SELF-HEALING NETWORKS PERFORMANCE IMPROVEMENT BY AUTOMATED SWITCHING ALGORITHM

Paul W COX
E.On Central Networks, UK
Paul.Cox@central-networks.co.uk

ABSTRACT

This paper explores a methodology for performing automated switching on high voltage (11kV) distribution networks to restore supplies following fault trips using an algorithmic approach based on real-time tracing and analysis of the electrical network model held in the Network Management System (NMS). The approach offers a number of advantages over local automation and pre-configured switching schemes:

- *A single algorithm to handle any network configuration.*
- *Impervious to network alterations.*
- *Reduced and simplified maintenance overhead of schemes.*
- *Comprehensive checks can be performed against the actual network diagram.*

INTRODUCTION

Distribution Network Operators are always seeking out innovative ideas to improve their performance in respect of Customer Interruptions and Customer Minutes Lost (SAIFI and SAIDI). Investment in automation on the network is one way in which this has been addressed, allowing operators to switch on the network to restore supplies without waiting for field personnel to arrive on site. Use of pre-configured automated switching schemes triggered by the opening of automatic devices allows further improvements in performance but these schemes are generally intolerant of abnormal network running arrangements, limited in the checks that can be performed prior to carrying out switching and dependent on operators manually switching the schemes off to prevent mal-operation. A further consideration is the data maintenance overhead imposed by pre-configured schemes as the network changes.

To address these shortcomings, Central Networks has developed an algorithmic approach to 11kV automation schemes that seeks to reproduce the actions that a control engineer would take when responding to a trip to isolate the fault and restore supplies. A key design aim of this methodology is to restore supplies quickly and reliably, and more rapidly than a human operator would be able to assess the situation and respond. Faster response enables the automated switching algorithm to deliver improved customer service and a tangible benefit to performance as customers tend to be more tolerant of short interruptions and more outages come under the regulatory accounting threshold of three minutes.

DISTRIBUTION NETWORK

To properly understand the described methodology it is necessary to understand a little about the distribution network owned and operated by Central Networks. The distribution network comprises mainly meshed networks at 132kV and 33kV with transformation at primary substations down to 11kV. The 11kV distribution network is generally operated radially from primary source circuit breakers to normal open points. The normal open points provide the capability to interconnect with other circuits to maintain supplies during planned work and restore supplies during faults. Typically a circuit might interconnect with three or four others but the number of interconnections varies across the network. It is the 11kV distribution network that this methodology addresses.

ENVIRONMENT

An important element for effective automation of any electrical network is the availability of all relevant network information in a centralised location. At Central Networks, the Network Management System used for control of the network in the east of the company is GE's ENMAC™ and a project is currently underway to deploy ENMAC™ in the west of the company as well. ENMAC™ provides Central Networks with a fully integrated suite of highly configurable applications covering SCADA, an Electronic Network Diagram, Network Management tools and Outage Management facilities. All the information from these elements – and hence all the information required to manage and control the electrical network in real-time – is stored within ENMAC™ and, crucially to the performance of the 11kV switching algorithm, the information is all linked back to the electricity network model. This includes the state of all switches on the network, all activities and work being carried out on the network and SCADA information. This provides the 11kV switching algorithm with access to the same information as the control engineers have available to them when making decisions about switching on the network. Although ENMAC™ is the NMS of choice for Central Networks, the algorithm described here is not restricted to use within an ENMAC™

environment and could be deployed on any system offering broadly similar facilities.

For completeness, this discussion merits a brief description of the Central Networks SCADA equipment as deployed in the east of the company. For major sites, i.e. grid and primary substations, Central Networks uses Ferranti Mk3 protocol RTUs polled over a private telecommunications network comprising microwave and private wire circuits. Most Pole-Mounted Auto-Reclosing (PMAR) devices are also handled in this environment together with a small number of remote controlled ground mounted 11kV switches in secondary substations. However, the majority of 11kV remote control devices on both the underground and overhead network are connected via GPRS over Vodaphone's wireless network. Rather than polling these devices, they operate in an unsolicited mode whereby changes and alarms are sent immediately to the masterstation without waiting for a request. These devices are contacted periodically (currently every 30 minutes) to prove the connection between the device and masterstation.

ALGORITHM

The heart of the Central Network approach to 11kV automated fault switching is the algorithm and its essentials are reproduced here. Note that most of the checks performed are omitted here for the sake of clarity but they are discussed below.

