Reactive power optimization configuration for distribution network integrated with microgrids

IOP Conf. Series: Materials Science and Engineering **563** (2019) 052102 doi:10.1088/1757-899X/563/5/052102

Reactive power optimization configuration for distribution network integrated with microgrids

Jiang Qian[1], Rui Jing[1], Ning Wei[1], Kun Qiao[1], Xiaopeng Zhang[1]

[1]State Grid Yuncheng Power Supply Company, Shanxi Province, China

153531077@qq.com

Abstract. In recent years, distributed generation (DG) and microgrid develop rapidly in distribution network. With the increase of its penetration, the distribution network is faced with many operation challenges such as voltage violation and voltage flicker, etc. Thus, it is urgent to perform reasonable reactive power planning and optimize the operation strategy of reactive equipment to handle the arisen problems in the distribution network. This paper puts up with a reactive power configuration method, optimizing the operation of shunt capacitor bank (C) and static var generator (SVG). The genetic algorithm (GA) is applied to solve the model. It is proved by the modified IEEE33 system that the proposed model could effectively improve the voltage eligibility rate, reduce the grid loss and achieve better economy, which provides the reference for the reactive power optimization configuration for the future distribution network. The method could be applied in the situation of the integration of microgrid with large capacity generation with randomness.

1. Introduction

In recent years, DGs which owns great randomness develop rapidly. Therefore, the concept of microgrid was applied to improve its energy utilization rate[1-3]. Microgrids are composed of DGs and control system, which has high practical value and economic benefits. However, problems such as voltage fluctuation and voltage violation will appear due to the integration of the DGs in microgrids[4].

There is much existing research on reactive power optimization for distribution network. Originally, on-load tap changer tap (OLTC) and parallel switchable capacitor bank were used to regulate voltage and reactive power[5-6]. The redistribution of reactive power could be realized by controlling OLTC taps and parallel switchable capacitor bank. However, traditional voltage and reactive regulating methods are far from the demands of regulation redundancy and real-time performance after the integration of microgrids[7].Afterwards, DG was regarded as controlled equipment and applied to participate in voltage regulation and control, cooperating with the traditional capacitor bank and other reactive power equipment[8-11]. Then, the flexible DFACTS equipment was configured to carry out the voltage regulation, and the optimized configuration of dynamic reactive power compensation equipment was studied[12-15]. With the development of power electronics, the cost of those equipment declined, and new types of dynamic reactive power compensation equipment such as SVC, SVG and STATCOM were increasingly used in distribution networks[15-16]. However, most of the research on reactive power configuration is about DG, and little consideration is given to the situation of the microgrid's integration. Thus, it's urgent to solve the problem of the optimal configuration of reactive power equipment in distribution network integrated with microgrids.

This paper presents a reactive power optimized configuration method, taking the economy and power quality into consideration, to meet the needs of new energy's integration, and promote new energy consumption rate.

2. Theoretical basis of reactive power optimization for distribution network with microgrids

In the simple distribution network, system power supply is equivalent to the voltage source. Based on the superposition principle of the circuit, after the integration of microgrid on point *j*, the voltage distribution of the network can be calculated considering the influence of system power supply and microgrid on the power flow respectively.

The voltage drop at any point *j* in the simple distribution network under the influence of microgrid and system power supply can be obtained by the principle of circuit superposition.

$$\Delta U_j = \begin{cases} \frac{j}{2}(2N-j+1)\frac{RP_i+XQ_i}{U_N} - j\frac{RP_{MG}+XQ_{MG}}{U_N}, j\in[1,i] \\ \frac{j}{2}(2N-j+1)\frac{RP_i+XQ_i}{U_N} - i\frac{RP_{MG}+XQ_{MG}}{U_N}, j\in[1+i,N] \end{cases} \quad (1)$$

The line terminal voltage is assumed to be u_0, then the voltage at any point *j* in the line is as follows.

$$u_j = \begin{cases} u_0 - \frac{j}{2}(2N-j+1)\frac{RP_i+XQ_i}{U_N} - j\frac{RP_{MG}+XQ_{MG}}{U_N}, j\in[1,i] \\ u_0 - \frac{j}{2}(2N-j+1)\frac{RP_i+XQ_i}{U_N} - i\frac{RP_{MG}+XQ_{MG}}{U_N}, j\in[1+i,N] \end{cases} \quad (2)$$

It could be concluded from the equation above that the capacity and location of microgrid integration will affect the distribution of the voltage. The power factor of microgrid has a great influence on the voltage distribution of the network because it determines the ratio of active and reactive power output of the microgrid.

