A CASE STUDY OF EXTENSIVE MV AUTOMATION IN LONDON

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INTRODUCTION

The LE Group is an EDF company and operates the three distribution networks of EPN, LPN and SPN. LPN covers the area formally known as London Electricity. A comprehensive network automation scheme now manages MV fault isolation and supply restoration for incidents within the LPN supply area. Over 1.8 million of the 2.2 million LPN connected customers are supplied from automated MV networks. This paper considers the drivers for automation, the design, implementation and the benefits obtained focussing primarily on reducing MV Customer Interruptions (CI).

LPN NETWORK OVERVIEW

Background

The London Network supplies an area of 655 Sq Km and has 2.2 million connected customers. The network is predominantly underground and the asset base is made up of;

- 2,000 Km EHV cable (above 11kV)
- 19,000 km LV cables
- 8,000 km MV cables
- 100 EHV/MV substations
- 13,000 distribution substations
- 5,000 distribution substations equipped with full remote control & telemetry functions

A typical LPN MV network comprises four of five radial feeders supplied from a common busbar. The feeders are configured in a ring and therefore any feeder will have (normally open) interconnection to at least two and in many cases three other feeders. The associated LV network can be operated either mesh or radial. The LV network in outer London is normally run radial in operation and a medium voltage fault will result in the loss of supply to all customers connected to the particular feeder.

Telecontrol

The source feeder circuit breakers are located at the 100 main substations. The majority has full telecontrol and telemetry facilities. Telecontrol is an integral part of the main control room SCADA system. Communication is by duplicate fixed circuits that are owned by LPN.

Remote Control

The present generation of remote control was first introduced in 1998 and by the end of 2002 nearly 5,000 of the 13,000 distribution substations are equipped with full remote facilities. Remote Control was driven by the need to meet quality of supply targets, in particular the reduction in customer minutes lost[1]. Remote communication is either by PSTN (Public Switched Telephone Network) or by PMR (Private Mobile Radio). Over 4,000 remotes communicate over radio.

The remote strategy had a number of key elements;
- Prioritising networks by substation based on quality of supply performance
- Targeting outer London radial networks first for the largest CML benefits
- Establishing a stand-alone central control system separate from the main SCADA system.
- Integrating remote control with main SCADA control system when principal benefits achieved
- Implementing a structured standardised approach rather than focusing on a circuit-by-circuit design
- Specifying double actuator ring main units
- Aiming for a remote network population 1:4 with migration to 1:2 for high risk networks
- Developing a simple switchgear remote terminal unit interface to facilitate slick commission procedures

Pre automation Network Performance

The implementation of Remote Control and telecontrol secured an improvement of 33.2% in availability (customer minutes lost) and 8.9% in security (customer interruptions per 100cc) over the 5-year period to 1999/2000.

<table>
<thead>
<tr>
<th>Category</th>
<th>1994/5</th>
<th>1999/2000</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability CML</td>
<td>58.1</td>
<td>38.8</td>
<td>33.2%</td>
</tr>
<tr>
<td>Security CI</td>
<td>39.7</td>
<td>36.2</td>
<td>8.9%</td>
</tr>
<tr>
<td>PRITH</td>
<td>81.1</td>
<td>84.5</td>
<td>3.4</td>
</tr>
</tbody>
</table>

THE CASE FOR AUTOMATION

Remote Control has delivered a small improvement in CI. It used limited automation functionality to “flip-flop” normal open points between feeders. To achieve major gains in CI a number of factors needed to be considered:

Target CI (HV major contributor)

In the regulatory year 1999-2000 MV incidents provided 66% of the sustained customer interruptions for the LPN network. Incidents at LV, although far more prolific, by comparison contributed only 17% of the interruptions. Initiatives to reduce MV CI would therefore produce the largest benefits.
Short Interruption 3 minutes
An automated sequence contains at least two successful switching operations to restore supplies. An open operation to isolate the fault and a close operation to effect the restoration.

Early automation trials indicated that restoration sequence could be completed within 70 to 80 seconds using either radio or telephone as the communication medium.

Following lobbying by the UK industry, OFGEM confirmed that from April 2001 it would adopt the 3 minute Short Interruption time of the European Norm BS EN 50160:1995 in order to stimulate the development of automated sequences.

Prior to this the UK definition of a short interruption was 1 minute.

