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On Optimization Principles of Power Systems with Distributed Generation

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Abstract—Electricity market restructuring, advances in energy generation technology and agreements on the reduction of greenhouse gas emissions have paved the way for an increase in the use of Distributed Generations (DGs). This work demonstrates a methodology for deploying DGs throughout a power system to allow for more efficient operation. Researchers at home and abroad have been studying on optimization of DGs and there are many methods and objectives proposed. The paper reviews and lists several common specific objectives and configuration. On the basis of summarizing all the optimization objectives, a reasonable optimization process is proposed and the key is to determine the optimal allocation of DGs by the use of "test factor". Finally, an example has proven that the principle is rational.

Keywords-optimum allocation; optimization process; optimization objectives; reliability; power losses

1. Introduction

Employment of DGs can drastically reduce power losses in the system, efficiently utilize resources, improve environment and reduce the end-user costs. DG inclusion also defers transmission and distribution upgrades, improves supply quality reliability and so on, so DGs have drawn the world wide attention and have been developed well in recent years. However, adding DG to a distribution system imposes a different set of operating conditions on the network, such as voltage rise, reverse power flow distribution, increased fault levels, reduced power losses, harmonic distortion and stability problems, the influence is closely related to the location and capacity allocation of DGs. Therefore, domestic and foreign scholars make researches on how to optimize the configuration of distributed power supply, reduce the negative impact of DG on the grid and a variety of different objectives of the DG optimal allocation model have been proposed. The authors of [1]-[3] have proposed graphic and genetic algorithm combination method, multi-layer particle swarm calculation to determine the optimal location for DG in networked system with an objective of loss minimization. A heuristic algorithm has been developed in [4] to minimize the investment and purchase cost to the grid. Authors of [5] made the largest installed capacity an objective to utilize distributed resources and save energy. The authors of [6] aimed to improve network reliability and reduce outage losses. The paper concludes these common configuration methods and develops research on the optimization principles of power systems with DGs, new optimization process and optimization objectives are proposed.

2. DG Optimization Model

2.1. Common objective function

1) Objective function to minimize the investment cost:

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$$\min f_1 = \min\left\{\sum_{\mathrm{i}=1}^{n_{DG}} (C_{i1} + C_{i2}) P_{di}\right\}$$

where n_{DG} is the total number of nodes to install DGs, P_{di} is the rated capacity of DG installed on each node i, C_{i1} and C_{i2} are equipment and installation costs of DGs' unit capacity installed on each node i.

2) Objective function to minimize the system losses

$$\min f_2 = \min\{p_{loss}(p_{d1}, p_{d2}, \dots p_{dn_{DG}})\}$$

where, p_{loss} is system loss, which is related to the grid network structure, allocation and capacity of DGs.

3) Objective function to maximize energy savings

$$\max f_3 = \max(\mathrm{E})$$

where, E is the energy savings in a load cycle.

4) Objective function to maximize the capacity of installed DG

$$\max f_4 = \max\left(\sum_{i=1}^{n} p_{DG_i}\right)$$

where, p_{DG_i} is active output of DGs.

2.2. Constraints

1) Power equalization and flow balance. The system power must be balanced when DGs are connected to distribution network. The literature [7] takes the power input and power output balance on a feeder road as a constraint, including DGs consume power themselves.

$$f(P, Q, V) = 0$$

2) Transmission capacity constraints. Transmission power can't exceed the maximum capacity.

3) Limit on total power generated by DG. The installed DGs' capacities are determined by the capital or environmental factor, we optimum allocation of DGs based on the determined capacity.

$$P_{DGi} \le P_{DG\max}$$

4) Voltage operational tolerance limits at all buses. The voltage level on all nodes is an important indicator to test the safety and power quality of distribution network. The authors of [8] choose the amplitude between actual voltage value and specified voltage amplitude as an objective function to maintain the voltage at a satisfactory level. A lot of papers put the voltage level as a constraint on the optimization of DGs [9]-[10].

$$U_{\min} \le U_i \le U_{\max}$$

5) Network topology. The restructured distribution network is radial and there should not be isolated.

6) Environmental constraint. With the intensification of the world's environmental problems, nations are paying more and more attention to environmental issues, Kyoto Protocol confined pollution gas emissions limits to every country. Literature [11] advances that the total annual power generation gas emissions will be limited to a certain level.