Besides, the randomness of the output of renewable energy in microgrid directly affects the apparent power. The microgrid output P_{MG} and Q_{MG} may take short-term changes sometimes, which may lead to the risk of voltage violation.

3. Optimal configuration of dynamic and static reactive power equipment in distribution network based on the whole life cycle of components

3.1. SVG grid-integrated control strategy and power flow calculation model

SVG in distribution network usually adopts distributed closed-loop control. The deviation between the bus voltage and the reference voltage can be obtained after SVG is connected. The SVG reactive power output can be adjusted by a given control method, such as Pi control, to ensure the real-time regulation of reactive power output and voltage stability.

Considering the error and the characteristic of SVG, the access point is regarded as PV node with voltage of 1 p.u to fully describe the fast regulation speed of SVG. Keep the rated voltage of the access point under the condition that the reactive power output does not exceed the limit. When the required reactive power is greater than the maximum compensating capacity of SVG, the access node is converted to PQ node and SVG is working at maximum capacity at this time.

3.2. Bi-level planning model of reactive power configuration

In order to get the most economical reactive power equipment configuration scheme, taking the difference of equipment service life and operation cost into consideration, this paper adopts the life cycle cost calculation model. The optimization must be considered to make the operation cost and voltage quality more accurate. Therefore, bi-level planning model is established. The basic idea is as follows. The capacity and location of SVG and C should be optimized by upper level planning, which is the constraints of the lower level. The lower level optimizes the time-sequent switching capacity of C and figures out the lowest operation cost. The obtained lowest operation cost would be given back to the objective function of the upper level. Thus, the interaction between the upper and lower levels is realized. The general bi-level planning model can be expressed as follows.

$$\begin{cases} \min f = F(x,w) \\ s.t.G(X) \le 0 \\ \min w = f(x,y) \\ s.t.g(x,y) \le 0 \end{cases} \tag{3}$$

Here F(·) refers to the objective function of the upper level, G(·) refers to the constraint condition of the upper level, f(·) refers to the objective function of the lower level; w is the upper target value; g(·) is the constraint condition of the lower level; x is the upper decision variable; y is the lower decision variable.

3.2.1. Upper level planning model based on life cycle cost Combined weight calculation. The upper planning control variables are the location and capacity of the capacitor C and SVG, with the goal of minimizing equipment life cycle cost and annual grid loss cost.

$$\min f_{up} = C_I + C_O + C_M + C_F + C_D + C_{OD} \tag{4}$$

Here, C_I refers to the equal annual value of investment expenses, C_0 refers to annual operating cost of equipment, C_M refers to the annual maintenance cost, C_F refers to annual cost of failure, C_D refers to the annual value of decommissioning disposal cost, C_{OD} refers to operating gird loss cost, which can be calculated by the lower level model.

The constraint conditions of capacitor capacity, SVG capacity in the upper level should be satisfied.

3.2.2. Lower level operating model for distributed regulation of C and SVG. The equipment operating strategy should be considered in the lower level model. The time sequent operation process of reactive power equipment is shown in the figure 1. There are differences in the control cycle of dynamic and static equipment. The information acquisition cycle of network is shorter than the control cycle of the capacitor bank. Therefore, short-term voltage fluctuations can be regulated by SVG, whose information acquisition cycle is the shortest.

