Fault Recovery of Micro-grid Based on Network Reconfiguration

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Abstract—This paper proposes a more suitable scheme for the practical application of micro-grid fault recovery. The micro-grid permanent fault is treated as a longer time transient fault and the network reconfiguration technology is used to optimize the micro-grid reconstruction. The mathematical model of micro-grid reconstruction is developed based on genetic algorithm with voltage stability as a precondition, ignoring the network loss, line capacity and some constraint conditions at the same time, and a minimum number of switching operations and restoring maximum load are taken as the target function. The CERTS micro-grid model is taken as a simulation example, and the results show that this scheme of fault recovery of micro-grid proposed here is valid and feasible.

Keywords—micro-grid; network reconfiguration; genetic algorithm; fault recovery

I. INTRODUCTION

Along with the current socio-economic development and the further deepening energy crisis, the world is badly in need of a new power technology which uses a variety of primary energy in the form of combination, efficiency, economy, and environmental. Micro-grid technology has emerged. Since the concept of micro-grid was proposed, it has got a large number of experts, scholars and government attention, and which is referred to the strategic level in some countries. So the micro-grid operation, control and protection and the other related technologies have been greatly developed. Based on the existing micro-grid technology and the characteristics of the micro-grid existing protection main use local protection methods such as literature [1], the micro-grid local load losing power cannot recover very well, which brings huge economic losses to users. Although the existing network reconfiguration technology is very mature, which are concentrated used in distribution network [2-5], of which there are references about the micro-grid research, but in the distribution network reconstruction just look the micro-grid as a overall. So far, no relevant research use it for the micro-grid.

This paper has explored the application of network reconfiguration technology in the micro-grid. Firstly, the CERTS micro-grid is briefly introduced. Based on micro-grid has the characteristics of simple structure, smaller size, shorter line, shorter recovery cycle of permanent fault [6], this paper proposed a more suitable scheme for the practical application

of the micro-grid fault recovery. Next CERTS micro-grid is taken as an example with genetic algorithm to simulate. Finally the simulation result is analyzed.

II. CERTS MICRO-GRID^[7]:

The CERTS micro-grid model will be taken as the simulation model. A single-line representation of the CERTS micro-grid is shown as Fig.1, which includes three micro sources, specified as A1, A2 and B1, and three local loads, specified as L1, L2 and L3. Each micro source can provide a maximum output power of 60kW and each load can consume a power up to a maximum amount of 120kW, where the total load of micro-grid should not exceed 180kW. The micro-grid is connected to the main grid through a fast semiconductor switch that is called static switch, shown as Fig. 1.

Figure 1. Simplified diagram of CERTS micro-grid

III. ESTABLISH THE MATHEMATICAL MODEL OF MICRO-GRID FAULT RECOVERY

Generally, distribution network fault recovery is a multi-objective, multi-stage, multi-constrained, nonlinear optimization problem, the effectiveness, rapidity, economy, reliability need to be comprehensively considered in a recovery

scheme. Namely, not only recovering the loss of power and the feasible of recovery process, but also the safety and economy of operation after fault recovery we should consider^[9]. However, micro-grid has the characteristics of simple structure, smaller size, shorter line, shorter recovery cycle of permanent fault. So we can treat permanent fault as a longer time temporary fault and ignore the economy consideration. And then we can put the effectiveness and rapidity in the first place, and reflect the reliability with a penalty factor in algorithm program at the same time.

A. So we can get the index included in objective function of micro-grid fault recovery are as follows:

(1) As far as possible to reduce operation switch:

$$\min N_o \xrightarrow{\text{normalized}} \min \frac{N_o}{N} \quad (1)$$

Here N_o and N are respectively the number of reconfiguration operation switches and micro-grid contains all switch.

