Smart Grid Planning Analysis Considering Multiple Renewable Energy Resources and Energy Storage Systems of User Side

Ya-lei Wang¹, Zi-xia Sang²*, Jia-qi Huang², Jiong Yan¹, Si-cong Wang², Ji-feng He¹, Dong-jun Yang¹, and Zhi Du²

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
*spadegadget@alumni.hust.edu.cn

Corresponding author e-mail: spadegadget@hotmail.com

Abstract. The integration of renewable energy resources and storage systems makes power delivery route reconstruction after the N-1 fault taking place more complicated. To solve the calculation problem of smart grid power transfer capability, the time-varying characteristics of renewable energy resources and storage systems were analyzed. Based on this, an N-1 recovery model was proposed on the base of the transfer capability index. Through making the calculation formula of the transfer capability index linear and adopting the artificial intelligence (AI) optimal algorithm based on topology simplification, the operation modes of the power grid, new energy generations and new energy storage systems can be optimized and the maximum power transfer capability of the grid can be achieved.

1. Introduction

N-1 transfer capability is an important index for power grid evaluation, and also an important basis for power grid planning, dispatching, operation and emergency recovery [1]. At present, the special research on the evaluation of distribution network transfer capacity is mostly based on the analysis method of transmission network transmission capacity, and combined with the characteristics of distribution network structure. Under the condition that the load of each node is determined, the capacity of the load level of the network load is checked through the power flow calculation of the distribution network, so as to determine the transfer capacity of the urban power grid. The main evaluation methods include capacity load ratio method [2], trial method [3], maximum load multiple method [4] and network maximum flow method [5].

Compared with traditional power grid, when N-1 fault occurs in smart grid compatible with DG / DESs, the mode of power supply recovery is more complex and the selection of transfer path is more diversified. How to quickly and accurately select the transfer path, give full play to the supporting role of DG / DESs, and construct the index system of smart grid transfer capacity has important guiding significance for future smart grid evaluation, planning, dispatching operation and emergency recovery.

In this paper, a simplified topology model considering DG / DESs access is established, and based on this model, the calculation model and algorithm of transfer capacity for smart grid are proposed.
2. Smart grid transfer capability index

When N-1 fault occurs in smart grid at time $T$, the standby power supply in the network includes source point transformer, distributed generation and distributed energy storage device in discharge state.

For the transformer $i$ at the bus source point, the maximum available transfer capacity is:

$$S_{i,\text{trans}}(T) = S_{i,\text{rated}} - S_{i,\text{output}}(T)$$  \hspace{1cm} (1)

When N-1 fault occurs, DG has three states: off grid operation, independent operation and grid connected operation which are shown in Table 1.

Table 1. DG operation modes in fault systems.

| DG type | Operation after the fault | Effect to the grid |
|---------|---------------------------|--------------------|
| A       | Off the grid              | Load from DG to grid |
| B       | Grid connected, no island operation | load node with negative capacity |
| C       | Grid connected or island operation possible | Island: standby power supply; grid connected: negative load node |

For DG with intermittent characteristics such as wind turbine and photovoltaic power generation, its power output is limited by external conditions and not controlled by human factors, so its transfer capacity is the actual output. The transferable capacity of this type of DG at time $T$ can be given by:

$$W_{k,\text{trans}}(T) = W_{k,\text{max}}$$  \hspace{1cm} (2)

The operation voltage of DG is constrained to be:

$$S_{k,\text{trans}}(T+1) \geq U_{\text{Low}}$$  \hspace{1cm} (3)

For DESs, its discharge power is closely related to its own capacity. Therefore, when considering its discharge power, the capacity of energy storage device must be considered.

