Engineering, **2013, 5, 32-36**
doi:10.4236/eng.2013.51b006 Published Online January 2013 (http://www.SciRP.org/journal/eng)

Overall Framework and Module of Distribution Network Coordinated Planning Considering Distributed Generation

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Received 2013

ABSTRACT

Combining with the characteristics of China's energy and the strategy of sustainable development, analyzing the pros and cons which caused by the appearance of DG and their operation connecting to grid, this paper points out that the two sides can achieve win-win under a reasonable combination between DG and distribution system, so as to optimize the allocation of resources, improve the utilization ratio of resource, and obtain maximum social benefit, harmoniously promote the development of power industry, economy and environment. As a word, this paper puts forward a new model of distribution network planning including DG and brings in penalty factorto guide the investment and construction of DG. Last of all, this paper presents the adoption of the coordination development coefficients which is to evaluate the power planning.

Keywords: Distributed Generation; Distribution Network; Planning; vPenalty Factor; Coordinated Development Coefficient

1. Introduction

Most ofdistributed generations (DG)arethe clean and renewable energy, they can enjoy priority scheduling rights under the domestic energy-saving scheduling rules [1]. Distributed generations also have a lot of advantages including low investment, low loss, high system reliability, easy siting, short construction cycle, reducing transmission congestion, delay the lifetime of distribution equipment and environmental protection,etc. [2-3].There is no doubt that DG is the key to solve the energy crisis, large environmental pressure and many other critical issues [4]. In recent years, in order to cope with the problem of energy shortages and environmental pollution, most countries around the world have enacted laws, regulation or action plan in succession, and present clear objectives and development paths of renewable energy development. China clearly plans to build 3TW hydropower and 30GW wind power, 30GW raw biomass power generation, 1.8GW solar energy, and makes the consumption of renewable energy achieve to 15% in energy consumption of the total by 2020.All of these give distributed power generation vast business opportunities, in particular, which are based on the distributed generations of renewable energy.

According to some survey, data indicate that the trend of DG connecting to grid is becoming more and more obvious under the policy of encouraging and supporting the generation of renewable energy connecting to grid, and often run directly in the distribution network[5], so DG brings many other impact on the economy of power system, planning and designing, operation, control, protection, security and stability. Therefore, the power supply companies is necessary to prospectively and scientifically predict the possible construction situation of future DG in the regulation planning stage, deeply research and analysis the influence which DG may bring to the distribution network systems, ensure the high flexibility of planning scheme for the development of DG.

This paper was inspired by the papers [6,7], combined with the relationship between DG and distribution network system, fully considered the optimized allocation and utilization of global resources, presents a mathematical model to promote the coordination between DG and distribution network planning, brings the concept of penalty factor into the distribution network planning to affect and guide the rational distribution of DG. To ensure the safe operation of grid, this design from this paper fully excavates the potential of generation power for renewable energy,reduces the adverse effects from DG to system, and make resources and environmental benefits maximize by scientific planning. The concept of coordinated development coefficient from literature [7] is used

in this model to assess distribution planning comprehendsively and systematically and gives the estimate results back to a new round of planning, so that to build complete overall framework which taking into account the coordination of DG distribution planning.

2. Harmonious Development Analysis Between DG and Distribution System

According to different investment subjects, there are two kinds of DG configuration modes: a. Power suppliers invest DG configuration in distribution network to meet new load growing demand, While saving the investment costs of the expansion of the distribution network and substation equipment; b. DG investors (including Power Generation Group, power users, etc.) configure the DG near the distribution network users' load, this configuretion mode makes the installation limit condition reduce greatly, and expand the DG investment sources [8]. Power Generation Group has more enthusiasm to building DG than Grid Corporation, thus the second kind of configuration mode is mainly used at this stage in our country. But DG investors and the power company are the different beneficiaries in this model, unreasonable DG building may affect the power company's economic interest, and hinder the smooth promotion of DG.

