A PLANNING APPROACH FOR ACTIVE DISTRIBUTION NETWORKS

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ABSTRACT

This paper assesses the various requirements to facilitate the transition towards active distribution networks (ADNs) based on the analysis of development stages home and abroad. A planning model for ADNs planning is proposed considering the planning goals, the technical and economical constraints, which can take the distribution network with various Distributed Energy Resource (DER) into consideration. A new planning approach for distribution system is also proposed so as to adapt the transition from passive to active distribution networks.

INTRODUCTION

Many potential new services will be provided by distribution network, including automated power management, micro-networks, distributed generation (DG), distributed storage (DS), and Electricity vehicle (EV). That is, the distributed Energy Resource (DER) together with load growth, and the increased consumer expectations have significantly changed the existing distribution networks [1].

However, as we shall see, DER is at best a partial solution. The transaction cost of electricity is relatively lower.. Therefore, the traditional approaches used in the planning, design and operation of distribution networks should be updated in order to secure the efficiency, security and reliability of distribution networks in the long run.

This paper analyzes the differences between traditional distribution planning and active distribution networks planning. The traditional distribution planning is following this sequence: load forecasting - HV distribution planning - MV distribution planning - LV distribution planning. After DG connecting to the network (maybe connected to HV, MV or LV), the ADN planning approach has been completely changed: Load forecasting should consider energy; all of HV、MV and LV distribution planning will consider the integration of DERs, so as to dramatically increase the entire network's value.

The basic ideas about ADN network planning is as follows: firstly, the load and capacity is determined by the traditional planning methods; secondly, the storage capacity is determined by the load fluctuation range; thirdly, the DER size and site is determined by planning model; fourthly, reliability analysis; fifthly, the marginal cost analysis for each DER project; finally, to determine the final network configuration with DER architecture.

The planning approach for ADNs covers different time horizons. Strategic plans (long term) define the final goal to reach, medium term planning defines the system development harmonized with the master plan, short term (day-by-day) planning solves daily problems within the framework of strategic plans. The planning framework is as follows:

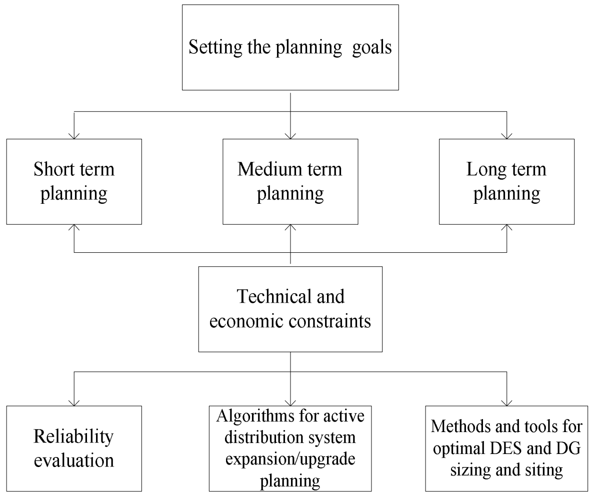

Figure 1 the framework of planning for ADNs

This paper firstly analyzes the various impacts on the distribution planning to facilitate the transition towards active distribution networks (ADNs), and then states the main considerations for ADN planning. Based upon the considerations for ADN planning, this paper attempts to propose a comprehensive planning model for ADN with planning goals, the technical, economical constraints. Finally, a planning approach for short term planning is also proposed.

BASIC DEFINITIONS

Distributed Energy Resource (DER): including DG (Distributed Generator), DS (Distributed Storages), EV (Electric Vehicles), and DSI (Demand Side Integration).

Medium Voltage (MV): Voltage levels rated < 35kV. In China, the definition of distribution network is more related to the function rather than voltage level.

Distributed generation (DG): Generation connected to the distribution network at MV (< 35 kV) or LV (< 0.4 kV).

Active distribution network (ADN): The term applies to distribution networks with DER. The network is operation-able and controllable under DER, so as to maximize the usage of DER with the best cost-benefit.

MAIN IMPACTS ON FUTURE PLANNING

Network Sel-healing Requirements

Currently, the most difficult problem for power system to overcome is to improve the network self-healing ability. Although transmission system is in the network structure, as the investment for routine and interconnection, transmission interconnection lines between the networks are relatively limited; and distribution network is only radial even if with ring design but also most of the networks are operated in radial. Because of the obstacle on investment, only a very small number of MV and LV distribution network are in the closed-loop operation. Therefore, during the failure, the self-healing capacity of electric power network is very limited.

If the planning problem for supply routine is not reasonablely considered during planning and construction stage of the network, then the appropriate transmission routines are not available during the operation. Therefore, self-healing ability of power system could not be improved only by distribution automation and intelligence technology, but on the one hand to change the network structure (which is closely related with the planning), and to change the control mode as well. The network planning has a great impact on the network structure and control mode, which means that if the planning does not set aside the possibility of the network structure by properly arranges the section switches and tie switches, and then it is impossible to optimize the power supply routine during outage.

