Power Distribution Grid Service Restoration Software Based on Load Balancing

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Abstract—After power distribution feeder fault, it is required to identify fault section, isolate the fault quickly, and then to restore the power supply of the non fault section. To solve the problem of power supply recovery of multi linked lines, the design of the software of distribution network fault recovery is proposed in order to solve the problem of distribution line load balance. In the heuristic search process, each level of linked feeder is the target of the load balance of the expected value, and gradually increases the non fault section to form the final fault recovery scheme. Automated services restoration software obtains the distribution operation data from distribution automation system and the feeder parameters data get from grid production management system. And the software realizes some functions include: on-line calculation load balancing of relevant fault area, put forward fault recovery scheme for distribution operators. The application results show that researchers proposed a variety of fault recovery strategies, aiming at the characteristics of high power distribution network, and generate fault recovery scheme rapidly.

Keywords-Services Restoration; Power Distribution Grid; Load Balancing; Power Distribution Fault; Software Design

I. INTRODUCTION

Electric power distribution network is the key to the custom in the power system as well as the key to improve the quality of power supply. According to the statistics [1-3], more than 80% power supply failure interruptions are caused by the distribution network. To improve distribution system reliability by identifying faults rapidly, responding to isolate the faults, and taking a broad view of the best method for restoring service to non faulted sections.

Distribution network varies from country to country. The traditional network is simple, and hand in hand is widely used structure [4]. To avoid overloading on the feeder for the transfer of load from one feeder to another, it needs to leave a capacity of 50% as backup. Now most of distribution circuits are multiple sectioned and multiple linked [5-7]. This makes the structure of the distribution network become more complex. Therefore, distribution network power supply service restoration is a multiple target, nonlinear, and multiple constrained optimization problems. Taking the load balancing as the goal, this paper proposes a power supply service restoration method and implements the service restoration method using software.

II. SERVICE RESTORATION ALGORITHM BASED ON LOAD BALANCING

A. High Power Supply Capability Distribution Grid

In China, high power supply capability distribution networks are multiple segments and multiple contact, multiple works and one backup. According the number of sectioned and linked, the structure of distribution grid is divided into two sectioned two linked, three sectioned and three linked, six sectioned and three linked, etc. And three sectioned and three linked feeder (Fig. 1), three worked and one standby (Fig. 2) are the widely used connection mode. The structure of high power supply capability distribution grid is complex. After fault isolation, it is a complex problem that how to quickly restore power supply to the load of the faulty section and avoid overload operation. Reference [8], a method based on the rules of minimizing the load degree of the power supply path is proposed after studying the characteristics of the distribution network.