As previously mentioned, the emergence of DG which largely connecting to the grid can give the grid company some interests on the one hand, for example: reasonable DG arrangement is able to reduce the energy loss, transmission and distribution costs, etc. [9]; DG also can provide emergency back-up energy or ancillary services to system, improve the reliability and stability of power supply. In addition, reasonable DG appearing will postpone or reduce the investment of power grid expansion. On the other hand, due to DG investors and power supply companies are the different market entity, there are some conflict interest between them, such as, they may cause the grid to produce stranded costs, increase standby costs, and that unreasonable DG connecting to network operation may lead to the increase of energy loss, and even make power system's reliability, stability and power quality serious deterioration [10].

Power supply companies are necessary and have the means to take positive and effective measures to guide the rational distribution of DG, promote the resources rational development and optimal allocation in their areas of jurisdiction, reduce the uncertainty to the distribution network planning by the appearance of DG, lowering the investment risk, improving efficiency, and achieving "win-win".

3. The Overall Framework for Distribution Network Coordinated Planning Considering DG

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The main task of traditional distribution system planning is based on load forecasting results in the network and the basic conditions of the existing network during the planning period to determine the optimal system-building programs under the premise of meeting the load growth and supplying power safely and reliably, making the cost of distribution construction and operation to the minimum [11]. However, with the emergence of DG, the traditional distribution network planning can't adapt to the needs of power industry development in the new period. The distribution network planning is no longer just the simple and traditional power system planning, but becomes the resource allocation optimization which closely links to national energy policy, sustainable development strategic initiatives.

The overall framework for distribution network coordinated planning considering DG presented in this paper includes two parts in detail: the distribution network planning and DG investment construction. Both of them interrelate and influence each other by penalty factor. The power companies affect and guide the investment planning of DG by penalty factorwhile the planning and construction of DG investors also have an impact on the penalty factor. The planning and coordinating process is shown in **Figure 1**.

3.1. Power Supply Company's Distribution Network Planning Section

In this new model, apart from the annual load levels and

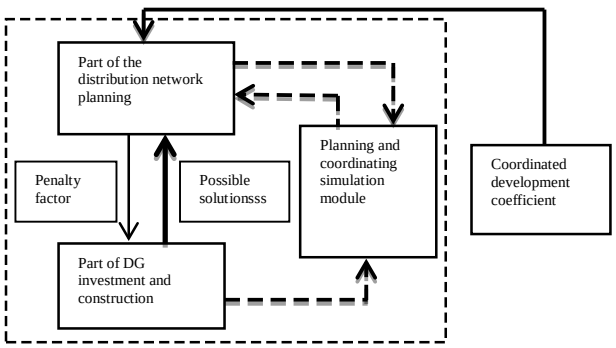

Figure 1. Theoverall framework for distribution network coordinated planning considering DG.

distribution of scientific forecast in futureneed to be referred, but also the various national energy policy should be activelyresponded and fully implemented in time, considering the energy characteristics and investors information of DG in the jurisdiction of the area, fully exploiting the potential for using the renewable energy under the premise what ensures a reasonable profit for the power companies, encouraging and supporting the development of DG.

First of all, in order to prevent the conflict of interest between DG investors and the power supply companies, and to avoid producing stranded costs and increased standby costs and so on, the most powerful way for the power companies is to grasp the determinate information of the DG investment and construction during the next planning period as much as possible. For example, to encourage the DG investors to actively participate in the grid planning, and to spontaneously submit development strategies of a self-research optimized electricity generation plan, as well as the information and data of DG investment construction during the to-be planning period, meanwhile encourage the DG investors which sign agreement and contract with power companies to share risk with the power companies after determining the to-be investing plan.

