Research on Islanding Strategy for Fault Recovery of Distribution System with Micro-grid

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Abstract. In order to adapt to the actual situation of power distribution system fault recovery with micro-grid, a recovery strategy for micro-grid to operate on island with important system load at first under fault conditions is hereby studied. Due to the weak overload capacity, large fluctuation and obvious influence of weather and time period of renewable energy in micro-grid, the dynamic changes of distribution generation and loads in non-fault power loss areas should be considered as much as possible when generating islands. According to historical data, the daily random fitting functions of photovoltaic power generation, fans and various loads are respectively generated by using respective optimization models. For judging the start and duration of the fault, using the fitting function to set the fitting power value of each unit in the distribution system and other information, and calculating the dynamic importance information of each load node as the heuristic condition for subsequent island search. The search strategy in this paper is to guide the load added to the island according to the dynamic importance of the load, and to analyze the reliability of island operation. This method controls the direction of island search, and gives priority to ensuring the recovery of important loads. At the same time, it can ensure the balance between the stability of island generation and the maximum utilization of renewable energy.

1. Introduction

With the continuous consumption of fossil energy, rational use of renewable energy has become the only way to solve the energy crisis and strengthen environmental protection [1-2]. As micro-grid control technology continues to mature, distribution system become more complex. So far, many researches have been carried out on the restoration of power distribution network faults [3-5]. Reference [6] analyzes various impacts of distributed generation supply access on power distribution system fault recovery. Reference [7,8] respectively uses different minimum spanning tree algorithms to study the islanding problem of distribution system with distributed generation. Reference [9] adopts a search method based on a root tree, which is a simple and effective island search method, but does not consider the different importance of loads and the fluctuation of distributed generation and loads with time. Reference [10] proposes a distribution system restoration method based on opportunity constraints, and theoretically analyzes the impact of photovoltaic addition.

When a fault is detected in a large power grid, the micro-grid will be separated from the power grid and operate on islands. This method is likely to lead to normal operation of non-important loads in the micro-grid and power loss of important loads outside the micro-grid. This paper formulates the strategy of island operation of important loads in the loss area of micro-mesh belt under fault conditions according to the requirements of power distribution system fault recovery. This ensures that
important loads near the micro-grid can be restored first, and renewable energy in the micro-grid can be fully utilized.

2. Description of Islanding Problem under Fault Condition of Distribution system with Micro-grid

2.1 The principle of dividing islands in distribution system with micro-grid

Priority Principle of Load Value
After the system fails, the islanding scheme adopted should maximize the dynamic value of the recovered load.

Principle of Maximizing Utilization of Renewable Energy and Energy Storage Devices
According to the characteristics of renewable energy and the properties of energy storage devices, maximum utilization is guaranteed under the premise of stability.

2.2 Stability Constraints

Power Balance in Island:
\[ \sum_{j \in V_s} P_{pvj} + \sum_{j \in V_s} P_{avej} - \sum_{k \in V_s} P_{avek} \geq 0 \] (1)

The sum of the dynamic average power values of all fans and photovoltaic output of the island \( V_s \) during the fault period is not less than the sum of the dynamic average power values of the load. \( P_{pvj}, P_{avej} \) and \( P_{avek} \) are respectively represent the dynamic average power values of each fan, photovoltaic and load included in the island.

The Line and Transformer Capacity Does not Exceed the Limit:
\[ I_{max} < I_e \] (2)

In the formula, \( I_{max} \) is the maximum current on the line and transformer and \( I_e \) is the rated current on the line and transformer.

2.3 Strategy Evaluation Index

Based on method of Sequential Monte Carlo, this paper uses random discrete data provided by various power generation units and load models to analyze the reliability of the strategy by using the following indexes to fully ensure the safety and reliability of the strategy.

The Island Electricity Shortage Expectation (EDNSI) is derived from Equation
\[ \lambda_{EDNSI} = \sum_{i=1}^{n} P_{sqdi} \] (3)

In the formula, \( P_{sqdi} \) —— Island Power Deficiency (kWh)) in the \( i \) th Step; \( n \) —— The total step number of island simulation; \( \lambda_{EDNSI} \) —— Sum of power deficiencies in island operation (kWh).

The first power shortage time expectation (FLOPT) is derived from equation
\[ T_{FLOPT} = \frac{1}{m} \sum_{i=1}^{m} t_i \] (4)

In the formula, \( t_i \) —— In the \( i \) th simulated operation of the island, the time (Min) when the power shortage first occurred; \( m \) —— Total numbers of simulated runs; \( T_{FLOPT} \) —— Expectation of operating time without load shedding for island (Min)

The probability of islanding without load shedding \( P_{ni} \) is calculated by equation
\[ P_m = \frac{N_{cg}}{N} \]  

In the formula, \( N_{cg} \) —— The number of times when there is no power shortage; 
\( N \) —— The total number of simulations runs. 
The above data are obtained by simulating the strategy for a unit number of times.