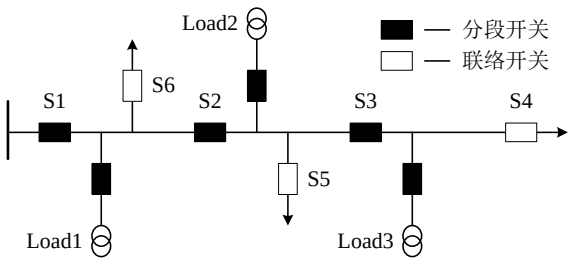

Figure 1. Three sectioned and three linked

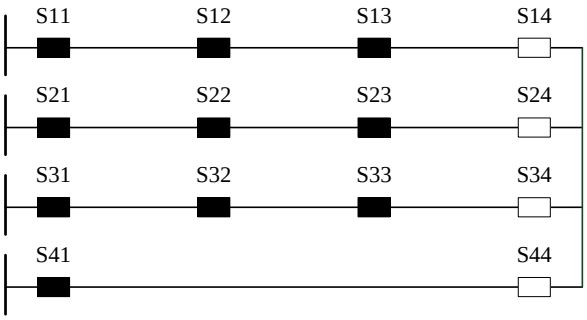

Figure 2. Three worked and one standby

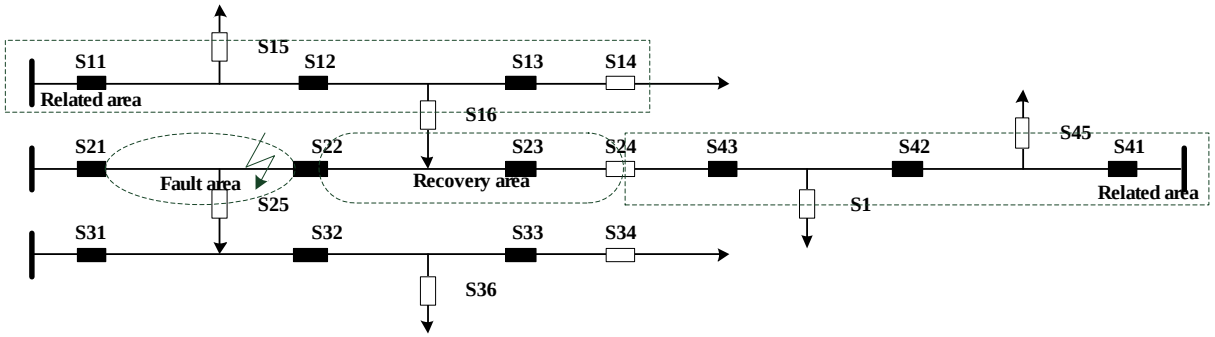

Figure 3. Fault area of three sectioned and three linked

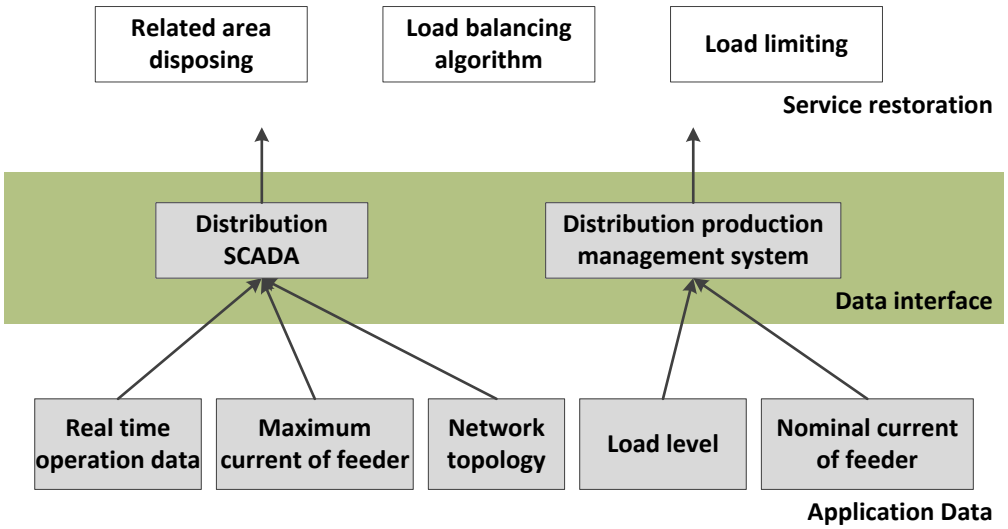

Figure 4. Fault area of three sectioned and three linked

B. Service Restoration Goals.

In order to avoid large area failure interruption, service restoration should make ensure have enough backup capacity. And the load balancing of a feeder is an important index. The goals of the service recovery for the distribution grid are:

a) Restore power supply as much as possible;

b) Various load levels should be treated differently and the important load should recovery first;

c) The feeder load balance and no overload feeder.

C. Load Balance Expectation

As showed in Fig. 3, the short-circuit fault is between switches S21 and S22. So, the recovery area is downstream of the fault from switch S22 to S24. The related area is connected with the recovery area with the switch as from S11 to S14 and S43 to S41.

