Multiple Resources Planning in Microgrid Based on Modeling Demand Response of User Side

Si-cong Wang¹, Qi-xin Wang¹, Zi-xia Sang², Ji-feng He², Jia-qi Huang², Jiong Yan¹, and Reng-cun Fang²

¹ State Grid HBEPC Economic & Technology Research Institute, Wuhan 430077, China
² State Grid Laboratory for Hydro-thermal Power Resources Optimal Allocation & Simulation Technology, Wuhan 430077, China

Corresponding author e-mail: spadegadget@hotmail.com

Abstract. According to the characteristics and development trend of microgrid, instead of being the pure load, demand-side is treated as a kind of possible power supply (equivalent effect of reduction of the load) which can actively participate in the planning and operation in microgrid. An integrated resources planning model considering direct load control (one of demand responses) in microgrid was proposed. The validity of the proposed model was proved. It can be achieved to minimize the total cost of system planning by using demand response to actively participate in the planning. Depth discussions for the case were done to give comparative analysis of different control strategies, parameters and costs and more planning proposals were given.

1. Introduction

The planning and design in the early stage of microgrid construction is an important topic in the research of microgrid. Generally, according to the available energy situation and the load requirements of microgrid, the optimization is carried out to determine the type and capacity of distributed generation in microgrid with the optimization of economy or power supply reliability. At present, microgrid planning research mainly includes the following aspects: microgrid planning model and algorithm [1-3], microgrid energy storage optimization configuration [4-5], distribution network planning research with microgrid [6], microgrid planning and design software development [7], etc. The above-mentioned literatures carry out research on Microgrid planning from different perspectives. The supply side micro source modeling is detailed, but the demand side processing is relatively simple. Modeling is only based on the results of load forecasting or considering an energy efficiency coefficient, and does not involve the impact of demand response (DR) specific measures that may be implemented in the operation stage on the load time series curve. The load in microgrid is more specific, and the characteristic data can be obtained through investigation, which provides a physical basis for the research on demand side response modeling in microgrid planning; on the other hand, the development of advanced measurement infrastructure (AMI) technology in smart distribution network provides more convenient hardware conditions for the research.

In this paper, an integrated resource planning method based on time series simulation is studied, which is based on the modeling of demand side response measures. Taking the mature foreign direct
load control (DLC) as an example, the demand side resources (DLC) and the supply side resources are treated equally, so as to achieve the goal of minimum total social cost. In China, the development speed of direct load control is very slow due to the lack of advanced measurement, control and other technical support in the hardware aspect. Under the background of smart grid construction, as a simple and practical load management method, it is getting more and more attention and development. With the improvement of marketization of China’s power industry, the role of demand side resources in the market is becoming more and more important. The traditional concept of taking the demand side as a passive load should be gradually abandoned. The method proposed in this paper can provide reference for microgrid load to actively participate in power grid planning and operation.

2. Direct load control
Direct load control (DLC) is a demand side response measure for load shaping. The power company uses monitoring signals to cut off the relationship between the controlled load and the system during peak load period, so as to reduce peak load, improve load rate, and reduce the impact on power companies and users as much as possible.

In this paper, the classical direct load control model is adopted. Its principle is simple and easy to operate, which is more suitable for the planning stage. The direct load control strategy includes full time control strategy, single period control strategy and two period control strategy. The whole period control strategy means that the interruption period of the controlled load is the maximum allowable interruption period of the load; the single period control strategy means that the interruption period of the controlled load is half of the maximum allowable interruption period; the two period control strategy means that the load interruption is completed in two times, each interruption period is half of the maximum allowable interruption period, and there is a minimum interruption interval between the two interruption periods Clearance requirements. The load is disconnected from the system during the interruption phase, so as to stop obtaining power from the grid, and then try to recover to the load level before the cut-off, forming a rebound load. The load after direct load control with full time control strategy can be given by:

\[
P(t) = f(t) - \sum_{i=1}^{n} b_i c_i \epsilon_i(t) - \sum_{i=1}^{n} b_i c_i z_i \epsilon_i(t)
\]