2.4 Strategic Evaluation Criteria

\[ F_{jc} = \sum_{k=1}^{n} M_k P_{avk} \]  

\( F_{jc} \) is the value of all power loss loads recovered by the island, \( M_k \) is the value adaptation value of load \( k \), and is set to 10,5,1 respectively according to the load grade from high to low. \( P_{avk} \) is the dynamic average power value of node \( k \) during the fault period.

3. Simplified Distribution System Model with Micro-grids

3.1 Micro-grid Access Mode

Micro-grids are all connected by feeders. Fig. 1 is a schematic structural diagram of a micro-grid containing renewable energy.

3.2 Island Control Mode

At present, there are many control methods for micro-grid island situation. The energy management system in each micro-grid is utilized to control the whole island in real time.

4. Rules and Processes of Islanding

4.1 Take Different Island Ways According to the Situation

When the total load in the non-fault power loss area is greater than the amount of electricity generated by renewable energy in the micro-grid, disconnect all three-level loads in the micro-grid, and then search according to the process described in 4.2.

When a micro-grid disconnects its own level 3 load during the fault period and still cannot meet its own operation requirements, it is called a non-output micro-grid.

4.2 Island partition model

Based on the above, the connection graph model of distribution system is established. The problem of island partition of distribution system with micro-grid is transformed into the minimum spanning tree
problem of finding connection graph. Graph is a complex nonlinear data structure. The binary group of graph G is defined as: \( G = (V, E) \). Where V is the node set, \( V = \{ v_i \mid 0 \leq i \leq n - 1, n \geq 0 \} \), \( v_i \) is the dynamic importance of the node, n is the total number of nodes. E is the set of edges, \( E = \{ (v_i, v_j) \mid W_{ij} \mid 0 \leq i \leq n - 1, 0 \leq j \leq n - 1, n \geq 0 \} \), where \( (i \in U \& j \notin U) \) is node connectivity, \( W_{ij} \) is the weight of the edge, which is determined by the dynamic importance of nodes not included in the isolated island.

4.3 Island Search Process

The specific process of island search is as follows:

1. In \( V_1 \) the micro-grid node with the largest \( v_p \) is selected as the root node and added to U.

2. Verify the dynamic power constraint according to formula (5). If the constraint condition is met, update the set \( T \) and the set sum \( E_1 \) and \( E_2 \).

3. Update \( V_1 \), then select an edge with the greatest dynamic importance in the \( E_1 \), and bring it into the island.

4. Repeat step until the set U contains all nodes in V or cannot meet the dynamic power constraint.

4. Repeat step (1) to (3) until it is an empty set.

In order to solve the problem of island fusion, the limit condition is added that when the edge in set E and its two nodes respectively exist in the node set of two islands, this edge is connected, thus the intersecting islands can be fused into a large island.

![Fig.2 actual simplified diagram of distribution system](image)

![Fig.3 connected graph of distribution system](image)
For the node with the largest option value in S, connectivity is verified through comparison with set E. After the addition is completed, whether the constraint conditions are met is verified according to formula (1) and the addition is completed.

After completing an island search, complete the second island search according to steps (3)(4) until all the micro-grid that can contribute are included in the island.

After the search of all the micro-grid that can contribute to the load is completed, the reverse comparison has been made on the load that has been included in the isolated island and the dynamic importance $\lambda$ of the three-level load in each network.

4.4 Constraints to Optimize Island Search Strategy

When two nodes of an edge in set E respectively exist in the node sets of two isolated islands, the edge is connected.

When the load nodes connected with the load nodes are in different islands, and each island cannot supply power to the load nodes individually, all the nodes in the islands can be connected to supply power jointly.

4.5 Policy Generation

The strategy is simulated and verified based on Monte Carlo method, and the viability of isolated island is obtained.

5. Conclusion

The island strategy proposed in this paper greatly reduces the possibility of power loss of important loads caused by insufficient power supply capacity of the main network and reduces the possibility of major economic losses and accidents caused by power loss of important loads. At the same time, this paper puts forward the index of island viability to ensure the successful operation of the island and prevent secondary failures. In the future trend of intelligent power grid, distribution system will operate under the conditions of great knowability and controllability. The control strategy described in this paper will be better applied.

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