Load balance is the load factor of the related area equal, and the ideal load factor is the expectation value of load balance. The load factor is the ratio of the average load over the peak load (normally the maximum demand). Load factor is normally found from the total energy used (kilowatt-hours) as equation 1. If there are in multiple linked switches with the restoration of power supply, it is necessary to fully consider the load balancing and to ensure no overload feeder.

$$LF = \frac{kWh}{d_{kw} * h} \quad (1)$$

where

LF =	Load Factor
kWh =	energy use in kilowatt-hours
dkw =	peak demand in kilowatts
h =	number of hours during the time period

D. Search algorithm based on load balancing algorithm

The algorithm is based on the main correlation area and sub correlation area to achieve the power supply recovery of the lost power load. If the standby capacity of the main related area is insufficient, the partial load of the first level contact feeder is transferred to the two level of the sub related area. Then the main fault recovery area of the main fault recovery area all the electricity load, if there is an overload, the over load control operation. The steps of the algorithm are as follows:

a) Determine the fault recovery area and its main related areas and sub related areas.

b) Obtain the maximum load of each feeder.

c) Determine whether the main relevant area of reserve capacity is adequate. If insufficient, then carry out the relevant area load transfer; If adequate, then directly to the main related zone fault recovery.

d) Sub correlation zone load transfer strategy.

e) Fault recovery strategy for the main correlation zone.

f) Overload check: If exist overload schema, then carried out that the overload control strategy; If does not exist overload, then end of the algorithm.

g) Carry out overload control strategy.

h) Fault recovery scheme end.

E. Overload Control and Optimization Strategy

When calculating the main related fault recovery area, it is necessary to determine whether the first level linked to the feeder overload or not. If the feeder overload loads reject directly, it may cause unnecessary power outages. Overload control and optimization strategy for overload circuit local fine-tuning, near to see whether there is a primary contact feeder for capacity, specific steps are as follows:

a) Select the most serious one level contact feeder as the overload control feeder.

b) In the premise of ensuring the maximum load section of the belt, the priority will be to get rid of the loss of the electric section (priority) of the other part of the linked feeder. The load distribution of the feeder is accomplished, and the next overload control strategy is no longer considered. The first level contact feeder and the assigned section are not considered.

c) Get rid of the segment as a new fault recovery area, and see if connected with primary contact feeder is still turned to capacity. If any, they are specified in the relevant area of main bidirectional search algorithm to calculate the load distribution.

d) Select new overload control feeder, and repeat the above operation, until the related area of all main linked feeder not overload.

III. DISTRIBUTION GRID SERVICE RESTORATION SOFTWARE

A. Software Structure

The software architecture of distribution grid service restoration is shown as Fig. 4. The software system divides into the two parts: data interface and service restoration strategy. The fault restoration software gets the real-time operational data, network topology data, feeder historical data from distribution automation system. And it gets customer important level, nominal feeder data from distribution network production management system (DPMS). Using the distribution network topology, the restoration software calculates the related area, and then uses load balancing, load limiting to propose the service restoration strategy.

B. Data Source and Interface.

The restoration software should get operation data, topology data, and load importance level data as below.

C. Real time operation data.

The distribution operation data such as voltage, current, switch status are in distribution supervisory control and data acquisition (SCADA) system and common information model (CIM) based on IEC 61968/61970 is used. So the operation data can be retrieved via the data bus [9-10].

D. Historical statistics operation data.

Historical statistics operational data such as maximum current of the feeders are also needed. The historical data are calculated and saved in distribution SCADA system historical database.

E. Nominal data of feeders.

Nominal currents of the feeders are often stored in the distribution production management system (DPMS) database. When restoration software needs to calculate the feeder load rate and load balance expectations, it can get the data from the DPMS database.

F. Network Topology.

Distribution network topology is modified with the switch position closed or open. To calculate the related feeder section, the network topology before and after failure are also needed. This can get from distribution SCADA system via an information bus [11-12].

G. Load importance level.

The customer (load) importance level is saved in the DPMS database. When overload, the lower level loads are often discarding to reduce load.

IV. SOFTWARE IMPLEMENTATION

The software is divided in four parts: the main function, relates area disposing, load balancing, and load limiting.

A. Main function.

The main function as shown in Fig. 5 includes six steps:

a) Calculate the recovery area and related area;

b) Get operation data of the recovery area and related area from SCADA;

c) Aim to the related area load balance, and propose the service restoration plan;

d) Determine the overload;

e) Discard load for overload feeders and fix the restoration plan;

f) Propose the service restoration plan.

