정전 구역 분할에 의한 배전 계통 복구

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SERVICE RESTORATION OF POWER DISTRIBUTION SYSTEMS BASED ON GROUPING

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Abstract: In an automated power distribution systems, the fault situation is controlled from the control center through remotely-controlled sectionalizing switches. In this paper, the service restoration strategy which can yield the minimal switching actions and constraint checking is proposed and an expert system which generates the appropriate switching actions is described.

Introduction

The service restoration deals with the emergency situation (mainly power outage) following a fault on the feeder. Since the problem deals with determination of ON/OFF status of switches, it has a combinatorial nature and requires a discrete search technique to be solved. The solution search space becomes huge as the number of switches becomes large. Operators rely on their empirical knowledge on the system topology, load priority, system status, characteristic of various devices, operating constraints, etc. to come up with a feasible restoration plan. The process generally involves grouping of customers so that they can be picked up by the backup feeders. There have been two approaches - heuristic algorithm approach [1] and expert system approach [2] - for the service restoration. In the former approach, the search space is reduced to the one with the manageable size using heuristic information as a search guide. The latter approach utilizes the heuristic knowledge by storing them in the knowledgebase explicitly and separating the processing mechanism i.e., inference engine. It has advantage over the former approach in those problem whose solution process requires a large quantity of independent knowledge and less quantity of the procedural knowledge. An expert system approach, we believe, is more suitable for the problem on hand since there exists a fairly good quantity of knowledge of good quality and analysis of the problem would easily reveal the fact that the logical search knowledge forms the majority of those knowledge and also the expert system approach has a higher adaptability to the real systems than the conventional algorithmic approach.

Grouping Strategy

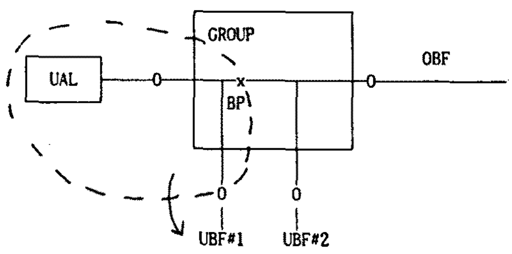
Two most critical factors in the restoration plan is the speed and the reliability of the switching actions. In order to secure those factors, the number of the operating constraint checking as well as the number of switching actions should be minimized. It is worth noticing that the number of groups dividing the outage region is the key factor. Discussions with operators and the thorough study on the distribution feeder systems have revealed that the network pattern recognized by operators during the planning process directs identification of the appropriate neighboring backup feeders and the load assignment. In most cases, the resulting control actions are quite faithful to the above-mentioned two conditions. Analysing the discussions with operators, the new grouping strategy which consists of four major steps - single grouping, multi-grouping, group modification, switching sequence - is proposed.

Single Grouping: The single grouping stage looks for the backup feeder (referred to as BF afterwards) which has enough margin for the whole outage load. It is not unusual to have such a BF in the real systems since under the current operating environment, it is a common practice to have about 50 % loading for each feeder which makes the restoration fairy easy in case of emergency.

Multi-Grouping: If there is no such BF, then whole outage region is divided into groups of zones based on the information on the BF margin, branch points, number of tie switches. To be more specific, it starts with assigning close loads to the largest margin BF. Once the group is formed, then the next largest margin BF is tried for another grouping. While assigning loads to the selected BF, if the branch point is encountered (Fig. 2), the branch load with less number of tie switches are to be assigned first. This can find its justification from the fact that more tie switches imply the better chance of restoration. In case of same number of tie switches, one with smaller loads will be included. If branch with no tie switch can not be included into the group, then grouping will be terminated at the branch point so that other branch may attempt to include it.

Group Modification: If any zones in the outage region (referred to as UAL) can not be assigned a group, then constructed groups will be modified so that no outage zone remains unassigned. For this the group adjacent to UAL is divided into two based on the branch point pattern and BFs unused for grouping (UBF) so that one of them can include UAL. This job consists of four steps - below branch separation, branch separation, branch transfer, forced grouping.