Alternatives to automation
Alternative solutions to automation for improving CI performance were considered including interconnection of the LV network, unit protection, sectionalising circuit breakers and improvements to the LV network.

Detailed studies confirmed that for London automation provided the best fast and generic low cost solution. Alternative designs of the MV network including unit protection and sectionalising circuit breakers have specific but relatively limited application because of the high cost to implement. LV initiatives are also high cost in terms of £ spent to CI saved.

Build on Remote Control Continuous Improvement
The implementation of remote control was from the outset designed to provide an infrastructure that could be progressively upgraded to full automation. A characteristic MV feeder will have 10 distribution substations. At least two normal open points and a minimum of two other substations equipped with remote control switchgear. Studies showed that the logic used by Control Engineers could be adapted within a small set of generic solutions to automate the MV restoration sequence.

AUTOMATION
The LPN automation scheme uses a central control module that interfaces with the remote control system and therefore has direct access to the 5,000 remote secondary substations. The work was commissioned in September 2001 and completed in March 2002 with 861 individual feeder “programs” covering the entire outer London radial network supplying some 1.8m end user customers.

Key Project Milestones
- January 2001 Commence software development.
- August 2001 Automation Module Acceptance.
- September 2001 First programs commissioned.
- March 2002 Completion of implementation phase 861 programs commissioned.

Automation Module Stand Alone System
Following on from an initial risk assessment it was considered that the major benefits of automation were possible without the need to develop and validate an interface between the remote control and the main SCADA system.

The initial scheme was therefore designed to be stand-alone and used only data from the remote control system. Integration was seen as a logical second step to be implemented once the automation module concept was developed and proven.

As the source feeder breaker operation was not to be captured in the initial stand alone remote control system, a separate trigger had to be used to start the fault restoration process. The trigger used was the loss of supply at LV. The substation remote terminal units continuously monitor the LV supply at the substation distribution transformer. The loss of supply had to be sustained for a period of time to allow for protective devices to operate for faults at voltages other than MV.

Automation Philosophy
Automation is achieved by dividing a feeder into a number of sections or zones, typically three. The outputs of the fault passage indicators at the boundaries of the zones are analysed using a truth table to determine the fault zone. The fault zone is then isolated and the other zones are restored.

Fault passage indicators have two states, operated and not operated. However, the truth table contains a third state, not known. The not known state is used if communication to the site cannot be established. Automation sequences work on positive information and cannot make assumptions by interpreting a not known state as not operated.

A three-zone feeder will have two substations used as zone boundaries. These substations are called ASPs (Automatic Switching Points). As each ASP has three states the truth table is a function or 3 to the power of the number of ASPs

<table>
<thead>
<tr>
<th>Zones</th>
<th>ASPs</th>
<th>Truth Table Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
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<td>81</td>
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<tr>
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<td>5</td>
<td>243</td>
</tr>
</tbody>
</table>

The Remote Terminal Units have been programmed with a new automation configuration and new logic program to provide the three fault passage states used in the truth table.

Communications
Experience has shown that the key to successful large-scale automation is understanding and managing communications. Automation is a sequence of time-related actions and events that can easily be halted if communications are interrupted. The scheme has various configurable timers, which allows for fine-tuning of the automation process to achieve maximum benefits.

Central versus Distributed Logic
The automation scheme relies on centralised as opposed to distributed logic. The main advantages of this approach are:

- A standard and consistent remote terminal unit configuration is maintained.
• Networks can be easily reconfigured to reflect changes in connectivity.
• Commissioning procedures are simplified.
• Each one of the truth table combinations can be tested and validated.

Models

The consistency of the HV network has allowed a standardised approach to be applied. The scheme is based on three generic models, which has simplified the testing and enabled in service modification and enhancements to be fully validated.

The three zone models are capable of restoring over 70% of supplies within 3 minutes assuming that customers are evenly distributed along the feeder.

New programs are built using templates. Creation uses standard windows tools. The wizard shown in the following screen shot represents part of the data entry for one of the three zone models.

The models include the restoration scripts. The program creation wizard offers the default restoration option otherwise alternatives can be simply selected from menus.

Module Functionality

The design had to manage automation for an entire network. Feeders are not operated in isolation but are linked to provide alternative routes to supply customers in the event of planned or unplanned changes to the network.

The MV network is therefore dynamic and subject to change. Permanent changes are managed by the ability to edit, delete and add new programs.