(2) As much as possible to recover lost load and DG :

$$\max \sum_{i \in \text{fault}} \|S_{ih}\| \xrightarrow{\text{normalized}} \max \frac{\sum_{i \in \text{fault}} \|S_{ih}\|}{\sum_{i \in \text{fault}} \|S_{il}\|} \quad (2)$$

Here $\|S_{ih}\|$ and $\|S_{il}\|$ are respectively the Module of recovery load and all lost load.

B. Reconfiguration constraint conditions:

In view of micro-grid lines not long, relatively speaking investment of line is not a problem, therefore the line capacity problem need not be considered. So micro-grid reconfiguration constraint conditions are shown as follows:

(1) The power flow equation is taken as the equality constraint :

$$\dot{V}_i \sum_{j=1}^n Y_{ij}^* \dot{V}_j^* = S_i \quad (3)$$

Here $\dot{V}_i$ and S_i are respectively node voltages and power injection of node i, n is the number of node of micro-grid.

(2) Node voltages are taken as the inequality constraint:

$$V_{i \min} \leq V_i \leq V_{i \max} \quad (4)$$

Here $V_{i \min}, V_i, V_{i \max}$ are respectively min voltage, node voltage, max voltage of node i.

In conclude we can get objective function of reconfiguration fault recovery of micro-grid as follows:

$$\max F = 1 - \frac{N_o}{N} + \frac{\sum_{i \in \text{fault}} \|S_{ih}\|}{\sum_{i \in \text{fault}} \|S_{il}\|} \quad (5)$$

In equation (5) symbolic have the same meaning as above.

IV. PROCESS OF FAULT RECOVERY OF MICRO-GRID

A. Flow chart of recovery scheme

When a fault occurs, we should analyze loss power zone at first and determine which zone is fault zone, search all power supply path of the blackout zone, namely search all section switches of blackout zone and loop switches of adjacent zone.

Based on analysis of the fault net shape and operation requirement, resection fault branches, the fault branches data are renewed from the original data. Namely the state of fault branches switch is set to 0, then the state of non fault switches of feeder and the state of loop switches of adjacent feeder are randomly combined. Different from the previous distribution network fault recovery scheme, the recovery scheme here treats permanent fault as a longer temporary fault. Recovery flow chart is shown as Fig. 2:

Figure 2. Flow chart of recovery scheme

Note: Figure t depends on the specific micro-grid circumstances.

B. Fault reconstruction algorithm steps:

When genetic algorithm is applied in the micro-grid reconfiguration, dealing with discrete problem, speed relatively fast and simple coding technology are significant advantages. So it is easy to implement. Micro-grid reconfiguration process is shown as follows:

Step1: chromosome coding:

According to switch numbering, all section switch and loop switch are coded in a binary digits 0 or 1 to form a gene (0 indicate branch disconnect, 1 said branch connect).

Step2: generating the initializing population:

In order to avoid to produce a lot of not feasible solution , fault branch is set to 0, then asking for the number of open switch is the number of loop switch minus the number of fault branch;

Step3: constructing fitness function:

Not only the requirements of the objective function, but also the role of constraints the fitness function should be reflected. Node voltage constraints are reflected by penalty factor in the fitness function. Based on the above ideas, the fitness function is shown as follows:

$$F = 1 - \frac{N_o}{N} + \frac{1}{n_l} \frac{\sum_{i \in \text{fault}} \|S_{ih}\|}{\sum_{i \in \text{fault}} \|S_{il}\|} + \sum_{i \in \text{over}} (V_{\max} - V_i) + \sum_{i \in \text{low}} (V_i - V_{\min}) \quad (6)$$

Here n_l is the total number of load which needs to be recovered. Other symbolic have same meaning as above.

Step4: Selection, crossover, mutation operation:

The selection operation takes Round-Robin method and crossover operation takes uniform crossover method, Chromosome size, crossover rate, mutation rate and keeping the number of fine varieties are based on the actual situation.