3. Optimal Placement and Size of DGs

3.1. Operation process

Domestic and foreign scholars make researches on the distributed power grid connection issues, such as how to optimize distributed power configuration, determine the optimal allocation and capacity, reduce impacts of DGs on the distribution network while reducing line losses and improve power supply reliability to achieve objectives such as minimum losses, lowest cost, environmental and reliable, which is the most important issue to resolve DGs planning issue. Summarizing all the optimization objectives, as shown in Figure 1, they may be summed up as three categories: economy, reliability and environmental protection.

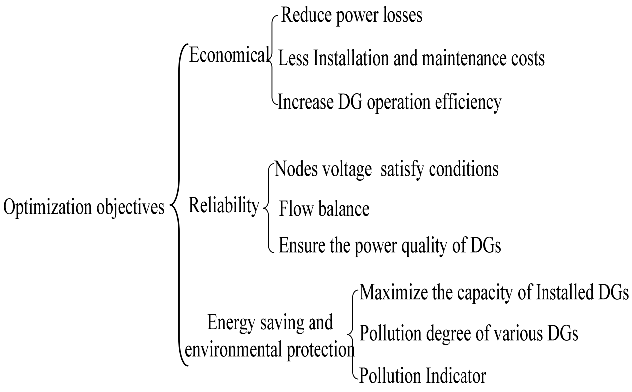

Fig.1. optimization objectives

This paper presents a reasonable optimization process shown in Figure 2, there are three "test factors" have been put forward to determine the optimal allocation and capacity of DGs, they are "reliability, environment and economy factor". The method synthesizes various optimization objectives and constraints, reflects the impacts and requirements of DGs truly and fully. It avoids the uncertainty and convergence characteristics of using the mathematical optimization methods, and can combine more objectives without considering the different dimensions to make the objective easy and reduce the number of constraints.

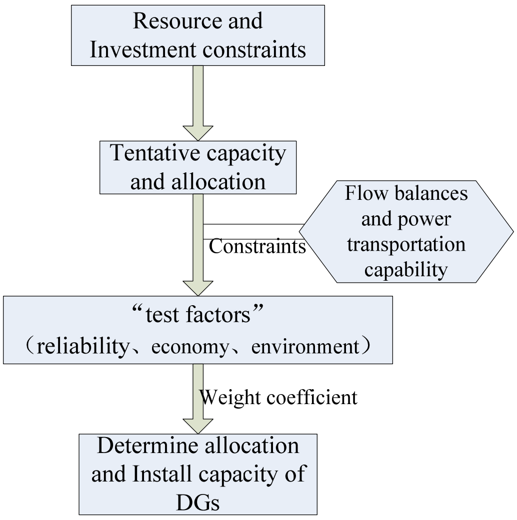

Fig.2. sollution process for optimal placement and sizing

The algorithm proceeds as follows:

1) Select possible installation sites and capacity based on the local resources situation and investment limit;

2) Input the distribution network information, according to the estimated installation sites and capacity, for the initial installation capacity and location, calculate system flow and "test factors";

3) Update installed capacity and installation sites, recalculate the "test factors";

4) Confirm the weight factor according to the project needs, then, compare the various "test factors" to achieve the optimum installation capacity and location.

3.2. Test factors

1) Reliability factor

As shown in Figure 1, the main impacts on reliability of DGs' access to grid include: nodes voltage, flow balance and the power quality itself. The reliability factor can be defined as

$$T = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{v_i - v_{imin}}{v_{imax} - v_{imin}} - \frac{1}{2}\right| \tag{1}$$

$$0 \leq \frac{v_i - v_{i\min}}{v_{i\max} - v_{i\min}} \leq 1 \qquad (2)$$

where $v_{i\min}$ and $v_{i\max}$ are the lower and upper voltage limit at each node i respectively, v_i is the voltage level at each node i after the DGs have been installed, N is the total number of all the nodes, all the calculation of reliability is based on that voltage level of every node is in accord with the requirements of networks, i.e. parameters should satisfy the voltage level constraints (equation 2), we can not analyze the reliability coefficient until all the parameters satisfy the condition. Therefore, the reliability coefficient values range from 0 to 0.5 and the smaller the coefficient, the higher reliability.