Secondly, the gradual promotion of DG technologies will have an impact on the node voltage, circuital flow, short circuit current, network reliability etc. in the distribution network, and its incidence is closely related to the location and capacity of distributed power. Therefore, in order to reduce or avoid the disorderly construction of DG do damage to the security and stability of distribution system, it is necessary for the power companies to take effective measures to guide the investors to choose the reasonable location and capacity of distributed power. In this framework, the power companies, which will effect and guide the DG's layout and capacitive construction by adopting the economic index, namely penalty factor, bring into the construction of the DG investment section

3.2. DG Investment and Construction Section

Before making the final decision, the DG investors must embark an individual study of the power generation planning project, which mainly includes the expected cost of the investment, the cost of operation,the existed risks, network combined problem and the possible impact on the power generation and so on. In addition, penalty factor must be taken into account which has an important affection on the DG investment profit under new planning mode. Finally, decisions are made by compareing with the several comprehensive information of the feasible DG layout points.

4. Model of Distribution Network Planning and Coordination of DG

4.1. Penalty Factor

Coordination factor, the key to operate this mode, is the convergence factor in the whole planning process, which is organically combined with DG investment planning and distribution network planning. The concept of coordinated factor is to reflect the comprehensiveeconomic indicator, bringing out by the impact of the feasible construction of the layout point to the comprehensive planning program, which refers two sectors including global coordination factor and local coordination factor. The essence is to direct the DG site selection and constant volume by using price leverage to restrict DG invested construction when the DG installation adversely affects the position of the power distribution system restricts, and to encourage the reasonable DG investment construction where the position has a favorable impact on the distribution network.

4.2. Coordination Optimization Model

In order to promote the harmonious development of the economy and environment, and to encourage and support the DG development, under the object of optimized resources of regional allocation which belongs to the power companies, this paper establishes DG construction and distribution network planning coordinated planning model as the minimum target cost investment.

1) Objective function ofdistribution network planning

The cost of distribution network planning investment includes comprehensive costs of the investment of building the substation, fixedly circuital investment, depreciation and overhaul, as well as the network loss. Grid planning model of the power supply companies mentioned in this paper is transformed from the investment model proposed in paper [12]:

$$J = \sum_{i=1}^{SS}\sum_{u=1}^{TU} C_{i,u}\delta_{i,u} + \sum_{i=1}^{TN}\sum_{j=1}^{M} C_{ij}\delta_{ij} + 8760\sum_{l=1}^{T}\beta^{l}\sum_{i=1}^{TN}\sum_{j=1}^{M}\frac{\Delta V_{ij}^{z}}{\left|Z_{ij}\right|}pfc_{e} + \sum_{j=1}^{M}\alpha_{j}D_{j}^{*} \tag{1}$$

In this formula, T, M, TN, SS, TU respectively represent the planned time, load point, all nodes of the distribution system, all substations of the distribution system, all transformers of the distribution system (including the to be built); C_{e} refers to the purchasing power price; $\delta_{i,u}$, $C_{i,u}$, δ_{ij}, C_{ij} respectively indicate the binary decision variables and comprehensive costs of the transformer u inside the substation i, circuit of the node i and load point j; D_j^* represents the reference value of the whole network number j penalty factor; α_j, in general, is the coordination coefficient of number j

feasible layout point.

2)The objective function of construction planning for DG investment

DG investors typically proceed investments planning by the maximize profittarget, while the minimum total investment cost (including overall equipment cost and installation cost) means more competitive. As a result, this paper aims to decide whether to invest in the DG construction by the assessment indicators of the total investment cost. The mathematical model is transformed from the model proposed in paper [13]:

$$F = \sum_{i=1}^{n_{DG}} [(C_{n1} + C_{n2}) p_{DGi} + D_j^*] \tag{2}$$

In this formula, n_{DG} is the amount of the feasible layout point of the installed DG; p_{DGi} is the comprehensive cost and installation cost of each equipment of the number*i* node.