Step5: Draw and evaluation results of reconstruction:

After some algebraic iteration, obtained the highest fitness chromosomes, and into the power flow calculation, evaluate the feasibility of the results of reconstruction.

V. ANALYSIS OF PRACTICAL EXAMPLES

CERTS micro-grid system as shown in Fig. 1 can be abstracted into a topological structure diagram, then plus four loop switches is taken as an example shown as Fig. 3.

Original data of line is shown in the table I and table II, assuming fault occurs in 5-6 branch and cut off it. The chromosome size, the crossover rate and the mutational rate are respectively set to 20, 0.6 and 0.001. After 20 iterations genetic algorithm is convergent. The reconfiguration program is used to get result. The results are shown as Fig. 4 and table IV:

Figure 3. CERTS micro-grid topological structure diagram

TABLE I. NODE INITIAL PARAMETERS

Node number	Node power injection (KVA)	Initial node Voltage values (kV)	PV Node voltage given value (kV)	reactive power compensation (kVar)	node types
1	0	400	400	0	1
2	0	400	400	0	3
3	0	400	400	0	3
4	-50-j30	380	0	00	2
5	50	400	0	0	2
6	50	400	0	0	2
7	-50-j35	380	0	0	2
8	35	380	0	0	2
8	-45-j30	380	0	0	2
9	50	400	0	0	2
10	-35	400	0	0	2

TABLE II. BRANCH INITIAL PARAMETERS

Branch initial state	Branch Head end number	Branch tail end number	Branch Impedance(Ω)	Branch trans-formation ratio K	Branch Head end location
1	1	4	0.1064+j0.0616	1	0
1	1	2	0.0266+j0.0154	1	0
1	2	3	0.0266+j0.0154	1	0
1	2	5	0.0266+j0.0154	1	0
1	5	6	0.0266+j0.0154	1	0
1	3	7	0.0266+j0.0154	1	0
1	7	8	0.0266+j0.0154	1	0
1	8	9	0.0266+j0.0154	1	0
1	9	10	0.0266+j0.0154	1	0
0	4	5	0.0532+j0.0308	1	0
0	4	10	0.0532+j0.0308	1	0
0	5	8	0.0532+j0.0308	1	0
0	6	10	0.0532+j0.0308	1	0

Note: branch head end location 1mean head end at k side. Node types 1is balance node; 2 is PV node; 3 is PQ node.

Figure 4. Reconfiguration result diagram

After the reconstruction each node voltage and power are shown as table III:

TABLE III. EACH NODE VOLTAGE AND POWER

node number	Node voltage(P.U.)	voltage phase angle	Node power injection (kW)
1	1	0	45.0054-14.9261i
2	1	-0.3992	59.8044i
3	1	-0.5515	50.1244i
4	1	0.0354	
5	0.9999	-0.0765	50
6	1	0.2602	-50-35i
7	1	-0.2264	35
8	1	-0.0942	-45-30i
9	1	-0.0086	50
10	1	0.1448	-35

Reconstructed branch switch state as table IV:

TABLE IV. BRANCH SWITCH STATE

Branch name	1-4	1-2	2-3	2-5	5-6	3-7	7-8	8-9	9-10	4-5	4-10	5-8	6-10
Branch state	1	1	1	1	0	1	1	1	1	0	0	0	1

Results Analysis:

Namely branch 5-6 is cut off, branch 6-10 is closed. The number of operation switch is 2. After the reconfiguration each node voltage is within 5% deviation range and lose electric load of node 6 get success recovery, the micro-grid can continue to stable operation.

VI. CONCLUSIONS

In this paper, a scheme for fault recovery of micro-grid is proposed. In this scheme, the micro-grid permanent fault is treated as a longer time transient fault, and a minimum number of switching operations and restoring maximum load are taken

as the optimization target. The simulation results through the case analysis show the efficiency and good reliability of power supply. Relevant references are also provided to the micro-grid operating personnel at the same time.

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