2) Economy factor

Economy is determined mainly by the active power losses and installation, maintenance costs. The authors of [12] put loss improvement rate as objective function to represent pecuniary loss. In order to reflect the economic affairs, the economy factor is defined as:

$$\lambda_1 = \frac{P_{DG(loss)}}{P_{(loss)}} \qquad (3)$$

$$\lambda_2 = \frac{c}{C} \qquad (4)$$

$$\lambda = \omega_1 \cdot \lambda_1 + \omega_2 \cdot \lambda_2 \qquad (5)$$

where, $P_{DG(loss)}$ is the active power loss when DGs have been installed and $P_{(loss)}$ is the active power loss without DGs, c is the all installation and maintenance costs while C is the maximum allowed costs for the project. λ_1 and λ_2 is loss improvement and cost savings rate respectively, ω_1 and ω_2 are weights, and $\omega_1 + \omega_2 = 1$, they denote the importance of system losses and investment costs in the actual projects.

According to equation (5), the economy factors are calculated. As the dimensions of system losses, installation and maintenance costs are different they can not be weighted directly or compared in other ways. However, when they are defined as the above proportions, they can be grouped together through weights, and the smaller the economy factor, the better the economical efficiency.

3) Environment factor

First, we should determine several pollution gases which make enormous effects on environment. Second, develop appropriate indicators W_i of various gases, w_i is the actual calculated indicator of every gas, if all the ratio results of w_i / W_i are less than or equal to 1, we can calculate economy factor according equation (6). And the configuration is not eligible when one ratio is more than 1.

$$r = \frac{1}{n} \sum_{i=1}^{n} \frac{w_i}{W_i} \qquad (6)$$

where, n is the number of pollution gases kind. The smaller the economy factor, the better the conservation of environment.

After we get all the "test factors" from the above formulas, weighting coefficients should be determined according to the actual requirement of projects, then using the weighted method to attain the single-objective optimization function:

$$f = \lambda_1 T + \lambda_2 \lambda + \lambda_3 r \qquad (7)$$

where, λ_1, λ_2 and λ_3 are weighting coefficients determined according to actual states, for example, when the project don't care about economic consumption, the value of λ_2 is 0.

4. Numerical study

In order to illuminate the benefits of the proposed optimization method, several hypothetical configuration options are determined. Voltage level on every node, system losses and pollution gases emission indicators of each optimization configuration are given in table 1.

If ω_1 and ω_2 are 0.8 and 0.2, the assumed parameters such as $v_{i\min}$, $v_{i\max}$, $P_{(loss)}$ are shown in Table 2.

According to the parameters in Table 2 and the calculating data in Table 1, we can get the Reliability, economy and environment factors of every optimization project shown in Table 3.

TABLE I. CALCULATE DATA

Optimal project	V_1(kV)	V_2(kV)	V_3(kV)	$P_{DG(loss)}$(MW)	c(￥10^4)	w_1(g/kwh)	w_2(g/kwh)
A	36.03	54.02	6.99	0.06	79	30.8	45.3
B	35.97	55.03	7.74	0.09	80	31.2	45.9
C	37.02	53.97	6.99	0.08	78	30.8	45.7
D	36.02	53.96	6.97	0.07	81	29.8	44.5

TABLE II. PARAMETERS

V_{1min}	V_{1max}	V_{2min}	V_{2max}	V_{3min}	V_{3max}	$P_{(loss)}$	C	W_1	W_2
35	37	53	55	6	8	0.087	85	31	46

TABLE III. RESULTS

Optimal project	T		r
A	0.01	0.74	0.989
B	-	1.02	-
C	-	0.92	0.994
D	0.015	0.83	0.964

As shown in Table 3, the reliability of project A is higher, but the economic is poor while the environmental protection of Project D is the best, reliability of it is worse. Therefore, on the basis of actual states, according with the actual requirement of the projects, for example, if the project require high reliability and environmental protection, but low economical efficiency, we can take λ_1, λ_2, λ_3 as 0.5, 0.4 and 0.1, then project A is determined to active according to the objective function. If the project requires high economical efficiency, we can take λ_1, λ_2, λ_3 as 0.3, 0.1, 0.6 and the project D is appropriate to be put in practice.

5. Conclusion

Recent years have seen a trend towards the development and deployment of distributed generation (DG) due to government policy changes and increased availability of small capacity generation technologies. As a burgeoning power generation, DG can be taken as a helpful supplement to the existing traditional power grid. The paper has a study on all the optimization processes of adding DGs to distribution network and the programming method based on “test factor” is proposed. It can simplify the optimal problem and the principle is simple. We can utilize regulating the weight coefficient to choose the appropriate optimal project and it is in keeping with the practice, it avoids many constraints on line of using the mathematical optimization methods. Example is given to prove the availability and superiority in the end.

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BIOGRAPHIES

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