Study on Self-healing Control Strategy of Smart Distribution Network

Li Liu , Xuan Zhao

***Abstract*--Self-healing is the most important characteristic of smart grid, and its content including two parts: self-adjustment at normal state and self-restoration at breakdown state. In distribution network, the objective of self-healing control is supply users ceaseless electric power. The paper proposes a rapid heuristic restoration algorithm to achieve the process from breakdown state to normal state. Combined with the mathematical model of breakdown state restoration of the power distribution network, make the process into five parts including self-support feeder restoration, whole area restoration, partition restoration, transfer load by lower level feeder and cut load, and get the suitable feasible solution set of power supply restoration. Find the optimal from the solution set with fuzzy comprehensive evaluation theory, and prove the validity of algorithm by example.**

***Index Terms*-- smart distribution network, self-healing, breakdown restoration, heuristic search, fuzzy evaluation**

I. Introduction

Smart grid has six main features: strong, self-healing, compatible, economic, integration, optimized, and self-healing is the most important among them. Self-healing includes two parts: On the one hand is when power grid operates normally, self-healing system will collect information and analysis it on super real-time in order to adjust itself to the optimum operation state. On the other hand is when power grid has been breakdown, self-healing system will restore the breakdown area according to self-healing control strategy formulated.

Self-healing control is the way to realize functions of self-healing. Usually operation of power system has been divided into five states : optimizing, normal, fragile, fault happening and breakdown state. Corresponding to the five states above, self-healing control can be divided into four kinds: optimization control, prevention control, emergency control and restoration control. Shown as Fig.1.

This paper mainly studies on restoration control and realize to supply breakdown area electric power.

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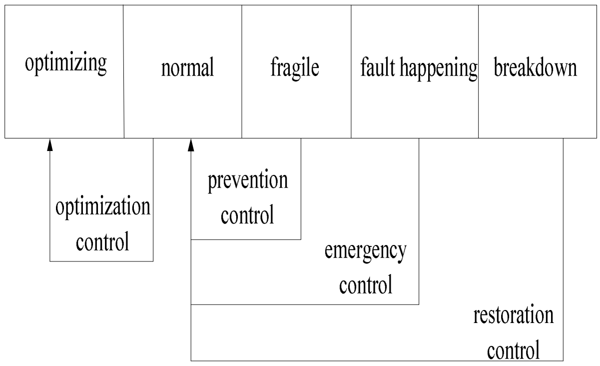

Fig. 1. Corresponding relations between running status and self-healing control

II. Technical Work Preparation

A Distribution network breakdown restoration mathematical model.

The breakdown restoration mathematical model comprises of restoration target and constraint conditions, in practice, it may be in the form of different mathematical expression according to different restoration purpose and emphasis.

Breakdown restoration target function:

1) Recover lost load as many as possible:

$$\min \sum_{i \in N_{cut}} I_i \quad N_{cut} \in N_{out} \qquad (1)$$

2) Recover important load first:

$$\max \sum_{i \in N_Z} I_i \quad N_Z \in N_{out} \qquad (2)$$

In two formulas above, I_i stands for load current on branch i ; N_{out} stands for all lost load nodes; N_{cut} stands for load nodes which need to cut; N_Z stands for higher priority load nodes.

3) Switch operation as little as possible:

$$\min \sum_{i=1}^{N_{sw}} x_i \qquad (3)$$

N_{SW} stands for the switch number to be considered in restoration process; x_i stands for the state change of switch i, if the value is 1, it means the switch has changed its state; otherwise the value is 0.

Breakdown restoration algorithm constraint conditions:

1) Branch capacity constraint: $S_i \leq S_{i\max}$;

$S_{i\max}$ stands for the maximum power allowed of each branch;

2) Node voltage constraint: $V_{i\min} \le V_i \le V_{i\max}$;

$V_{i\min}$ and $V_{i\max}$ stand for the lower and upper limit of the node voltages;

3) The network topology constraint: When system has been recovered, the structure of distribution network should keep radial, it does not allow to form a ring structure.

B Breakdown restoration based on heuristic search

Power supply restoration is a nonlinear optimization problem with multiple targets and multiple constraint, and the scale of this problem will expand with the scale of distribution network. Using exhaustively way may bring a combination explosion problem. Relatively speaking, heuristic algorithm is more agile, faster and has better adaptability. The heuristic rules fuse the professional knowledge, which can help to reduce search area and avoid blind search, to get solutions of problem.