Programs are grouped by feeding zone to minimise the risk of major customer interruption. Loss of LV supply can be a result of incidents at voltages above MV. A major supply loss can effect a number of programs and the module will inhibit operation in these instances by blocking all the programs in the group.

Development & Acceptance Testing

Software simulation was used throughout the development and test phase of the project and is now used as a training aid.

The remote control test environment was also used to test the automation module. The test system remote terminal units are connected to switchgear simulators and can communicate using either radio or telephone. The RTUs were configured to represent the three generic models.

The test scripts covered the ease of use of the automation module and program operation, including an extensive range of failure modes. The failure modes included failure of communications, conflicts in EFPI reporting, switch control failures and supply loss conflicts. In all hundreds of fault scenarios were tested.

Implementation

Implementation included the build and commissioning of the 861 feeder programs from the desktop. The updating of RTU configuration had to be performed on site in order to avoid compromising overall network performance.

Risk Assessment

Before the scheme was commissioned an updated risk assessment was conducted to ensure that there were no unmanaged safety or performance implications. Areas covered included risks to third parties, staff and equipment.

LESSONS

What could we have done better?

There were two areas where the scheme performance could have been enhanced from the outset.

The original voltage level for the loss of LV supply trigger setting proved too low. Back feeds via temporary or spurious LV fusing prevented the system from triggering correctly.

The voltage level trigger has now been raised, however, this entailed revisiting over half of the remote sites a second time.

In real life it also proved difficult to determine why a restoration sequence had stopped because detailed information on communication was not available for analysis after the event. The scheme now includes communication logging.

Network Operation (Outages)

Although the programs can be edited to reflect network changes they are normally restricted to permanent as opposed to temporary changes.

In order to keep the initial system simple a feature of the scheme is the ability to enable and disable programs whilst the circuits are running abnormally. A major factor in the potential automation performance is therefore the duration of outages and the population of outages. Experience has shown that at any one time up to 15% of programs can be disabled because of network activity.

Scheme Management

Automation of an entire network provides a considerable challenge to manage feeder states, configuration changes, edits and outages. The scheme requires powerful management and reporting tools to ensure that the maximum potential is being realised and this was major consideration in
the design.

**Scheme Operation**

It is vital that the Control Engineer can quickly comprehend the scheme outputs and dress the connectivity changes in the main SCADA model in order to continue the fault restoration process manually. Experience of the initial scheme operation has confirmed that in its present form, three-zone is the practical limit for the stand-alone system.

**LINK TO MAIN SCADA**

Having proven the viability of the initial stand-alone system, the second stage of the project was to develop and implement the link between the automation module and the main SCADA system. The source feeder circuit breaker would then form an integral part of the automation process. In addition the main SCADA system would be capable of controlling the automation module program states.

**Development & Testing**

The solution has provided a TCP/IP protocol interface between the two systems. The interface allows each party to read and write to the other. The three generic models were modified to take in the feeder circuit breaker status and controls. The scheme went through a full retest before being implemented in a single process.

**Project Milestones.**
- February 2002 Basic design completed.
- March 2002 Project Approval
- April 2002 Software Development
- July 2002 Testing.
- August 2002 Commission.

**Implementation BIG BANG**

The change was implemented in August 2002 and only took an hour to complete. The scheme being based on standard models meant that a simple script enabled the program restoration options to be updated in a controlled and proven manner.

**AUTOMATION PERFORMANCE**

Since commissioning the MV initial automation scheme has handled in excess of 210 MV faults of which 110 have resulted in the restoration of supply in under 3 minutes. Monthly performance has varied from as low as 25% of faults being restored automatically without manual intervention to as high as 75% with an average of approximately 50%. The introduction of MV automation has not only significantly reduced MV CI but has also reduced Customer Minutes Lost (CML) as well.

An improvement of 4.88 CI for MV customer interruptions were reported in the first year of operation 2001/02, equivalent to an improvement of 18.1% over the previous year. MV CI is anticipated to fall by a further 3 CI in 2002/03, based on performance up to December 2002.

**MV CI 1998/99 to 2001/02**

MV Customer Minutes Lost improvements of 3.31 CML were reported in the first year of operation 2001/02 equivalent to an improvement of 19.4% over the previous year. MV CML is anticipated to fall by a further 2 CML in 2002/3 based on performance up to December 2002.