The integration of DER

The followings about the impacts of integration DER on network planning should be considered:

1) The optimization of distribution network design policy and strategic investment approach with DER.
2) The improvement of the Micro Grid reliability by optimizing DER scale.
3) Distribution network operation performance and control by DER.
4) The Network Design with large-scale access of DER
5) The output forecasting of DER and real-time management.
6) Network evaluation tool for DG access, such as the loss of voltage change caused by DG, the fault current, the fault conditions of the island issue.

The access of distributed energy storage

Typically, the network planner may make assessment for electrical energy storage based on load duration curve or through a simulation analysis, including how many times a year it will down, how long each stop opportunities and how much electrical energy storage device needs to be stored to successfully cope with power outages and so on. In addition, the period for the completion of the off-peak charging of energy storage, distributed generators should be required to determine how much capacity. Electric energy storage can be used as a way of power supply enterprise, but also can be used as a backup uninterruptible power supply power users [2].

The improvement of reliability

In addition to distribution system itself, relying on the three kinds of distribution of resources (storage, distribution automation, DG) in a large range, the needs of different users for different levels of supply reliability can be met. In today's electricity market, the following items are entirely possible: the competitive prices, low quality, low cost, and without the needs to force users to accept the same reliability.

Regardless of cost, reliability is not difficult to meet; only considering the quantity, quality and cost jointly, the high cost-effectiveness can be obtained for reliability.

The conditions of existing network

Existing power system technical requires a large enough generator capacity margin (cold standby, hot spinning reserve, the general running time of approximately 6000h), large enough transformer capacity margin (load ratio generally less than 50%), and line capacity margin (multiple lines), as a response to the problems such as frequency, voltage, N-k failure and continuity of power supply, and a great alternative means huge investment and waste.

The major defects of the existing network are: lack of reach in the network, lack of capacity of the network, inadequate intelligence, lack of security, poor network design, and lack of storage capability. The last one often attributed to an inherent technical difficulty in storing electricity [3].

THE MAIN CONSIDERATIONS FOR ADN NETWORK PLANNING

In carrying out the study of the future grid, the followings should be considered:

1) **Developmentt stage**: The construction scale of power grid has reached a stable stage or not: if it is in a stable stage, the problem of the inherent capacity for the existing power grid should be considered; if in the development stage, it is need to judge whether the existing planning models or new planning model should be used.
2) **Reliability levels**: In some countries, the annual outage time per household is generally less than 2h; the best has reached 5min, while in some countries the average annual outage time per household is generally more than 9h. If a high level has been reached, only the intelligent distributed energy technologies could be rely on; if low, it will have to consider a new planning model and approach.
3) **Evaluation Methods**: Evaluation methods should be judged that whether it is based on system approach and the principle of minimum cost or based on the project orientated approach. The system approach is in terms of quantity, quality and cost, emphasizing the maximization of the marginal cost-effectiveness for reliability. The

project orientated approach is only to determine the amount of the total investment costs for each project. Especially, it is necessary to consider the cost benefits when improving the reliability of the network.

COMPEREHENSIVE PLANNING MODEL FOR ADN NETWORK

Because of the uncertainties about DER, such as electric vehicles, which can only be seen as a random load, either positive (charging) or negative (discharging). So when DER access into network, the DER should be taken as load as usual in the power network planning, but only the switch will have to consider the impact on short-circuit current. That is, when DER is taken as the load, the access of DER is no different from ordinary load, as long as the network structure and capacity can meet the requirements. When the DER is taken as the power generation, the planning model should take the cost function of DER, and take the lines and substations power balance constraints.
The ideas about objective function and constraints are considered in detail as follows:

Table 1 Variables table

Symbols	Description
$NL, NN, NS,$ NLW, NG, NH	The number of lines, the number of nodes, the number of substations, the number of line switches，the number of DERs, Planning horizon year
i, j, k, l, m, n, t	Line index, Node index, Substation index, Line Switch index, Tie Switch index, DERs index, DER operates time index
L_i	Line length，km
PL_i	Line power，MW
PN_i	Node power，MW
$PDER_n$	DER power，MW
PS_k	Substation Capacity，MVA
$ILWS_l$	Installation of the line Switch, =1,install , =0 not install
C_{Li}	Line cost coefficients, 10^4yuan/km
C_{Sk}	Substation cost coefficient, 10^4yuan/kVA
C_{pn}, C_{en}	DER capacity and energy cost coefficients,yuan10^4/kW, including cost coefficients for DG, DS, EV.
C_{wl}	Line switch cost coefficient

Objective functions

Objective function-1 is a linear function, which minimize three kinds of investments for line length L_i, the number of switch $ILWS_l$ and substation capacity PS_k separately.
Objective function-2 is a linear function, which maximize the DER energy and minimize DER capacity $PDER_n$, by which the carbon emissions can be as low as possible.