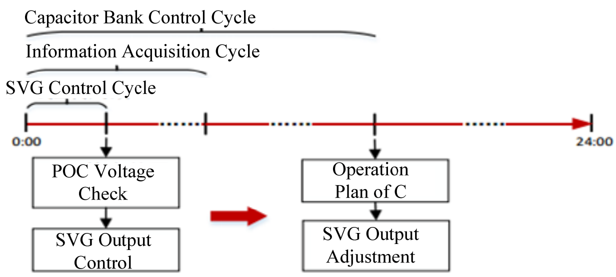

Figure 1. The time sequent operation process of reactive power equipment

The control variable in the lower level operation model is the number of time sequent switching capacitor groups. Since the SVG access point has been set as PV node, its output can be optimized automatically according to the demand of reactive power. The configuration scheme given by the upper level is used as the constraint. The capacitor operation strategy that minimizes the operation cost in a certain situation could be obtained through an optimization algorithm. Finally, the sum product of the target value of each situation and the probability of the corresponding situation should be returned to the upper level model.

The goal of the lower level model is to minimize the annual grid loss cost.

$$\min f_{down} = C_{OD} = \sum_{s=1}^{12} \left(C_{LOSS}^{s} \cdot P_s \times 365 \right) \tag{5}$$

Here, C_{sLOSS} is the grid loss cost in typical daily situation s. P_s refers to the probability of situation s.

The constraint conditions of power flow, voltage deviation, current and control variables in the lower level should be satisfied.

4. Model solving

Genetic algorithm is a global optimized and random search algorithm that imitate the behaviour of chromosomes in the evolution of natural organisms. The steps of genetic algorithm include setting initial values for the population, selection, crossing and mutation, etc. Traditional genetic algorithm is easy to trapped into locally optimal solution. Thus, this paper has made some improvements based on traditional genetic algorithm to strengthen the global optimization ability of the algorithm. a) Improving selection. In roulette selection, individuals with high fitness value are easily to occupy the population quickly in the early period and individual's fitness values don't vary much, causing the evolution stops in the later period. In order to avoid that, a selection algorithm based on the rank of individual fitness is proposed., b) Improving crossing steps. After the random selection of parents, n times crossing is performed to generate 2n individuals. Then, 2 optimal individuals are selected to join the new population to speed up the evolution. c) Adaptive crossing rate and mutation rate are adopted in this paper.

5. Case study

The modified IEEE 33 node system is used to carry out simulation based on MATLAB. This paper takes the distribution network with industrial microgrid's integration as the study case. There are two microgrid systems integrated to node 3 and 12 based on the original example. The system reference voltage is 11kV, the reference power is 5MVA, the voltage deviation limit is ±7%, and the maximum load is 3.72+2.54MVA.

The optimized configuration model established in this paper converges after 100 cycles in the upper and lower level. The calculated configuration is as shown in table 1.

Table 1. The calculated configuration

Node	Compensation Capacity of SVG	Compensation Capacity of C
29	0.4	0.5
13	0.2	0
3	0.4	0.5
12	0.2	0.5

The one-off equipment investment of the scheme is 0.78 million yuan. Annual comprehensive cost considering the life cycle of the equipment is 1.563 million yuan.

The following four schemes are used to perform the reactive power compensation regulation to analyse the effects of different optimization strategies.

a) No reactive compensation.
b) Only shunt capacitor banks are used for reactive compensation.
c) Only SVG is used for reactive compensation.
d) Dynamic and static coordination compensation.

The optimization results of each scheme are shown in the following table.

Table 2. the optimization results of each scheme

Plan	Compensation Location and Capacity of C (MVar)	Compensation Location and Capacity of SVG (MVar)	Initial Investment	Annual Comprehensive Cost (Million)
Plan A	—	—	0	—
Plan B	29(2) 13(0.5) 12(1.5)	—	0.7	—
Plan C	—	29(1.2) 13(0.2) 3(0.6) 12(0.6)	1.04	1.796
Plan D	29(0.5) 3(0.5) 12(0.5)	29(0.4) 13(0.2) 3(0.4) 12(0.2)	0.78	1.563

The node voltage without reactive compensation at 0am and 12pm in the original example are shown in the figure 6.

