Efficient Algorithms for Distribution Networks Switching Plans

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Abstract: - Distribution control systems are normally managed by experienced control engineers who manage the different switching operations in order to isolate one or more stations for maintenance or for repairing faults. Whenever a fault takes place, these engineers have to quickly prepare a switching plan to isolate a station or a complete circuit which is a very logically complex task due to the complexity of current and voltage flow and the challenging task of ensuring the minimum disturbance to the current supply to the customers. The distribution network is a very dynamic environment of changing circuits and flow and contains thousands of substations, switching stations, feeders, poles, switches, circuit breakers and cables. Preparing a switching plan requires knowledge of the up-to-date network. The switching plan is normally prepared manually and can take from a few minutes to a few hours to complete in order to reduce risk to field workers and to minimize the supply disturbance. In this paper, we have analyzed the switching plans mechanism and developed a number of algorithms to help the control engineers prepare switching plans quickly and put them to action. Our method not only ensures that the disturbance of the supply to customers is reduced but also minimizes the risk to the filed engineers. In this paper, we show only a sample of the many automatically prepared switching plans which have been tested and proven.

Key-Words: - Switching Plans, Distribution Network; Distribution Control Center; Control Engineering, Algorithms

1 Introduction

The Distribution Network System is a collection of electrical circuits consisting of tens of primary stations (feeders), thousands of substations (distribution), hundreds of switching stations and thousands of overhead poles all linked via switches and cables, see Fig. 1. Overhead poles contain special switching devices such as jumpers and fuses. Stations are linked to each other through switches, which are fixed in the stations. Every station may contain one or more switches and has one or more bus-bars, where every bus-bar can be considered as a station by itself. Primary stations are the sources that feed other stations, except in some rare situations where they act as a switching device. Substations are the stations that are fed by primary stations. Switches on primary stations are called circuit breakers. All connecting stations linked to a circuit breaker represent an electrical circuit. Electrical circuits form the Electrical Distribution Network, see Fig. 1.

For many years the attention researchers was directed to generation and transmission systems rather than to distribution networks [15]. This was due to the complexity and challenges of the problems associated with those systems as well as the very high investment, operating and outage costs of almost any unit in those networks. In addition, possible outages in generation and transmission systems can affect huge numbers of customers. It should also be noted that the solutions produced for generation and transmission systems often cannot be directly applied to distribution systems.

Although the elements of distribution networks do not cost as much as the elements in generation and transmission networks, distribution networks have a very large number of elements which can run into tens of thousands. The complexity of the distribution networks as well as the capability of facilities for operating these networks have increased considerably in recent years.

The problem of fault restoration in distribution systems is a dynamic combinatorial problem [1], [2], [8] & [14]. The problem is in finding both (1) an admissible post-fault configuration and (2) the sequence of switching operations to reach such configuration [1], [2], [9], [12] & [13]. Research on the problem solution has been focusing on the search for admissible post-fault configurations; the sequencing of switching operations is usually disregarded. However, the sequencing of switching operations determines the admissibility of the intermediate configurations and therefore the effectiveness of the overall restoration plan. The problem of fault restoration in distribution systems was addressed in [3] in a two phase approach. In the first phase a network optimization evolutionary approach is proposed to find the optimal post-fault configuration. In the second phase a dynamic programming approach is proposed to determine the optimal sequence of switching operations.

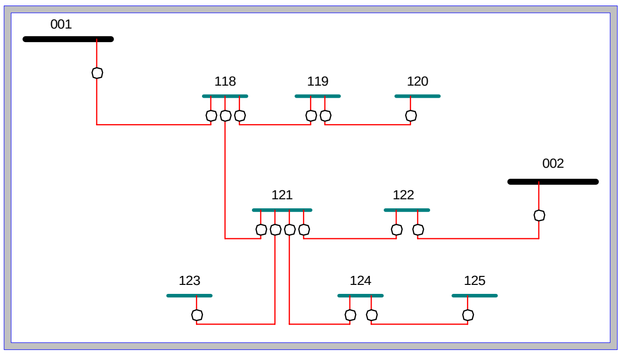

Fig. 1: A sample of a distribution network

Power supply cuts to customers are the most serious failure of power system functions [8]. The damage caused by system outages has serious consequences for both customers and utilities. Following an outage resulting from a fault or an overloaded network element, control engineers have the difficult task of restoring power to customers in the most efficient way. The main aim is to produce an efficient network restoration solution and to prepare such solutions to aid control operators who are short of experience in coping with outages [1], [5], [6], [13], [14] & [16]. Pre-prepared switching plans scenarios depend on assumed input data in terms of the potential and actual network topology/configuration and loads. Distribution networks are dynamic in two ways and this data input can easily seriously mismatch the real data at the time the problem occurs: (i) loads are constantly changing and the actual network topology changes almost each hour; (ii) even potential network topology changes in terms of introducing new and withdrawing old network elements. Therefore, control operators are faced with a formidable task in analyzing and readjusting the pre-prepared solutions. This could often be a task of the same degree of difficulty as finding an original solution. All these tasks have to be conducted under the pressure of an actual emergency. It is these difficulties and risks that have prompted researchers to research into methods and systems to support the control engineers [1], [2], [3], [4], [5], [6], [7], [9], [10], [11], [15] & [16].