Basic constraint functions

Compared with the traditional planning model, the planning model with DER in the planning formulation should be considered as:

(1) Line power balance constraints：For each line i, line power PL_i is not smaller than different between the summation of each node power PN_j and the summation of each power DER_n, where j and n belong to i. The number of constraints is equal to NL .
(2) Substation power balance constraints：For each substation k, substation power PS_k is greater than the summation of each line power PL_j, where i belongs to k. The number of constraints is equal to NS.
(3) Line switch allocation constraints: For each line i, for the maximum line length is 4 km, the summation of each line switches is smaller or equal to 3, so line length/number of line switch ≥ 1.3, the line length Li is greater or equal to the product of 1.3 and the summation of the line switch.The number of constraints is equal to NL.
(4) DER constraints: The generated energy of DERs should be above zero. Furthermore, the total power of DER connected to a line is lower than total node loads of that line. The number of constraints is equal to NG, i.e., the number of DERs. The number of constraints is equal to NL.
(5) Load growth constraints: Different areas and stages of development are taken into account, so the load growth rate r is between 1% and 5% in this paper with an evaluate period of 20 years. The number of constraints is equal to NN.

Planning Model

Objective function-1(traditional investment) :

$$\min\left\{\sum_{i=1}^{NL} C_{Li}L_i + \sum_{l=1}^{NLW} C_{wl}ILWS_l + \sum_{k=1}^{NS} C_{Sk}PS_k\right\} \quad (1)$$

Objective function-2(DER) :

$$\max\left\{\sum_{n\in k}\sum_{t=1}^{NT} C_{en}t\times PDER_n - \sum_{n=1}^{NG} C_{pn}PDER_n\right\} \quad (2)$$

Basic Constraints:

Line power balance constraints：

$$\sum_{j\in i} PN_j - \sum_{n\in i} PDER_n - PL_i \le 0, i = 1\ldots, NL \quad (3)$$

Substation power balance constraints：:

$$\sum_{i\in k} PL_i - PS_k \le 0, k = 1\ldots, NS \quad (4)$$

Line Switch Installation:

$$L_i - 1.3\times\sum_{l\in i} ILWS_l \ge 0, i = 1\ldots, NL \quad (5)$$

DER constraints:

$$\sum_{t=1}^{NT} t\times PDER_n \ge 0, n = 1\ldots, NG \quad (6)$$

$$\sum_{n\in i} PDER_n - \sum_{j\in i} PN_j \le 0, i = 1\ldots, NL \quad (7)$$

Load growth constraints:

$$PN_{i\max} = PN_1(1+r)^{NH}, i = 1\ldots, NN$$
$$\text{Where load growth rate } r = 1\% \sim 5\% \quad (8)$$

Variable constraints:

Line length: $2 \le L_i \le 4$ (9)

Line power: $0 \le PL_i \le 15$ (10)

Substation power: $PS_k \le 100$ (11)

DER power: $PDER_n \le 10$ (12)

Line switch installation: $0 \le IWS_l \le 3$ (13)

Node load: $0 \le PN_j \le PN_{\max}$ (14)

After ADNs planning is completed, reliability evaluation will be executed.

PLANNING APPROACH

A new planning approach for distribution system is also proposed to adapt the transition from passive to active distribution networks, by which the distribution network will harmonize with various DER integrations. The study in this attempt to pave the way to establish a sophistic planning mathematic model for ADN planning.

Based on the framework shown in Fig.1, this paper gives the short term planning approach for ADNs basically as follows:

Step1: Set goals of the planning, select economical set for lines and transformers.

Step2: Weak points study (the existing system analysis without DER)

Step3: Load forecasting, and Energy forecasting (load utilization factor)

Step4: Base case study (based on traditional planning approach without DERs)

Step5: Alternative studies (base on the proposed ADNs planning model with DERs)

Step6: Cost/benefit marginal analysis considering reliability

Step7: Decide the optimal alternative based on Cost/benefit marginal analysis.

Test example

A test example [4] is used to verify the correction of the proposed ADN planning model, in which NL=7, NS=1, NN=18, NLW=14, NG=14. According to this model, the total number of constraints is *4NL+NS+NN+NG (=61)* and the total number of variable is *2NL+NS+NG+ NLW+NN (=75)*. The number of constraints is less than the variables, so the planning model is reasonable and can be applied to the ADN planning.

CONCLUSIONS

Various considerations and impacts on the distribution planning to facilitate the transition towards active distribution networks (ADNs) were studied in detail. A comprehensive ADN planning model was proposed in this paper with multi-objective functions (investment, DER) and constraints (line and substation balance, DER balance, network configuration). A planning approach for short term planning is also proposed. The proposed planning model was verified to be reasonable by a test example to be applied in ADN planning. The study has paved a way for the future study on ADNs planning.

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