NEXT GENERATION NETWORK RESTORATION APPROACHES ON DISTRIBUTION FEEDERS

John DULLER
UK Power Networks – UK
john.duller@ukpowernetworks.co.uk

Ahsan HALIM
UK Power Networks – UK
ahsan.halim@ukpowernetworks.co.uk

Gordon PATON
General Electric - UK
gordon.paton@ge.com

Bill TRAILL
General Electric – UK
bill.traill@ge.com

Steven SPARLING
General Electric – UK
steve.sparling@ge.com

ABSTRACT

This paper describes the operation of the Adaptive Power Restoration Scheme, a unified algorithmic approach to implementing self-healing networks in the event of an unplanned outage (fault) on the 11kV/6.6kV (HV) network. The schemes are deployed across all three distribution areas that UK Power Networks own, serving London Power Networks (LPN), the Southern Power Networks (SPN) and East of England Power Networks (EPN). The solution has been shown to intelligently manage abnormal network configurations, switch operation failure and communication failures when a HV fault occurs on the network, and has realised a 25% improvement over more traditional automation schemes in the key performance indicators, while continuing to ensure safe operation of the network.

INTRODUCTION

UK Power Networks owns, manages and operates three electricity distribution networks in the UK serving 8.2 million customer connections: London Power Networks (LPN), South-Eastern Power Networks (SPN) and Eastern Power Networks (EPN), serving a total of around 8.2 million customers over an area of 29,000 km^2. The networks cover a mixture of both densely urban underground network, and rural overhead network

UK Power Networks measures key performance indicators as defined by the regulator (Ofgem) [1] for:

- *Customer Interruptions (CI) = Number of supply interruptions (>= 3 mins) per 100 customers*
- *Customer Minutes Lost (CML) = Average number of minutes that a customer has had their supply interrupted*

Over the period from 2010 to 2015, UK Power Networks invested in several areas to improve KPI performance, including increased SCADA deployment, and creation of a large number of automatic restoration schemes. These were developed and implemented in a centralised manner in the Advanced Distribution Management Systems (ADMS) – GE's PowerOn Fusion. Because of this investment, CI's were reduced by around 20%.

These improvements have helped transform UK Power Networks to be the best performing DNO group in the UK for CI's, and LPN the best performing DNO for CI's. However, UK Power Networks and the Regulator strive for continuous network improvement and customer satisfaction. Therefore, to achieve further improvements, UK Power Networks has invested in more SCADA and automation, including the implementation of the next-generation Adaptive Power Restoration Scheme (APRS) module in their ADMS system. APRS is an intelligent restoration approach which aims to act like a human operator to restore faults, but in far shorter timescales.

The implementation of APRS in place of the static template-driven schemes has yielded significant improvements in customer restorations under three minutes, as well as reduced overall maintenance costs.

SYSTEM LANDSCAPE

UK Power Networks

- LPN – Underground network consisting of radial, parallel and LV interconnected circuits, 210 Primary RTUs and 11,460 secondary RTUS.
- EPN- Mixture of Underground & Overhead circuits, 803 Primary & 10,740 Secondary RTUs
- SPN - Mixture of Underground & Overhead circuits, 559 Primary & 7421 Secondary RTUs

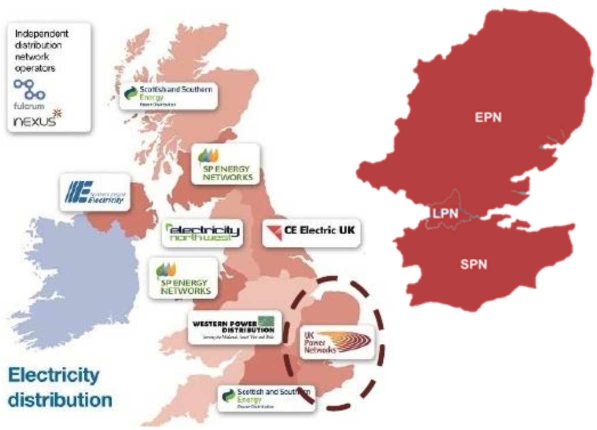

Figure 1 - UKPN Service Areas

Communications Infrastructure

At UK Power Networks, there is a large communications infrastructure supporting the network operations. The infrastructure provides monitoring and control to both primary and secondary substations in LPN, SPN and EPN.