We have surveyed and reviewed all published algorithms and systems for distribution network restorations. A number of researchers have proposed systems and algorithms for these tasks. The proposed algorithms and systems from the nineties till recently have not presented solid solutions for real life problems and demonstrated their benefits. Our approach has built in intelligence in that it studies the current connectivity and flow of power and automatically derives an efficient switching plan which will list the exact steps the control engineer has to follow in order to carry out the necessary tasks such as isolating a station or a cable and all the other tasks necessary to restore the system. Our approach guarantees that the switching plan is presented as a series of sequential steps which can be followed by the engineer. The system develops the switching plan based on the live data from the network and hence there is no danger of having conflicting states of switches or flow which might cause death or injury to the field workers. It goes without saying that the issue of safety to the field engineers and to the network as well as the speedy restoration of the network is top on the agenda and thus were considered in the design of the algorithms. We have tested the system in a real life situation and proved that it can be trusted and used in a real live network.

One major achievement of our algorithms is that they are not restricted to one type of circuits, but rather applies to a variety of distributions circuits consisting of substations, switches, cables, poles, transformers and feeders. The flow of the power and rerouting the flow is part of our system but is outside the scope of this paper.

2 Distribution Networks Switching Plans

The **E**lectrical **D**istribution **N**etwork **S**ystem is a large and complex system. It contains thousands of devices and can cover several thousands of square kilometers. To operate in such environment, the operator needs to get quick, reliable and detailed information about any area of this large system. Further, in some cases such as in the case of failures, the engineer must develop a quick switching plan to isolate the fault and make another set of connections in order to minimize the effect.

In order for the Control Engineers to carry out their jobs at the control center and process these jobs in the field through field engineers, switching plans must be prepared, checked, edited and then executed. There are different types of switching plans, these include *manual*, *automatic*, and *fault*. A switching plan consists of a number of switching and restoration steps, which handles a wide variety of purposes, e.g., substation maintenance, substation isolation, cable connections, adding new stations, etc. Associated with each switching plan is a number of work authorization procedures aimed at ensuring safety.

2.1 Manual and Automatic Switching Plans

In a **Manual Switching Plan** the control engineer tries to find the best series of steps to perform the required task (isolate a substation, isolate a cable, add a cable, add a substation, etc.) with the minimum effect on the other circuits. First the engineer finds another power source to support the substations and poles affected by the required task. The engineer has to keep in mind that the total load that the new source can offer and the total load required, and that there is no overlap with other switching plans. Further, airports, hospitals, certain factories, police stations, etc must not be affected and thus any switching plan must guarantee that the power to these vital places is maintained. This requirement would necessitate an intelligently developed switching plan involving a number of switching operations.

The next steps before processing a switching plan is checking and approving it. Processing a switching plan required a control engineer, who normally works on three to five switching plans at the same time, communicates with the outside crew through a radio. The field engineers or the outside crew carry out the control engineer orders in the site. Accordingly the control engineer then changes the status of the circuit graphic representation to reflect the real situation.

The main difference between the Manual Switching Plan and the **Automated Switching Plan** is how each of them is created, see Table 1. Both have to be checked and approved before processing, and the sequence of processing is the same for both. Usually manual switching plans require a few days to prepare, where in some situations time is very critical. In such cases an automated switching plan is required since it is fast to create, supposed to handle all the missing points that may be missed by the engineer. Furthermore, it is easy to calculate the total load, mentioning the critical places, and ensuring that there is no overlapping with another switching plan.

	Manual Switching Plan	***Automated Switching Plan***
Method of creation	*Manual*	*Automated*
Speed of creation	*Slow*	*Fast*
Decision support	*No*	*Yes*
Operater	*Expert control engineer*	*Any control engineer*
Human mistakes	*Possible*	*No*
Correction	*May contain some mistakes*	*No mistakes*
Flexibility	*More*	*Not flexible*
Alternative solutions	*Difficult*	*Yes & automatically*

Table 1: A comparison between manual and automatic switching plans

2.2 How to prepare a switching plan

Let's take a simple example as shown in Fig. 2, such as isolating a substation in a sequence of only two switch substations.