**MV CML 1998/99 to 2001/02**

**Failures**

The scheme logic is based around always working on positive information. As a result there have been no examples of failure as a result of the automation logic being incorrect. Failure to restore supply are fully investigated and the primary causes have been found to be:
- Communication delays - primarily radio
- Earth fault passage indicators malfunctions
- Switchgear problems
- Network maintaining LV voltage above the threshold trigger
- Programs being disabled (abnormal running).

**Summary of Program Failures in 2002**

<table>
<thead>
<tr>
<th>Cause</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Delays</td>
<td>22</td>
</tr>
<tr>
<td>EFPI Malfunctions</td>
<td>2</td>
</tr>
<tr>
<td>Switchgear problems</td>
<td>4</td>
</tr>
<tr>
<td>LV Voltage Trigger</td>
<td>18</td>
</tr>
<tr>
<td>Disabled</td>
<td>42</td>
</tr>
<tr>
<td>Other</td>
<td>16</td>
</tr>
</tbody>
</table>
FUTURE DEVELOPMENT

Link remote control and main SCADA

The interface developed between main SCADA and automation can be used to enable the control of the secondary remote terminal units from the main SCADA system. The ability to include both the indication and control of secondary remotes from the main SCADA will reinforce automation and provide further CML and CI gains. The main uses will be to extend the restoration process, to provide alternative restoration options when there has been automation failure and in particular to provide a degree of restoration for the network where automation is disabled.

Enhance Automation

A number of options are being evaluated:

- Increase the number of zones above the present limit of three.
- Provide a second stage restoration by using intermediate remotes where they exist.
- “Flip-flop” residual normal open points.
- Improve communication speed as this appears to the main restriction, with four zone models being the realistic limit for PSTN or PMR systems.
- Introduce dynamic reconfiguration to overcome the limitation of having to disable programs whilst networks are running abnormally.

Automation’s Other Uses

Automation is in its infancy. The immediate drive has been to gain fast simple improvements in CI and CML, however in the long term it is expected that automation will be used not only for basic fault isolation and supply restoration. Intelligent systems could be used to control voltage, minimise losses, prolong asset lives by reconfiguring the network to avoid plant overloads, and to equalise the rate of use of asset life.

Another potential use of automation is in conjunction with incipient fault detection and location. Automation could be used to reconfigure a network to limit supply interruption or ultimately eliminate supply interruption before they occur.

Automation in EPN

Following the experience of LPN, EPN are at present developing an automation application within their main SCADA system. The plan is to roll out automation to 1,200 feeders. The process is also based on generic models that can be fully tested before being implemented. The sequence switching scripts being based on control engineer logic with the trigger being the source circuit breaker.

CONCLUSIONS

Large-scale generic automation has provided LPN with a fast low cost solution to reducing the number of sustained customer interruptions. The scheme covers the entire London radial network of some 1.8m end use customers and CI gains of 18.1% and CML gains of 19.4% have been achieved in the first year 2001/02.

The use of generic models has enabled a rapid implementation and removed the need for complex circuit-by-circuit testing. It is believed that the application of generic models can be adapted for any MV distribution network provided the common factors are identified.

Fast reliable communications has proved to be a major consideration in automation design and scheme performance. The existing communications limits any enhancements to 4 zone programs, however inclusions of second stage automation including flip-flop of normal open points could in theory produce 12 zone programs.

Automation on this scale requires effective network management and powerful management tools to make the best use of the systems capabilities.

Operational experience of the scheme has identified a potential relationship between the levels of planned network activity that results in abnormal running arrangements and an increased number of unplanned outages. More data and analysis is necessary but there does appear to be a statistically significant relationship.

The link to the main SCADA is the first step in securing a fully integrated control system that includes both automation and remote control. Future systems will increasingly be capable of reacting to any incident and providing a major degree of rapid supply restoration without manual intervention.

Remote control and automation have already significantly reduced MV CML and CI for LPN. As a direct result of improvements at MV, the percentage contribution to overall CI & CML that LV incidents will display in the quality of supply statistics have risen significantly. LV incidents are far more prolific and will require different approaches including condition monitoring, asset replacement and network redesign, although the possibility of applying aspects of remote control and automation is under consideration.

Large-scale generic MV Automation has proven to be an effective low cost solution but it is not the only tool to reduce CI and CML and a variety of condition monitoring and asset life techniques have a complementary and pro-active role to play in improving network performance.

References:
1. CIRED 2001 “Remote control & automation of urban distribution systems CM Walton & R Friel”