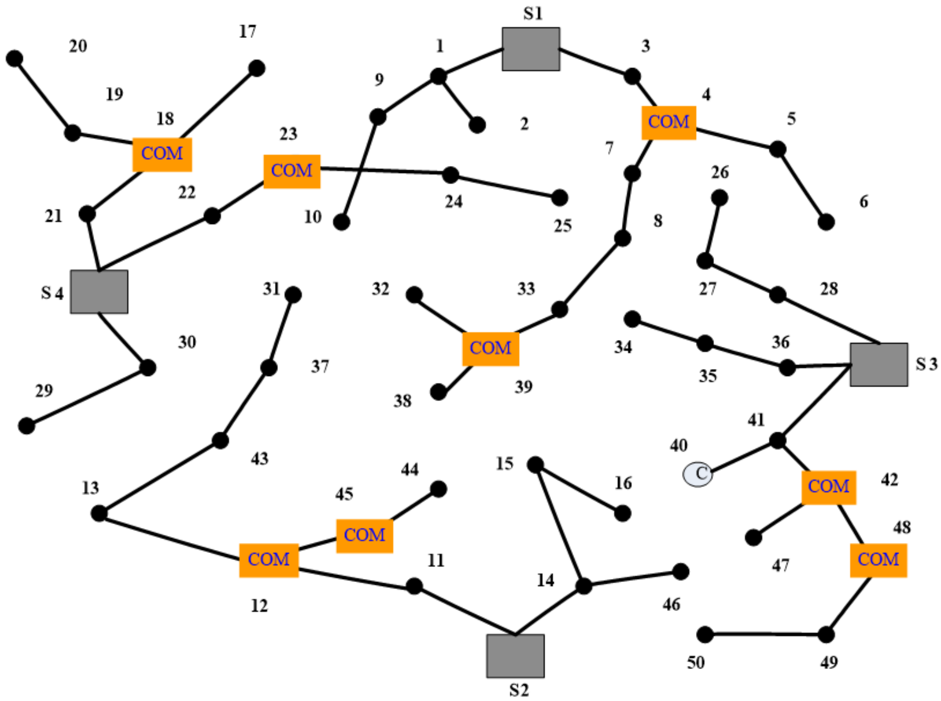

Figure 3. Reactive power compensation optimization scheme when considering V2G

5. Discussion of Results

The voltage fluctuation of the regional power grid has the phenomenon of exceeding the limit before optimization. Although the phenomenon of the voltage exceeding the limit of the reactive power compensation distributed power participating in the reactive power optimization dispatching of the regional power grid still exists, there is a certain improvement [6]. This is due to the fact that the distributed power itself affects the nodes. Voltage has a certain supporting effect; voltage-controlled distributed power sources participate in reactive power dispatch and the phenomenon of over-limit voltage fluctuations is eliminated, indicating that voltage-controlled distributed power sources have a stronger ability to control voltage. In general, the satisfaction of distributed power generation in the dynamic reactive power

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optimization dispatch of the regional power grid has been greatly improved, which is conducive to improving the economy and safety of the regional power grid.

Before optimization, with the continuous changes in the output and load of the distributed power supply, the number of operations of the capacitors C1, C4, and 6/10 kV transformer all reached the maximum limit under the premise of limiting the number of operations of the control equipment in the optimization cycle [7]. Distributed power generation participates in the reactive power optimization dispatch of the regional power grid, and the number of actions of the control equipment is significantly reduced. In particular, the voltage-controlled distributed power supply participates in the reactive power optimization dispatch, and the transformer taps and capacitor banks no longer have oscillation adjustment. Therefore, giving full play to the voltage and reactive power adjustment capabilities of distributed power sources is beneficial to increase the service life of control equipment, thereby improving economy.

6. Conclusion

The grid-connected operation of distributed power has a great influence on the original system. According to the control characteristics of distributed power grid-connected, this paper divides distributed power into voltage control type DG and reactive power compensation type DG, considering its difference with traditional voltage and reactive power control. Combining methods, constructing a fuzzy dynamic mathematical model with the comprehensive goal of reducing power loss and suppressing power grid voltage fluctuations, and adopting an improved genetic algorithm to solve the scheduling strategy in time periods. The simulation example shows that the network loss has been greatly reduced, the voltage limit is exceeded, and the oscillation adjustment phenomenon of the control equipment has been significantly improved. In particular, the voltage control type DG has a stronger ability to adjust the dynamic reactive power optimization dispatching of the regional power grid. Therefore, giving full play to the auxiliary role of distributed power sources is conducive to improving the safety and economy of the power grid.

References

[1] Li, Z., Peng, Y., Yao, F., & Liu, M. Research on the strategy of cooperative control between photovoltaic grid-connected and reactive power compensation technology. The Journal of Engineering, 2 (16) (2019) 2278-2283.

[2] Wu, H., Liu, Y., & Wang, Z. Implementation of a new high-power current-source single-stage PV grid-connected system with reactive power compensation. IET Renewable Power Generation, 13(11) (2019) 1873-1881.

[3] Behera, M. P., & Ray, P. K. Reactive power and harmonic compensation in a grid-connected photovoltaic system using fuzzy logic controller. International Journal of Emerging Electric Power Systems, 22(2) (2021) 161-175.

[4] Merai, M., Naouar, M. W., Slama-Belkhodja, I., & Monmasson, E. Grid connected converters as reactive power ancillary service providers: Technical analysis for minimum required DC-link voltage. Mathematics and Computers in Simulation, 15(8) (2019) 344-354.

[5] Kolhe, M. L., & Rasul, M. J. M. A. 3-Phase grid-connected building integrated photovoltaic system with reactive power control capability. Renewable Energy, 15(4) (2020) 1065-1075.

[6] Raju, V. N., & Premalatha, M. A novel approach for reactive power compensation in hybrid wind-battery system using distribution static compensator. International Journal of Hydrogen Energy, 44(51) (2019) 27907-27920.

[7] Radwan, E., Nour, M., Baniyounes, A., Al-Olimat, K. S., & Awada, E. Direct control of active and reactive power for a grid-connected single-phase photovoltaic inverter. International Journal of Power Electronics and Drive Systems, 12(1) (2021) 139-150.