3) The simplified mathematical model of distribution network planning including DG

In order to reflect the characteristics of the coordination model and reflect the risk of the planning, the formula (1) and (2) are simplify to (3). The objective function of the new model is a mathematical model of typical dual output.

$$\begin{cases} \min F = \{F^*\} + KD^* \\ \min J = \{J^*\} + (1-K)D^* \end{cases} \tag{3}$$

In the formula, $\{F^*\}$ and $\{J^*\}$ respectively indicate the DG without considering penalty factor and investment costs ofindependent planning inthe distribution network; D^* is the reference value of the penalty factor in the wholedistribution network(namely, the equivalent reference value of the power planning risk in this round);K is the equivalent weight factor of the whole distribution networkwhich ranges [0, 1], the purpose of which is to coordinate the DG and distribution network planning.

4) Calculation of the penalty factor

The global coordination factor reflects pros and cons under the situation that the volume and capacity of the DG is on the largest scale in the current planning scheme. In accordance with related national and local energy policy, planning and DG investors' information, from the macro perspective, the grid planning personnel will try their best to estimate the DG investment construction with the area during the planning period as much as possible.Therefore, the calculation of the index can be easily obtained for its equivalent to the deterministic one.

Local coordination factor reflects the pros and cons caused by the construction of the investment to system in every feasible layout point. From the microscopic point of view, the possibility of the DG's appearance in every feasible layout point is random and difficult to predict, so the calculation of index, which is more complex, must be obtained by other means.In this paper, calculations of local coordinated factor are determined by two steps. For one thing is the reliable index caused by the influence of every feasible layout point to the distribution network; then by another impact, that is transfer function transform the index from benefit to the economy.

Some researchersestablished a comprehensive evaluation coefficient (IMO) of the position and capacity, which is an effective evaluation of multiple indexes involving network loss, voltage, short circuit current. Details of the computational method can be found in paper [14] and [15].Inspired by that paper, suppose DG installation do more harm to the distribution network (namely, the IMO is lower), the greater efficiency losses will cause. Therefore, the local coordination factor can be determined based on global coordination factor and comprehensive reliable index. That is:

$$D_j^* = \frac{D^* IMO_j}{\sum_{i=1}^{n_{DG}} IMO_i} \tag{4}$$

In the formula, D^* and D_j^* respectively refer to the global coordination factor and the local coordination factor; IMO_j refers to the index which is the impact of distribution system caused by the number j feasible layout point; n_{DG} is the total of the feasible layout points with DG installation.

5. Coordinated Development Factor

With the further development of power market and performance of all the aspects of energy policy, the increasing number of DG and connecting to the grid, all of which enhance the uncertainty of this distribution network planning, reducing investment risk, so as to have a clear guidance on the whole distribution system and DG coordinated planning system.The paper [7] introduces the concept of coordinated development coefficient, which uses the ratio of planning risk cost and actual risk cost as λ, that is, the coefficient of DG and the coordinated development of the distribution network. λ, bounded to 1, is divided into three states representing the poor, qualified and good. The power planning will be made a full range of system assessment in this round after λ determined, and make the appropriate guidance and adjustment to the next round of planning.

6. Conclusion

DG and power distribution system are an organic whole which are interrelated, interdependent and contradictory with each other on the whole. In spite of some certain micro conflict of interest exist between DG investors and the power supply companies, with a reasonably coordi-

nation and planning, the safety benefits of each other, the economic benefits as well as environmental effective will improve, at last, to maximize the social benefit. The model of distribution network planning considering DG presented above will optimize the allocation of resources to be a higher level, at the same time, transform the uncertainty into the certainty in the new grid planning period, and make planning approachas the way of certainty. Besides the presented penalty factor and coordinated development coefficient which effectively guide construction of investment and distribution network planning, are easy to achieve a rational distribution and constant volume of geographical and time-domain as well as to reduce the investment risk of the DG investors and the power supply companies, in line with the sustainable development needs of environmental protection and energy in the new era, to realize the social benefits to maximize accompany with the healthy and harmonious development of the DG construction, distribution network planning, the economy and the environment, so as to provide a foundation of further study on distribution network planning considering DGfor the new era.For the reason that the distribution network planning including DGrelates to the stationing and constant volume of DG, the planning and design of distribution network, as well as the calculation and introduction of penalty factor, which will be a challenging and innovative work in the future.

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