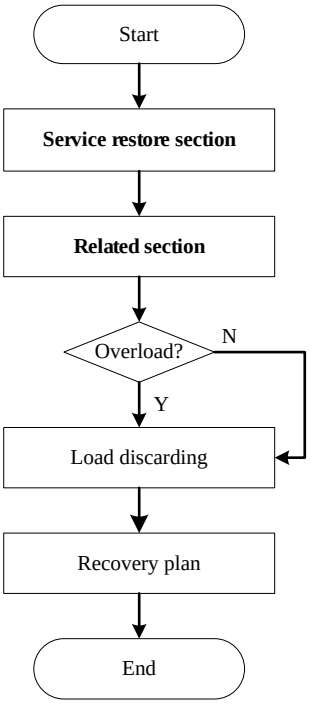

Figure 5. Fault area of three sectioned and three linked

B. Relate area disposing.

Related area search algorithm includes the following steps:

a) Determine the main line and branch line, including multiple branch linked switch, take the largest spare capacity linked switch to participate in the calculation;

b) Calculate the related area load balanced expectation;

c) Use load balancing algorithm to propose a recovery plan.

C. Load balancing

Determination of main feeder

The two switche having the biggest spare capacity are selected as the starting node and the end node, and then form the main feeder.

Branch line treatment strategy

After determining the main feeder, the line may have many branches, the calculation of the branch line is parallel, and the branch is not affected by each other.

a) If there is no linked switch on the branch, the total load of the branch shall be equivalent to that of the main road connecting the main road;

b) If there is one linked switch for the branch connection, link this switch to the main feeder of the main feeder in order to achieve the desired value or search to the main feeder. If the desired value represents the contact switch assignment complete, residual section according to (a) equivalent to the main feeder; If the search to the trunk line has not yet reached the expected value, the branch distribution of contact switch, then the virtual is directly connected with the main feeder virtual linked switch.

c) If there is a plurality of contact switches in the branch, the linked switch, which is the largest of the standby capacity, is selected as the branch, and is processed in accordance with (b).

D. Main Feeder processing strategy

After the completion of the branch, the line is only the main line, and no branch of the trunk line. The main line of the relevant area is the contact switch.

a) Calculate the expected value of load balance.

b) The search for a non fault section of the fault is carried out from the starting node along the main line to the desired value.

c) An increase in the non distribution section is in turn until the most recent value is reached, or the search for the section is connected with other contact switches.

d) If achieve the desired value of search and other contact switch connected section, to determine the size of the contact switch now (sections) spare capacity and the section of the connection contact switch spare capacity: if the contact switch spare capacity big, the segment is connected contact switch rounding, does not participate in the fault recovery, skip to Step f); otherwise, the contact switch no longer increases with contact switch is connected with the section, the section assignment complete, section is connected contact switch as a new starting point, skip to Step f).

e) If you meet the expectations, said the contact switch assignment complete, will complete the assignment of this contact switch and a contact switch between residual section (unallocated portions) equivalent to a contact switch connected segments, as a new starting point, jump to step f).

f) The remaining blocks are allocated to the last contact switch, the end of the algorithm.

E. Load Discarding.

Using the service recovery plan proposed by section C, backup feeders may be overloaded. To avoid overloading, load limiting is needed. If overload, some load should be ruled out. The software determines the load before failure on the restore area, and then compares that load with the spare capacity on backup feeders. If the capacity is large enough, then the recovery plan is OK. If capacity is not enough, then some load on the lower important level should be discarded, and the recovery plan is OK.

V. CASE STUDY

The software is implementation based on KH-8000 distribution SCADA system. KH-8000 distribution automation master station system uses the open, distributed architecture, and Client/Server mode. And it has SCADA, feeder automation, and fault information management functions. The load balancing service restoration is an application module based on KH-8000. The service restoration software gets operation data from KH-8000 SCADA, and gets feeder information from GPMS system. It proposes the service restoration plan for KH-8000, and show on the man-machine interface distribution operator personnel.

VI. CONCLUSIONS

To avoid overloading, this paper proposes a service restoration method based on load balancing and service restoration software is realizing. The implementation instance shows the load balancing service restoration method is effective to avoid overloading.

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