1. Trace the dead network from the trip device down to open points identifying all SCADA switches.
2. Build a simplified tree model of the affected network comprising only the SCADA devices with the trip device at the root. Other switches are defined as being downstream from the root.
3. Trace from all SCADA controlled open points to their source identifying the cable/line in the circuit with the minimum rating, the source load and the source capacity.
4. Starting at the trip device, work down the tree of SCADA devices to find the most downstream device that passed fault current. This device requires to be opened to isolate the upstream side of the fault. The most downstream device to see fault current could be the trip device itself, in which case it will already be open.
5. If a switch was found in 4, then after it has been successfully opened then the trip device can be reclosed. If the most downstream device was the trip device itself then no action is required at this point.
6. For the device found in 4 (or for the trip device if none was found) find the next downstream devices that are closed (and hence, by definition, that did not pass fault current). These switches require to be opened to isolate the downstream side of the fault.
7. If any switches were found in 6 and there is a further downstream open point, then if the switch was successfully opened the open point can be closed.

At this point, the fault will have been isolated by opening the switches that encompass it and supplies will have been restored to healthy network where possible. It can be seen from this that the algorithm can be divided into two parts. Firstly there is the tracing of the network to gather all available information and reduce it to a relevant subset, and secondly there is the analysis of this data subset to determine the location of the fault and the automated switching to be performed.

In reality, the tracing in steps 4, 5 and 6 is slightly more sophisticated than described and the algorithm is actually capable of handling multiple faults on different legs of a circuit. However, it cannot distinguish nested faults.

Algorithm prerequisites and assumptions

The algorithm has been developed within the constraints of the data available to the NMS in Central Networks. Although some of these conditions could be handled by smarter tracing or analysis, or by changing the network equipment, at present it has been decided to accept them.

They key prerequisites and assumptions made are:

1. A switch can only be a candidate for opening if it has associated fault flow indications. This is required as the algorithm opens switches to isolate the fault so must be able to tell which side of the switch the fault is on.
2. The direction of fault flow must be deducible. Again, the algorithm must be able to tell which side of the switch the fault is on to isolate the fault.
3. A trip caused by SEF will cause the sequence to abort. This is because of issues with SEF grading reliably and the fact that it tends to indicate that conductors are on the ground.
4. Protection operates correctly. A failure may lead to the scheme taking inappropriate action.
5. Fault flow indicators operate correctly. A failure may lead to the scheme taking inappropriate action.
6. SCADA data is up to date and reliable. Again, if the data is not correct then the scheme may take inappropriate action.
7. A fault will always cause at least the closest upstream fault flow indicator to operate.

The first three points are relatively straightforward to detect and handle so don't cause problems. The latter ones are more problematic and ultimately could lead to the scheme reclosing on to a fault. These issues have been considered as acceptable in a risk assessment and the actions taken are actually no different from those a control engineer would take given the same information.

Algorithm Checks

Underpinning the operation of the algorithm are a number of checks that seek to reproduce the response of a control engineer to the same inputs, the majority being performed during the data gathering phase. The checks desired to be made will vary depending on company policies and working practices, so the particular checks performed by Central Networks might not suit all companies and, indeed, within Central Networks they are expected to develop as the availability of data and circumstances dictate. The checks can be categorised as follows:

Network Topology Checks

Checks are performed during the tracing phase to ensure that the circuits involved in any automated sequence switching are topologically configured in a manner that the algorithm can handle. Essentially this means ensuring that the faulted network was being fed radially and that there are no closed loops containing SCADA devices. The principal reason for these checks is that algorithm requires to know the direction of passage of fault current when performing the analysis and this information is not generally available for parallel networks or closed loops. A closed loop in the circuit that contains no SCADA devices is acceptable since the algorithm only requires to know for each SCADA switch whether the fault lies upstream or downstream. Further checks are made of the energisation status of the network affected by the fault and the potential donor circuits to ensure that they are dead or energised as appropriate. The scheme will abort if topology problems are detected.

Central Networks has also elected to perform parallel checks on the donor circuits, primarily because such a situation is generally transient and hence implies ongoing switching activity on the donor circuit that may invalidate further checks, particularly load and rating checks.

Work and Activity Checks

Since the trace is being performed against the NMS network model, all work and safety documents logged against the network are available for checking during the tracing phase. The presence of such items as delegated field control, live-line work and proximity dressings and instructed operations awaiting confirmation will cause the scheme to abort. The reasons for this are to protect people working on or near the network who might have inadvertently caused the initial trip.

Some similar kinds of checks are performed on donor circuits to avoid adding load on to a circuit that is being worked on.

Plant Checks

For SCADA monitored plant that might be switched by the scheme, checks are performed to ensure that it would be appropriate to operate them. These include checking for the presence of embargos or local restrictions on the operation of particular switches, checking that fault flow indications exist for any switch that might be a candidate for opening, and checking that the SCADA indications and analogues are of good quality.