Links to primary substations are 'always on', with the following types deployed:

- In SPN and EPN, approximately 1,300 RTUs are deployed to Primary (EHV/MV) substations. Communication is over satellite communications. This medium is highly resilient and especially suitable for rural areas. In cases of bad weather, backup links are available over mobile phone infrastructure (2G & 3G)
- In the LPN area, approximately 230 RTUs are connected by direct copper lines and fibre optic cables owned by UK Power Networks

Links to secondary substations are not continuously polled due to the large number. Instead, they report every 12 hours or if urgent data to report and are accessed on-demand. When activated, the link stays available for between three and five minutes. The following types are deployed:

- Approximately 18,000 RTUs in the EPN and SPN areas use Packnet, a packet-switched radio communication system available in the UK
- Approximately 11,000 RTUs are connected using mobile telephony, mostly 2G (GPRS)
- Approximately 500 RTUs in the LPN area use dial-up connections over Public Switched Telephony Network (PTSN) lines. These are gradually being migrated to faster ADSL connections

For all secondary connections, there is a connection time of between 2 and 30 seconds before data can be transferred.

Existing Automation Schemes

The use of programmatic restoration scripts has been in operation for many years [2]. The existing automation schemes installed in UK Power Networks prior to 2015 were based on the scripting functions available within the ADMS. A set of template programs were developed, based on the standard network configurations that were encountered in the UK Power Networks regions. Programs were developed as templates, with the capability to apply the template to the specific network area in each case, for example, specifying the circuit breaker, tie points, etc.
The programs activate from a trigger condition, typically a circuit breaker trip. They are deterministic in nature, and will operate when a fault is detected. The indication of the Fault Passage Indicators (FPI's) are used to determine the fault location, and the predefined telemetered switches / breakers are used to isolate the fault and restore supply to the maximum number of customers.

The static programs are deployed widely across the UK Power Networks' regions, but management of the programs was time-consuming, with over 5,000 circuits deployed with different programs.
Additionally, while the static programs worked effectively in the normal conditions, there were situations where they would abort or fail to run optimally, including:

- Where the network was in an abnormal running situation
- Where some fault passage indicators failed to operate correctly
- Where communication or switch failures take place, the program would abort
- Limited functions for load allocation were available, meaning more advanced restoration strategies were difficult
- Automatic Sectionalising Point (ASP) are pre-defined telemetered points on a distribution feeder used by automation to isolate the fault.
- Normal Open Point (NOP) and Source Circuit Breaker are used for restoring customers following isolation.

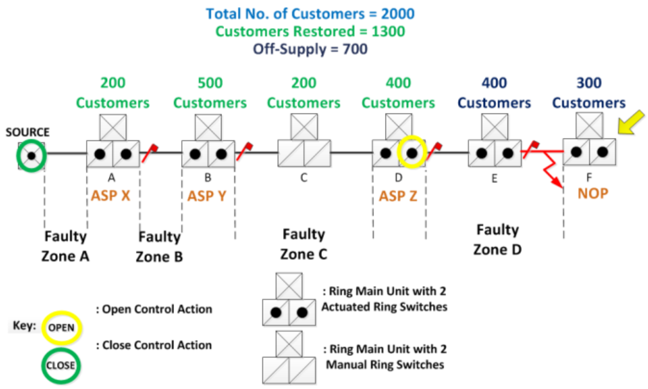

Figure 2 - Restoration in an example 4-zone template script

FEATURES OF APRS

Adaptive Power Restoration Scheme (APRS) is a module of GE's PowerOn ADMS system designed to make intelligent decisions automatically for fault location and restoration. APRS is a centralised approach, and because it is a module of an integrated SCADA/DMS/OMS system, it has access to full network visibility with which to make decisions on restoration strategy.

Management of APRS

APRS allows the system administrator to create a small set of profiles for operation of schemes on the network. Each profile is a set of configuration settings, for example: the set of timer values, method for load allocation, restoration priority strategy, etc.

APRS is deployed on a circuit-by-circuit basis, either replacing existing automation schemes, or newly deployed. In place of the static approach of templates, APRS is enabled with a specified profile for different circuits. As an example, there may be a different profile for rural circuits which have slower communication infrastructure and therefore require larger time-out values.

APRS uses the same automation framework as the older template-based schemes, but this still allows for enabling / disabling of schemes using symbols on the schematic diagram, as well as organising schemes into hierarchies allowing sets of schemes to be enabled or disabled by a single action.

Fault Detection and Location in APRS

The detection of faults using APRS is based on circuit-breaker trip alarms received from telemetered protection devices. This triggers APRS which immediately evaluates the quality of the signal and records the measured load of the circuit prior to the trip. Subsequently, APRS issues 'poll' commands to all SCADA monitored points down-stream which serves to both establish communications to remote devices, as well as to validate the status of the circuit.

The ADMS system at this point also generates an electronic work order which provides operators with:

- A diagram symbol showing the presence of fault work, positioned half way along the determined faulted section
- An electronic switching log to record timestamped restoration activities
- A record of affected customers
- A record of estimated load restored and estimated load still off-supply
- Header information (time, zone, etc.)
- APRS also has the ability to identify more than one fault and isolate and restore accordingly.