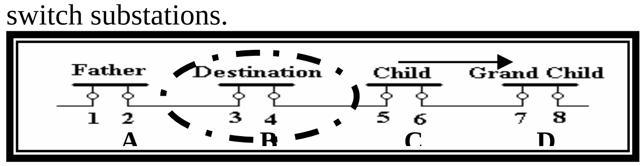

Fig. 2: Isolating a substation

Before isolating the destination substation, a new source must be found in order to counteract the effect of the isolation. This is to be done by finding an open point in the chain of substations supplied from the destination substation B. This open point, once switched to ***on***, must be able to feed ALL the effected substations which will form a dead circuit once the substation B is isolated. In some special cases, searching for open points is not needed. Below is the method which is also illustrated in Algorithm 1 below:

- *Switch no. 1, switch no. 2 or switch no. 3 is* ***off*** *(open), i.e. the destination substation is dead. In this case* *whatever the status of switch 4, or 6 must be switched **off** to ensure that the destination substation will never have the power from the other route.*

- *Switch no. 6 is **off.** In this case the grandchild is fed from the other direction, and thus can supply its father (child substation) with power during the isolating time. Switching no. 6 **on** and switching no. 5 **off** does this.*
- *Switches no. 5, no. 6 or both are **off**, i.e. the child is either out of order or fed from other substation rather than the destination substation, for that no need for further switching.*
- *Switch no. 4 is **off**, in situations like these only switch no.5 has to be switched **off** providing safety for the team working in the destination substation.*
- *In the normal situation, a search for an open point is done. If the open point is connected to a live circuit and can cover the total load resulting as a result of switching the substation off (dead), it has to be closed (switched **on**, causing a parallel situation). The next step is switching no. 5 to **off** position.*
- *Now substation **B** is independent from the rest of network, the final step is to isolate it from its feeder (father switch no. 2), i.e., switches no. 1 and no. 3, no. 2 must be opened.*

Algorithm1

/ Searching sequence */*
Get the destination substation
Find its father
Find its child
If the destination substation is alive then
If its child is alive and fed by it then
Find the open points
Let the user decide the open point to be closed
Switch the chosen open point to off status (close it)
Else
/ Its child either dead or feed from another source rather than destination substation sources. */*
Keep the child as its
Else
/ The destination substation is dead */*
No change
/ Switching sequence */*
If (the destination substation switch in the child substation is not (off or earth status)) then
Switch it off.
If (the destination substation switch in the father substation is not (off or earth status)) then
Switch it off.

Isolating a Substation

One of the complexities of preparing switching plans to isolate a substation is that substations can have 1 or more outlets and thus are connecting to one or more circuits. This means that it can be fed from one or more different circuits and can feed one or more different circuits. The circuits in Fig. 3 shows that the substation to be isolated has three switches, ie, it can be fed from two different circuits or can be used to feed two different circuits. Therefore, when isolating this substation, we need to find supply for the two circuits that are fed from it.

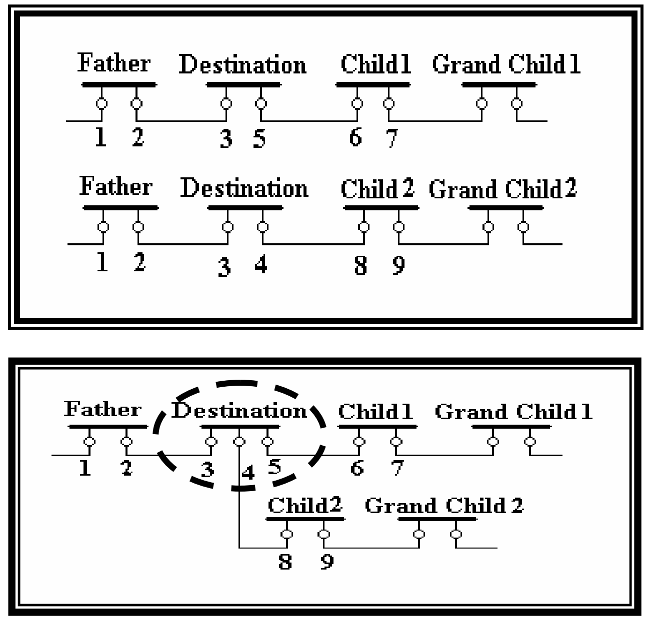

Fig. 3, Case 1: Destination substation has more than two switches.