The essence of restoration is reconstruction after fault happened. The principal aim of breakdown restoration is supply power to load that lost electric as much as possible, and the second aim is considering frequency of switch action. If there are more than one lose electric area, these areas will arrange their recovery order according to their amount of lose electric load. Get rid of those switch which cannot meet the radial topology constraints, and only consider those one end connected directly to restore the area, and the other end connected to normal power feeder. This consideration can satisfy the requirement that contact switch limited number, and greatly reduce the search space, also reduced the switch of combination of space dimension. On this basis every switch which found to meet the requirements should calculate the flow to check this recovery plan whether or not can meet the node voltage and branch current constraint. If the current and voltage both break their limit happening at the same time, preferred to deal with the current. This paper proposes a fast heuristic search restoration strategy for the purpose of maximizing restoration lost load. By this strategy the restoration process has been divided into five steps: self-support feeder restoration, whole area restoration, partition restoration, transfer load by lower level feeder and cut load. Set up the relevant constraints and consider the priority of load at the same time. Algorithm process is shown in Fig. 2.

Due to the known state of the system fault and the failure quarantined. Firstly, algorithm according to the calculation results records the initial information and switch state before recovery, and the recovery order of lose electric area based on considering importance and amount of the lose electric load. For each fault zone, self-support feeder recovery is the best and first option to consider. When the self-support feeder can't realize the recovery of power supply, based on the number of switch operations to consider, closed a suitable tie switch to realize the whole area recovery. If the support-feeder appears the situation of current or voltage break their limit, we will find another tie switch to proceed partitioning recovery operation. If partitioning recovery operation strategy also cannot achieve lose electric region recovery, it will need to divert the normal load to lower level in order to increase their own space capacity for finding more recovery of the partition way recovery path;

When all possible recovery plan has been search ended, and still has the more limited situation cannot restore,it will arrange their recovery order according to their amount of lose electric load and cut load processing, as a final recovery plan.