The primary method for locating faults on UK Power Networks' system is to use Fault Passage Indicator (FPI) devices. A common cause for failure of template-based automation was that FPIs were not reported correctly, either due to not being reset correctly from a previous fault, or due to communication failure meaning they did not report their status correctly. In contrast, APRS intelligently handles both conditions in the same manner that a control engineer would, by being able to configure and disregard these fault FPI's for fault location purposes.

While APRS also supports alternative methods for fault location such as distance / impedance to fault, UK Power Networks has elected not to utilise these methods at the current time as many circuits contain branches meaning this method may be less effective.

APRS Restoration Strategy

After detecting a fault and determining the likely section containing the fault, the basic approach to isolation and restoration of the section is as follows:

1. Analyse the faulted circuit to determine the loads prior to the fault, as well as the available capacity of neighbouring circuits
2. Create and execute restoration plan, recording steps in electronic switching log
    a. Start with up-stream isolation of the fault and restoration of the remaining customers
    b. Potentially in parallel, downstream isolation is made, with restoration from one or more adjacent circuits
3. In the case of failure at any switching step, the network is re-evaluated and alternatives found

APRS supports some advanced restoration strategies for down-stream restoration, including:

- Split Restoration: Energising service points down-stream of the isolated network from more than one donor circuit
- Load Transfer: When a donor circuit has insufficient spare capacity to restore the affected section, switching can be made to transfer some load of the donor circuit to an adjoining circuit.

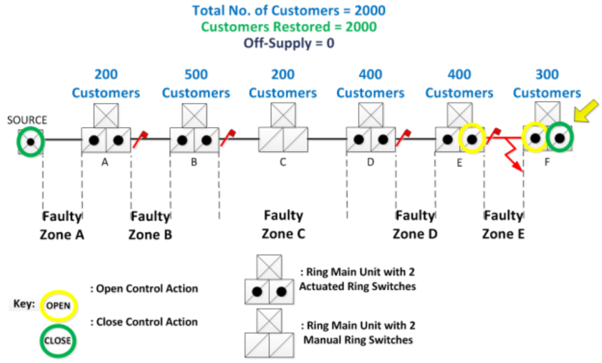

Figure 3 - Automatic restoration using APRS

Speed of Operation

To provide UK Power Networks with a reduction in CI figures, customers must be restored in under three minutes. As the communication links to secondary devices are slow in nature, some additional strategies are available in APRS to allow for faster restoration which meets the target timeframe:

- As it can take up to 30s to establish connections to remote RTUs, the APRS system will automatically determine all remote devices which might be required and sends connection requests as soon as a fault is detected
- Option to send controls for isolation and restoration in parallel instead of sequentially.

Safety Considerations

UK Power Networks considers that safety is the primary consideration when implementing any automation scheme. Accordingly, several features are built-in to the APRS algorithm to ensure safe operation:

- Prevention of over-loads of adjacent circuits
- APRS immediately aborts if any recent work has taken place on the affected or donor circuits within a specified time period
- APRS also immediately aborts if any switching operations are marked as instructed to field crews on the affected circuits or devices
- APRS intelligently recognises any control inhibit tags placed on switching devices and will not utilise these in the restoration plan
- APRS will abort if there is an issued permit for live-line work on the affected circuit, and will also not utilise any donor circuits which have live-line permits issued on them.

The older template-based schemes required to be disabled whenever a circuit, or possible donor circuit was configured in an abnormal way. As APRS always uses the 'current' network conditions there are significantly fewer situations where control engineers are required to manually disable automation.

EXPERIENCE AND RECOMMENDATIONS

Preparing for Deployment

In order to deploy APRS there are minimum requirements for remote (SCADA) control and indication at:

- the primary substation,
- suitable secondary split point with fault passage indicators (Phase & Earth)
- alternative supply (open point).

Above the minimum requirements, greater benefits can be realised by increasing the number of remotely controlled and monitored points until there is remote control and indication at all sites.

The processes of requirements definition and design for the APRS scheme are also worth to mention. While it was UK Power Networks' intention to utilise standard product from the vendor wherever possible, it was also realised that it was likely that network configurations and operating procedures would be discovered which did not 'fit' the standard product as it would be installed 'out-of-the-box'.

To address, this UK Power Networks collected historical restoration scenarios from across the three network areas, both automatic restorations and those made by control engineers. This allowed UK Power Networks and the vendor to make a gap analysis in advance of project deployment to determine where additional enhancements would be required.

Testing and Deployment

To enable successful deployment of the APRS module, UK Power Networks devised a test roll-out strategy to ensure correct and safe operation of the new functionality.

Testing

The test strategy started by identifying examples for each type of template using the previous automation. Full test systems were created which are replicas of the production ADMS system.