To isolate the substation encircled in Fig. 3, algorithm 2 below is used.

Algorithm2

Read the starting substation
Get its father
Get its children
Push (children) into child stack1 & child stack2
While not end of substation stack1 do
Pop (child) from child stack1
If the destination substation is alive then
If its child is alive and feed by it then
Find the open points
Let the user choose the open point to be closed
Switch the chosen open point to off status (close it)
Else
/ Its child either dead or feed from another source rather than destination substation sources. */*
Keep the child as its
Else
/ The destination substation is dead */*

No change
End do

/ Switching sequence */*
While not end of child stack2 do
If (the destination substation switch in the child substation is not (off or earth status)) then
Switch it off.
End do
If (the destination substation switch in the father substation is not (off or earth status)) then
Switch it off.

There might be a substation that has more than two switches anywhere in the circuit. This substation can be considered as a father of two, or more, circuits. As a result there will be two or more open points. If this is the case, the user has to be given the authority to choose from a list of the open points found. This case is already covered in the algorithm2.

Isolate a cable

Isolating a cable is not that simple as it seems, many abnormal conditions may arise whilst trying to isolate a cable. Consider the example in Fig. 4.

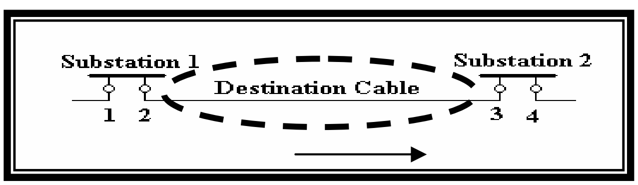

Fig. 4: Case 1: The cable is between two normal substations.

This is a base case which can be used in the other cases. Isolating a cable can simply be implemented as following:

- *Trace to find an open point starting from substation 2.*
- *Close the open point (the circuit now is running in parallel situation).*
- *Open switch no. 3 in substation 2 (switch it **off**).*
- *Open switch no. 2 in substation 1 (destination cable is isolated now).*

The complete algorithm to achieve this task is given in algorithm 3 below:

Algorithm3
/ Searching sequence */*
Get substation one information
If (the substation one is the feeder) / check the SAT_OUT table */*
Then
The head = substation one
The tail =substation two
Find the open point start from the tail
Else
The head = substation two
The tail =substation one
Find the open point start from the tail
If (there is more than one open point)
Then
Show the path for each
Let the user chose the best one to be closed
/ Switching sequence */*
Close the chosen open point
Open the head switch on the tail substation
Open the tail switch on the head substation

Isolate a Group of Substations.

Case 1: group of two switch substations.

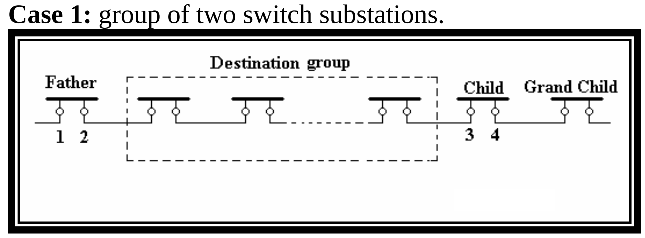

Fig. 5: isolating a group of substations

This condition can be solved by assuming that the destination groups as a single substation (Fig. 5) and treat it as isolating a single substation, i.e., find an open point starting from the child substation, close the open point, and open switches 3 and 2.

Case 2: Destination group contains one or more substations and having more than two switches (see Fig. 6). This situation can be solved in the same way as when isolating the substation given in case 1.

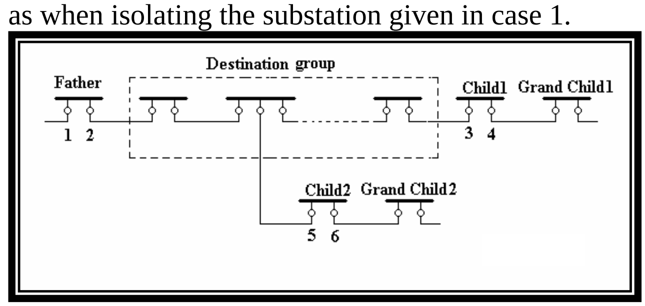

Fig 6: isolating a group of substations with one substation having three switches

4 Conclusions

This paper presented a sample of the algorithms developed for processing distribution networks.

Example switching plans for a variety of operations normally requiring the preparation of a switching plan were presented. We have developed these algorithms for developing automatically generated switching plans which would guarantee speed in dealing with emergency situations in the distribution network and guarantee safety for the field workers, which could be at risk from a human error when the control engineer prepares a manual switching plan.

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