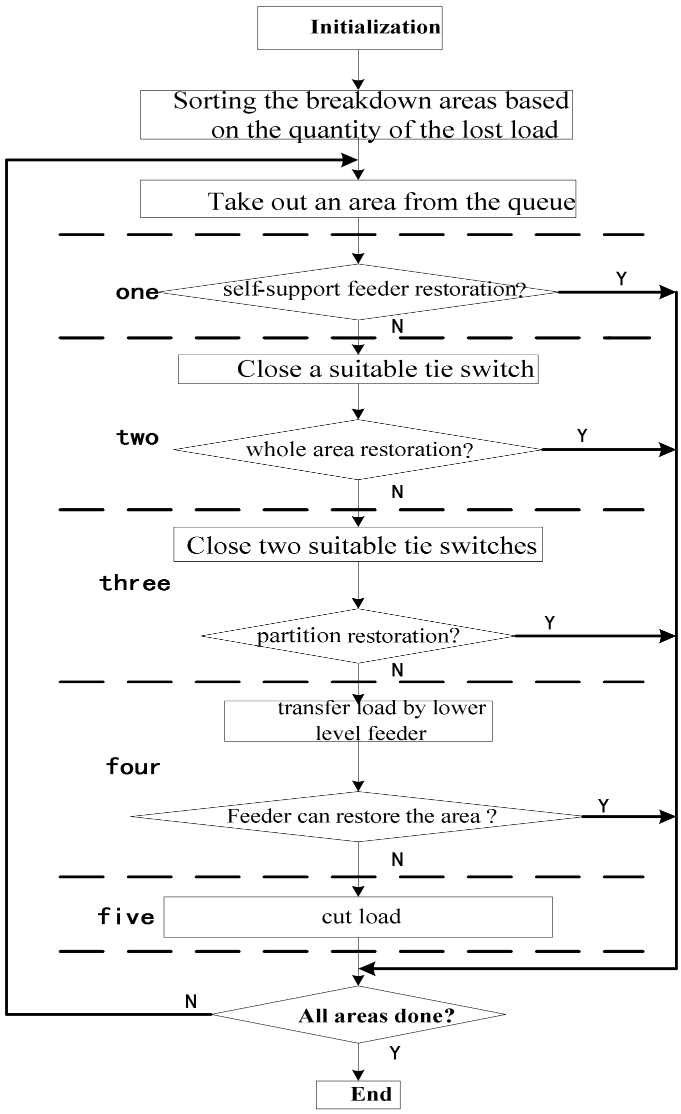

Fig. 2. Algorithm flow chart

C Multi-objective fuzzy evaluation

There are too many branches in distribution network, which makes it's structure complicated. Usually through calculation we can get more than one restoration solutions, if we provide them all to system dispatcher, it could be difficult to make a optimal choice according to personal experience or historical data. In this situation, this paper introduces four evaluation indexes include the maximum number of switch action, margin capacity of feeder, load transferred from normal area, the maximum load rate of feeder. Use (4) to calculation:

$$f = \max(W_{SN}\mu(SN) + W_{MLR}\mu(MLR) + W_{LT}\mu(LT) + W_{M/L}\mu(M/L)) \quad (4)$$

we can consider the plan with the largest value as the final restoration solution.

III. CALCULATION EXAMPLE

Use Digsilent simulation software build a 32 nodes simulation example (Fig. 3). This power supply system consists of 4 power feeders, 32 nodes, 3 tie switches and 28 section switches.

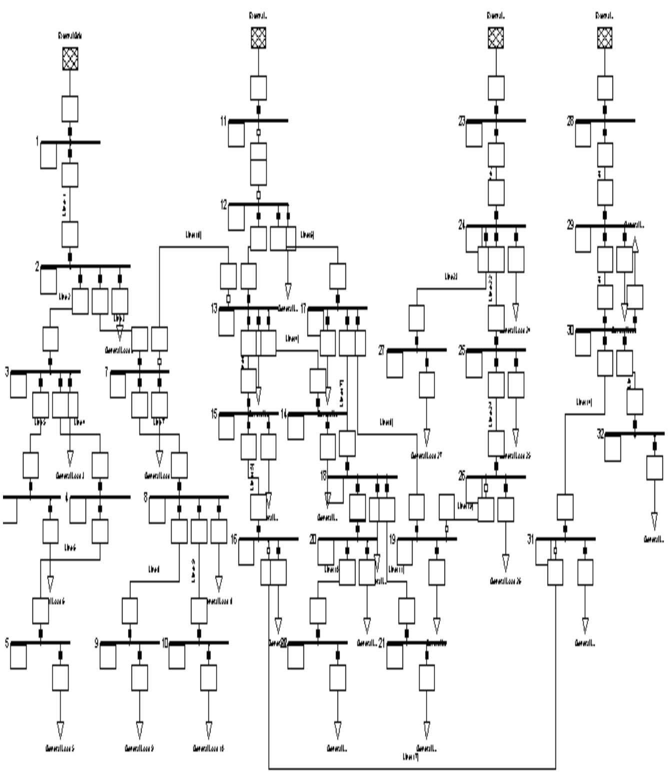

Fig. 3 32 nodes calculation example

When a malfunction happened between node 11 and node 12, system will locate the fault and open section switch 11-12.The malfunction caused downstream branch {12-13，12-17，13-14，13-15，15-16，17-18，17-19，18-20，18-21，20-22}composition area as a electric lose area.

it is known that switches directly connected electric lose area are TS7-13, TS16-31 and TS19-26,and sort them according to the space capacity as follow: $I_{M7-13} > I_{M16-31} > I_{M19-26}$. It's only value of I_{M7-13} greater than I_{loss} through calculation. Close switch TS7-13 to restore the area, and form the initial solution. Switch operation is comparable only under certain condition that less than three times. Realizable recovery solution set according to initial solution and their switch combination and fuzzy appraisal value are shown below：

Plan	Switch action		Evaluation indexes				Evaluation result
	close	open	$\mu(SN)$	$\mu(MLR)$	$\mu(LT)$	$\mu(M/L)$	
1	TS7-13	-	1	0.554	1	0.793	0.887
2	TS7-13,TS19-26	SS12-17	0.667	0.914	1	0.993	0.894
3	TS7-13,TS16-31	SS13-15	0.667	0.894	1	0.983	0.886
4	TS7-13,TS19-26 And TS16-31	SS12-17 SS13-15	0.667	1	1	1	0.867

Tab.1 Scheme evaluation results

can be tell from the table ,plan 2 has the highest value and it should be chosen to restore the supply power.

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