For the specified energy storage system $i$, its capacity at $T+1$ is:

$$E_i(T+1) = E_i(T) - \int_T^{T+1} \left( \frac{P_{i,\text{output}}(G)}{\eta_i} \right) dt$$  \hspace{1cm} (4)

The power supply capacity of a single energy storage device $i$ at time $T$ should be considered as:

$$E_i(T) - k_i(G) \int_T^{T+1} \frac{P_i,\text{output}}{\eta_i} dt \geq E_i,\text{min}$$  \hspace{1cm} (5)

$$P_{i,\text{output}}(G) \leq k_{i,\text{max}}P_{i,\text{rated}}$$  \hspace{1cm} (6)

$$k_{i,\text{max}} = \min \left( \frac{P_{i,\text{max}}}{P_{i,\text{rated}}}, \frac{E_i(T) - E_i,\text{min}}{\int_T^{T+1} \frac{P_i,\text{rated}}{\eta_i} dt} \right)$$  \hspace{1cm} (7)

When the index model of transfer capacity is applied to power grid planning, the output setting method of transfer point under N-1 fault is different from real-time calculation, so appropriate adjustment should be made. Table 2 summarizes different application scenarios and variable value methods.

Table 2. Index selection of planning and operation modes.

| Transfer capacity of transformer | Outgoing transmission capacity | Outgoing line | Transfer capacity of intermittent DG | Actual output | Transmission capacity |
The calculation of transfer capacity mainly includes two steps: fault area isolation and load recovery in non-fault area. Among them, load recovery path selection in non-fault area of distribution network is a complex large-scale nonlinear integer combination optimization problem, which needs to be realized by intelligent optimization algorithm.

### 3. Strategy of smart grid transfer capability

#### 3.1. Boundary selection of power supply restoration area

When the radial grid fails and the fault elements have been removed, the power grid will be divided into three categories: fault area, normal power supply area and non-fault outage area. The tie line between the non-fault outage area and the normal power supply area is called the boundary tie line [6]. Considering the DG / DESs access model of smart grid transfer capacity, the boundary of non-fault power supply area to be restored will be more complex, and more factors need to be considered in the selection of power supply recovery path. In order to achieve the goal of maximum transfer capacity, the transfer recovery area connected by DG / DESs includes but is not limited to the non-fault outage area formed after fault isolation.

The undirected component network graph \( g' \) is used to represent the studied power grid and \( g' \) is the computational network. Before the calculation, the components in \( g' \) are in power-off state, other networks are in charged state, and \( g' \) is connected to the outside world through tie lines. The power supply restoration algorithm takes \( g' \) as the research object, and realizes the power supply recovery of the outage load by changing the status of the contact switch and the section switch in the calculation network.

#### 3.2. Topology simplification

By expanding the boundary area of the calculation of the transfer capacity, the search space of the optimization algorithm is increased, and the probability of finding the optimal solution is improved, but the computational efficiency of the optimization algorithm is inevitably reduced. Therefore, after the topological analysis based on CIM [7], it is necessary to simplify the grid structure to form a calculation grid that is easy to obtain the transfer capacity.

According to the actual operation requirements, the load of the same branch line should be restored at the same time when the power supply recovery path is selected. Therefore, in the initial selection set of the optimization algorithm, the switches on the branch line should be removed and only the switches on the main line should be retained. In order to facilitate the calculation of transfer capacity, the load between terminal equipment and “T” node should be accumulated and merged while the branch line equipment is removed.

Figure 1 is the flow chart of topology simplification of Smart Grid Considering DG / DESs access. When the branch line contraction function is called to simplify the network, the lines containing DESs / DG should not be regarded as branch lines and need to be treated as trunk lines.
4. Conclusions
In this paper, a power grid access model considering the time-varying characteristics of DG / DESs is established. Based on the model, an index system of transfer capability for smart grid is proposed. Based on the boundary selection of power supply area, topology simplification and connectivity constraints, the model has practical application value for studying the rationality of power grid construction and transformation, analyzing the security, economy and compatibility of power grid operation, and ensuring the quality and reliability of power supply.

In smart grid, the transfer capability index focuses on the ability of DG / DESs to deal with system failure. The combination of transfer capability and energy storage capacity index can comprehensively reflect the impact of energy storage device access on the safe and economic operation of the system. It is suitable for the research and development of real-time dispatching operation and grid planning of smart grid compatible with DG / DESs access.

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