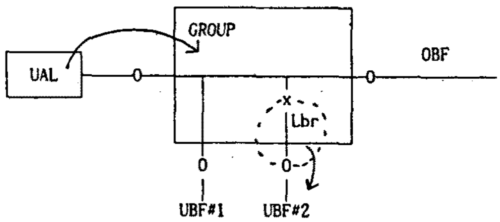
Below Branch Point Separation: Among UBFs in the adjacent group, one which is closer to UAL and has enough margin for loads below the branch point including UAL is selected and a new group with loads below the branch point and UAL will be formed and the original group is to be reduced (Fig. 1). Here OBF denotes BF to which the group has been assigned.



M(UF#1) > UAL + Below BP Load.

Fig. 1 Modification by Below BP Separation

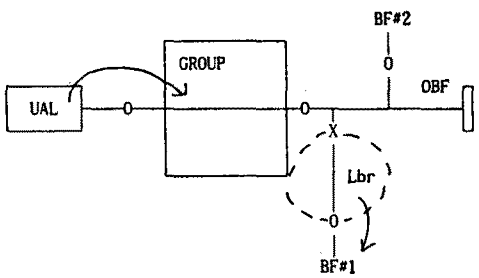
Branch Separation: A UBF with enough margin for the branch load which is bigger than UAL is selected and a new group with the branch loads will be formed and the original group is to be reduced (Fig. 2).



M(UBF#2) > Lbr (Branch Load)

Fig. 2 Modification by Branch Separation

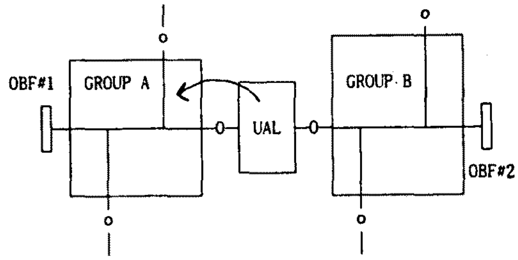
Branch Transfer: A branch belonging to OBF is to be transferred to its neighboring backup feeder in order to make margin in OBF to cover UAL. Then UAL will be included into the original group (Fig. 3).



M(BF#1) > Lbr (Branch Load)

Fig. 3 Modification by Branch Transfer

Forced Assignment: UAL is to be put into its adjacent group which would have the less severe overloading (Fig. 4).



R1 < R2 Ri: OVERLOADING RATIO OF OBF i

Fig. 4 Modification by Forced Assignment

Switching Sequence

Once the service restoration plan is determined, the proper switching sequence is to be generated following the switching principle and operating characteristic of switches. The switching principle can be summarized by "close-before-open" rule for the live load transfer and "open-before-close" rule for outage load switching.

Expert System Development

A rule-based expert system which implements the above-explained strategy has been developed using PROLOG and C. It has the capability of identifying the necessary switches for the fault isolation and deciding whether the tripped circuit breaker can be reclosed and generating the appropriate switching sequence for whole restoration process. As shown in Fig. 5, its basic structure has three major parts - database, knowledge-base, inference engine.

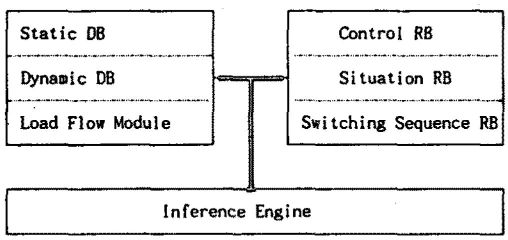


Fig. 5 Service Restoration Expert System Structure

Database

The database consists of the static and dynamic databases. The static database contains data that are independent of the current operating status such as system topology, installation capacity, line impedance while the dynamic database contains time-varying data such as switch status, voltage, current loading, etc.. For representation of those data, basically the frame is used since it provide the efficient way for representing the tabularized information.

Knowledge-Base

The service restoration strategy has been formulated into two kinds of rules: about 15 control rules and 40 situation rules. The former determines what to do next when no situation rule can be applied during the reasoning process. The latter corresponds to the heuristic rules which directs the detailed jobs in each step. Rules are stored in the knowledgebase in the form of the if-then production rule in the form of control_rule(Reference#, Conditions, Actions) and situation_rule(Reference#, Conditions, Actions). Note Reference# given to each rule is introduced for rule tracing.