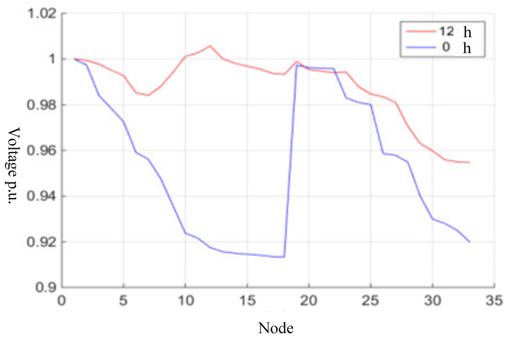

Figure 2. The node voltage without reactive compensation in the original example

The fixed load of the original system increase due to the microgrid's integration during the low load period. Thus, the voltage may exceed the lower limit as the result shows. PV output period corresponds with the original high load period, so the voltage doesn't exceed the upper limit.

Therefore, the lower voltage limit constraint should be focused. The node voltage curve at 0am after reactive power compensation under each scheme is shown in the figure 7. It can be seen that the voltage drop increases from the root node to the terminal node. Voltage at the terminal node is at risk of exceeding the lower limit. Voltage regulation effect in scheme 2 is the best, then the scheme 3. Scheme 1 has the worst voltage regulation effect.

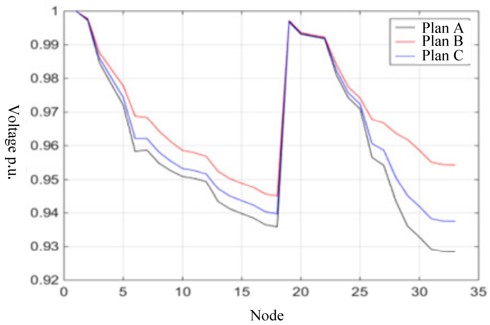

Figure 3. The node voltage curve after reactive power compensation under each scheme

6. Conclusion

In this paper, based on the whole life cycle of components, a reactive power optimal configuration model is proposed, aiming at the minimizing annual comprehensive cost. The life cycle, investment cost and maintenance cost of SVG and C are taken into consideration to obtain the optimal reactive power compensation equipment scheme. The optimal configuration model adopts a two-layer structure, with the upper layer for equipment configuration planning and the lower layer for equipment operation optimization. The method proposed in this paper is proved to be economical and effective, saving the investment and improving the utilization rate of equipment. To sum up, the optimal configuration method of dynamic and static reactive power coordination compensation can better meet the needs of microgrid integration, improve the voltage quality, promote new energy consumption, reduce grid loss and improve economic benefits.

References

[1] Hatziargyriou N , Asano H and Iravani R 2007 *Power & Energy Magazine IEEE* **5(4)** 78-94
[2] Chengshan W and Peng L 2010 *Automation of Electric Power Systems* **34(2)** 10-14
[3] Ming M, Shichao C and Shujun Z 2017 *Modern electricity* **2017(1)** 1-7
[4] Bo hu, Yudo N and Ryuichi Y 2012 *Automation of Electric Power Systems* **36(3)** 34-38
[5] Xiaojun T, and Dongxia Z 2009 *Power System Technology* **33(18)** 34-38
[6] Chen L and Li H 2015 *IEEE Transactions on Smart Grid* **PP(99)** 1-10

[7] Xu C, Yongjun Z and xiangmin H 2016 *Automation of Electric Power Systems* **40(1)** 143-51
[8] Huang T, Lu Z and Pengwei 2014 *Power System Technology* **38(9)** 2590-97
[9] Yong W, Ming C and Ming Z 2017 *Power System Technology* **2017(12)** 50-59
[10] Gongbo L, Wentao Y and Wenbin Z 2015 *Automation of Electric Power Systems* **2015(15)** 49-54
[11] Xiaoyang H, Zhuding W and Dongsheng S 2016 *Power System Technology* **40(7)** 49-54
[12] Fuju Z. Research on Control Strategy to Improve the Power Quality of Microgrid Based on UPQC 2015
[13] Ganguly S 2014 *IEEE Transactions on Power Systems* **29(4)** 1801-10
[14] Ahmad M, Kumar N and Singh B 2017 *IET Power Electronics* **10(12)** 1529-38
[15] Jianfeng Z, Yaqin G and Shouqi W 2007 *Electric Power Automation Equipment* **27(12)** 57-60
[16] Gitibin R and Hoseinzadeh F 2015 *Electrical Power Distribution Networks Conference* **2015** 90-100