3. Micro source models of microgrid

3.1. Microgrid model
The microgrid system studied in this paper is composed of wind turbine, solar cell, diesel engine, energy storage battery and load. The load can be divided into uncontrollable load and controllable load. The controllable load can be cut off by the load control device in the peak period to reduce the load demand and play the role of virtual micro source. Therefore, the electric energy exchange with AC bus of power grid is represented by two-way symbol. The microgrid system structure is shown in Figure 1.
3.2. Wind turbine model
The output of the wind turbine is related to the average wind speed at the height of the shaft and the output characteristics of the wind turbine can be given by:

\[
P_{W} = \begin{cases} 
    P_{R} v - v_{c} & v < v_{c} \\
    P_{R} - v_{c} & v_{c} \leq v \leq v_{R} \\
    P_{R} v - v_{R} & v > v_{R}
\end{cases}
\]  

(2)

3.3. PV model
The output of photovoltaic cells is only related to light intensity and ambient temperature, which can be expressed by:

\[
P_{PV} = P_{STC} G_{AV} \frac{1 + k(T_{c} - T_{k})}{G_{STC}}
\]  

(3)

3.4. Battery model
When the battery is discharged, the remaining capacity is:

\[
S(t) = S(t-1)(1-\sigma) - \frac{P_{SB}(t)}{\eta_{D}}
\]  

(4)

When the battery is charged, the remaining capacity is:

\[
S(t) = S(t-1)(1-\sigma) - P_{SB}(t)\eta_{C}
\]  

(5)

4. Integrated resource planning model for microgrid
The objective function of the model is to minimize the net present value of the total cost of electricity demand, and it can be given by:

\[
f = \min (f(c_1) + f(c_2) + f(c_3))
\]  

(6)

In the planning period, the sum of the power generated by all micro sources in the T period is not less than the load in the T period, and it can be given by:

\[
\sum_{1}^{N} P_{k}(t) \geq P(t)
\]  

(7)

The capacity of the k-th micro source in the microgrid should not exceed the maximum allowed by the planning, and it can be given by:

\[
X_{k} \leq X_{k}^{max}
\]  

(8)

The power generated by the k-th micro source in the t-th period does not exceed its rated capacity, and it can be given by:

\[
S_{max} \geq S(t) \geq S_{min}
\]  

(9)

The controlled load capacity constraints and daily controlled load constraints are shown as:

\[
n_{max} \geq n
\]  

(10)

\[
\sum_{i=0}^{96} b(i) \leq m
\]  

(11)
Through the above formula, the nonlinear programming optimization algorithm can be realized by software programming.

5. Conclusions
In this paper, a microgrid planning method combined with operation demand side response modeling is proposed. The demand side response measure modeling is integrated into the integrated resource planning model of microgrid. The demand side resources and supply side resources are treated equally to achieve the goal of reducing peak load and achieving the optimal total social cost of microgrid system. Further work can be considered to deal with the different performance of controlled load in planning and actual operation, the combination model of other demand side response measures and planning, and the improvement of calculation speed and convergence of multivariable nonlinear system planning.

Acknowledgments
This research was supported in part by the State Grid Hubei Electric Power Company Science and Technology Project (521538180019).

References
[1] Basu, A. K., Bhattacharya, A., Chowdhury, S., et al. (2012) Planned scheduling for economic power sharing in a CHP-based micro-grid. IEEE Transactions on Power Systems, 27: 30-38.
[2] Guo, L., Liu, W. J., Jiao, B. Q., et al. (2011) Multi-objective optimal planning design method for Stand-alone microgrid system. Proceedings of the CSEE, 34: 524-536.
[3] Ma. X. Y., Wu, Y. W., Fang, H. L., et al. (2011) Optimal sizing of hybrid solar-wind distributed generation in an islanded microgrid using improved bacterial foraging algorithm. Proceedings of the CSEE, 31: 17-25.
[4] Chen, S. X., Gooi, H. B., Wang, M. Q. (2012) Sizing of energy storage for microgrids. IEEE Transactions on Smart Grid, 3: 142-151.
[5] Zhu L., Yan, Z., Yang, X., et al. (2012) Optimal configuration of battery capacity in microgrid composed of wind power and photovoltaic generation with energy storage. Power System Technology, 36: 26-31.
[6] Kirthiga, M. V., Daniel, S. A., Gurunathan, S. (2013) A methodology for transforming an existing distribution network into a sustainable autonomous micro-grid. IEEE Transactions on Sustainable Energy, 4: 31-41.