Inference Engine (IE)

Since the inference mechanism provided by PROLOG is very limited to the backward chaining system and the problem on hand requires the forward chaining, the inference engine shown in Fig. 6 has been designed using the built-in pattern matching and backtracking schemes.

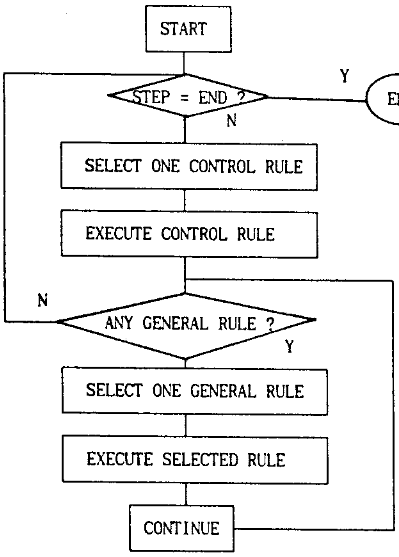


Fig. 6 Inference Flow

Test Results

The developed system has been tested on the real systems shown in Fig. 7 [2] which has six feeders with 43 zones and 43 sectionalizing switches.

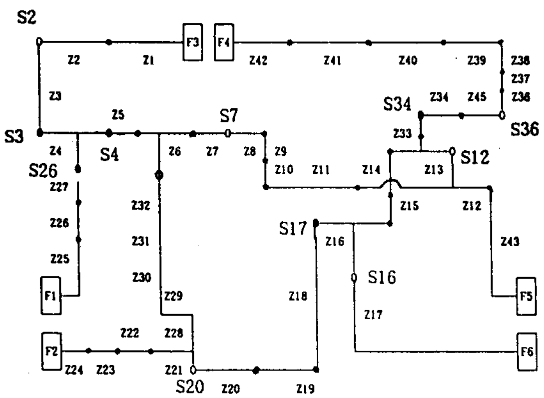


Fig. 7 Example System

case	fault	outage zones	grouping	switching sequence
1	z4	{z3, z5, z6, z7}	{z3} {z5, z6, z7}	open: {s3, s4, s26} close {s2, s7}
2	z17	{z20, z19, z18, z16, z15, z14, z13, z33, z34, z35}	{z33, z13, z14, z15, z16} {z20, z19, z18} {z34, z35}	open {s16, s17, s34} close {s36, s12, 20}

CASE 1 shows the successful application of the multi-grouping, i.e., starting from the largest margin BF, F5, one group of (z7, z6, z5) is formed and then with F3, another group of (z3) is constructed. CASE 2 gives an example of the group modification through the branch separation. Two BFs, F5, F2, according to the multi-grouping strategy, have formed two groups of (z13, z33, z34, z35, z14) and (z20, z19, z18) respectively leaving (z16, z15) unassigned. In order to handle this UAL, the branch of (z34, z35) is moved to BF F4 forming a new group and UAL of (Z16, z15) is assigned to F5 completing the grouping. In both cases, since no load transfer is involved, only the outage switching principle - "open-befor-close" is applied.

Conclusion

One of the most important function in the distribution automation, the service restoration problem is dealt with in this paper. The service restoration strategy consisting of single grouping, multi-grouping, group modification is proposed and an expert system which can come up with a switching control plan to put the system back into service is described. The developed system has shown a satisfactory performance in various operating situations. However it need expansion of the knowledge-base to cover the worst case in which the constraint violation occurs. Moreover, various S/W and H/W issues for integration into the control center should be resolved for the real system application.

References

[1] K. Aoki, K. Nara, M. Itoh, T. Satoh, H. Kuwabara, "A New Algorithm for Service Restoration in Distribution Systems", IEEE Tr. Power Delivery, Vol.4, No.3, July 1989.
[2] C.C. Liu, S.J. Lee, S.S. Venkata, "An Expert System Operational Aid for Restoration and Loss Reduction of Distribution Systems", IEEE Tr. Power Systems, Vol.3, No.2, May 1988.
[3] S.Kato, T.Naito, H.Kohno and et. al, "Computer-Based Distribution Automation", Proc. IEEE 1985 PICA Conference, pp. 374-380.