A further check relating to the fault flow indications is that protection is switched ‘in’ on automatic switches. This is important for certain types of device as no fault flow indications will be received if protection is switched ‘out’.

If a problem is found with a particular switch it is eliminated from the SCADA device tree and its children are reassigned to its parent, i.e. it is treated like a non-telemetered switch. However, the sequence scheme will continue to operate.

Other Checks

Amongst other checks that are carried out are tests of how recently switches have changed state. For example, if the trip device had recently been subject to a Close command then the scheme will abort on the basis that a control engineer is already operating in that area of the network, or if the open points have recently tripped, then the scheme aborts on the basis that the circuit may have been in parallel at the time of the fault.

The time of the triggering event is checked to ensure it is not so old as to be stale. Also, to allow for poll times on the SCADA network, the traces are postponed for 45 seconds to allow time for any other SCADA data relating to the event to be recovered as this may affect the traces and the analysis performed.

Checks are made on donor circuits to ensure that they have sufficient capacity and that ratings will not be exceeded in picking up any load. At present this done on the basis of a simple factor but a more sophisticated approach is being considered that looks at the proportion of connected capacity that would be restored as a mechanism to apportion the lost load.

BENEFITS OF THE ALGORITHMIC APPROACH

Central Networks considered a number of approaches to automation including greater use of local site based schemes and preconfigured schemes based on templates to handle particular network configurations. It adopted the algorithm based method because it offers a number of advantages over these other approaches:

1. All relevant information about the whole network held in the control system can be taken into account in deciding what switching is appropriate.
2. The data maintenance overhead is minimal. The only configuration required is that a particular device should be a trigger.
3. Abnormal network conditions are automatically taken into account.
4. Network alterations are automatically taken into account.
5. Operators do not have to switch the schemes in and out. (This capability is provided but all the circumstances thought of so far that would make it desirable for the scheme not to operate would be detected and abort the scheme.)
6. Any changes to schemes that may be desired in the future need be made in only one place.

IMPACT ON NETWORK DESIGN

This paper would be incomplete without a few words on the impact that deployment of automatic sequence switching can have on network design. While remote control without fault flow indication can be used by control engineers for sectionalising and general switching purposes, it is of limited use to the methodology described in this paper. This is because the algorithm is based on knowledge about the direction of fault flow through a given switch and that generally it seeks to avoid reclosing on to a possible fault. It is therefore imperative to the best operation of the algorithm that this information is available. Fault flow indicators should also be provided at normal open points to allow for situations where the network is abnormally fed.

A further issue occurs at changes from underground to overhead network. A ground-mounted remote control switch with an earth fault indicator will not see phase to phase fault current that results from a downstream fault on overhead network, potentially leading to the algorithm misdiagnosing the location of the fault. Ideally there should be phase fault indicators as well as earth fault indicators on all remote control switches and also a remote control switch wherever the network changes from overhead to underground.

The location of open points on the network can be determined on a number of factors such as ease of access, load distribution or minimising network losses. The switching algorithm demands that the open points should be telcontrollable to maximise the opportunity to restore supplies. Moving an open point to a non-telecontrolled switch may give benefit against one measure but be detrimental to other measures.

The key point that comes out of this is that network strategists and designers need to consider carefully how to create a network that maximises the potential for automated switching schemes to operate as a method of improving network performance.

FUTURE ENHANCEMENTS

Looking to the future, there are various ways in which this algorithmic approach to sequence switching could be developed.

1. The results of power analysis calculations could be incorporated to check whether the network will remain within its voltage and thermal limits both at the time of switching and in the hours ahead.
2. The impact on fault levels could also be assessed leading to further switching or warnings to operators.
3. Different protection schemes could allow closed mesh networks to be handled.
4. More intelligent protection on automation devices could enable remote reconfiguration to allow for new running arrangements following operation of a scheme.
5. Under some circumstances, e.g. on windy days, it may be desirable to attempt to reclose the trip device prior to attempting fault isolation on the basis that the cause of the fault is likely to have been transient.

CONCLUSIONS

A limitation of automated switching has always been the requirement to predefine the checks and operations that are performed for a given scenario. A modern NMS environment enables a more intelligent algorithmic approach to automated switching, capable of dynamically adjusting its behaviour based on current network configuration, plant restrictions and work activities logged against the network. The faster supply restoration provided by automated switching programmes delivers better customer service and improves network performance. This algorithmic approach also offers a lower maintenance overhead than other methods, improved reliability of operation, and relieves operators from needing to decide whether schemes should be switched in or out.