A critical component of the test environment was a SCADA simulator which emulates concurrently all slave RTUs on the UK Power Networks system. The SimSCADA simulator was used for this purpose, allowing UK Power Networks to develop scenarios scripts to test different behaviours. The SimSCADA tool also allowed emulation of different RTU failure modes to ensure the APRS scheme could cope effectively. The use of the SCADA simulator allowed for significantly faster commissioning of the APRS module and gave greater confidence of correct operation.

After initial testing on an off-line test system, the ARPS module was deployed onto the production ADMS system running in parallel with the existing automation schemes but configured in advisory (open loop) mode. This feature allowed APRS to only produce recommended restoration schemes which were then compared to the actual restoration actions that were undertaken by the static automation template schemes. This exercise proved effective in identifying areas of improvement for the APRS deployment, but with the restriction that only the initial restoration plan could be tested in this way – how APRS reacted to unexpected responses and communication problems could only be tested in the simulator.

Deployment

UK Power Networks elected to take a phased approach to deployment of APRS. The initial deployment was made to the LPN region which had a higher penetration of remotely monitored and controlled equipment. Circuits with statistically higher failure rates were selected for the initial deployment to increase the chances of scheme operation occurring.

After successful operation on the initial circuits, an incremental approach was taken, replacing template-based schemes with APRS across the LPN region. Deployment to approximately 1000 circuits was made over the course of 1 year. In parallel, deployment started on the SPN and EPN regions, and APRS is currently deployed on 5000 circuits serving over 7 million customers. This means that 71% of all UK Power Networks' circuits are armed with APRS, serving 87% of the customers supplied.

Running and Maintenance of the Schemes

During the deployment of APRS, UK Power Networks placed a high level of importance on post-fault analysis. APRS provides a comprehensive log of the decision-making the algorithm made during operation, allowing the analysis engineer to make detailed investigation into the reasons particular switching operations were made. Since deployment of APRS, two failures have taken place where APRS was unable to make any restoration – both times due to communication failures with remote field units.

Management of APRS has also proven to be easier in two main aspects. Firstly, the commissioning of new schemes due to network extension or new telemetry is simpler as the commissioning engineer is no longer concerned to select the correct template and identify the key points. Secondly, the operating instructions for the control engineer are simpler due to fewer situations where automation requires to be disabled due to fault or planned work. This has shown to be a valuable feature in storm situations where the operator has a higher workload.

CASE STUDY

By way of an example,

Figure 4 shows the operation of APRS as happened on a section of the LPN network during 2016.

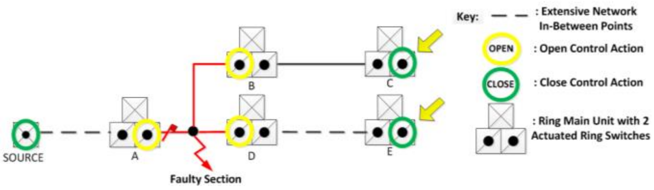

Figure 4 - Example APRS Operation

The recorded statistics for the operation are made in the following tables.

	Feeder	Restored	Off-Supply
Customers Affected	3428	3428	0

Action	**Isolation**	**Restoration**
Switching Operations	3	3

Total APRS Execution Time	56 seconds

	Customers	Percentage
APRS Improvement vs static automation	731	21%

PROJECT OUTCOMES

As of January 2017, APRS has run successfully across all three regions managed by UK Power Networks. Statistics of the number of runs is made in Table 1.

DNO Area	LPN	SPN	EPN
No. of Operations	345	301	259
Safety Incidents	0	0	0
Average Improvement over Static Automation	25%		

Table 1 - APRS Operations since commissioning

FUTURE WORK

The deployment of APRS has shown that the adaptive approach to self-healing grids can be effective in improving the reliability of supply. As a result, there are additional benefits anticipated if APRS can be extended to areas of the grid where it is not currently applied. These include:

- Automatic restoration of supply following loss of a primary transformer or substation
- Areas of the 11kV network where distributed generation or meshed network configuration mean that directional fault passage indicators need to be used
- Automation of the LV network, building on previous UK Power Networks innovation projects: Smart Urban Low Voltage Network [3] and Flexible Urban Networks [4]. Note that in the specific case of LV, the correct regulator incentives would need to be in place to build the business case for deployment of the infrastructure required.

REFERENCES

[1] Ofgem, 2012, Electricity Price Control: Glossary of terms for the RIGs https://www.ofgem.gov.uk/

[2] R.E. Jackson & C.M. Walton, 2003, "A case study of extensive MV automation in London" CIRED 17th International Conference on Electricity Distribution Paper 36

[3] UK Power Network, 2014, Overview – Smart Urban Low Voltage Network, http://innovation.ukpowernetworks.co.uk/

[4] UK Power Networks, 2016, Flexible Urban Networks – Low Voltage Cost Benefit Analysis (SDRC 9.6), http://innovation.ukpowernetworks.co.uk/