INTRODUCTION

EDF Energy Networks Branch is a division of EDF Energy responsible for the distribution of electricity in the South East of England. The Network is split into three geographical areas, which historically have developed separately. The registered companies covering the three licensed areas are EDF Energy Networks (EPN) plc, which covers the East of England, EDF Energy Networks (SPN) plc, which covers the South East area, and EDF Energy Networks (LPN) plc which covers the London area. EDF Energy Networks Branch own and maintain the network at all voltage levels from LV (230/400 volts) up to 132kV.

This paper focuses on the recent introduction of automated switching on the EPN 11kV network, and draws comparison where appropriate with similar schemes within the LPN and SPN licensed networks.

The EPN network serves over 3.4 million customers and is the largest network (in terms of customer numbers and circuit length) in the UK.

Restoration of supplies to customers following a fault has traditionally been achieved by a combination of manual and remote-controlled switching. This allows the network to be reconfigured to restore as many customers as possible. Historically, all switching operations were initiated and overseen by a control engineer. With the implementation of automation on the network, remote controlled switching is automated under the control of a centralised computer system.

In Great Britain, the regulator Ofgem sets Customer Interruptions (CIs) and Customer Minutes Lost (CMLs) targets for each distribution network operator. Interruptions restored within three minutes are classed as short interruptions and do not contribute to CI or CML counts. Achieving this three minute restoration period has been the main driver for installation of automated switching on the network, and is the design objective of EDF Energy’s automation schemes.

OVERVIEW OF THE EPN SYSTEM

In order to allow successful roll-out of the automation system on the EPN network, it has been necessary to ensure that all candidate feeders (11kV circuits) are equipped with sufficient remote-control* switchgear to enable remote controlled switching. The physical requirements for tele-controlled equipment are the same as those for automated switching, since the centralised control system dispatches control signals in the same way, whether initiated by automation or a control engineer. Once the remote controlled mechanisms are in place, it is a relatively easy transition to convert these circuits to automated operation, but it is important to identify all fault and network loading scenarios in order to avoid maloperation.

Automation is designed to replicate the initial switching operations that would be carried out by a control engineer. Once automation operation has completed, it is expected that a control engineer will continue switching operations to restore the maximum number of customers.

Network configuration

The EPN 11kV system accounts for 75% of all faults affecting customers, and consists of radial feeders which terminate at a normally open point (NOP). The NOP is a switch which allows connection to another feeder (fed from the same substation, in an ‘open ring’, or more commonly another substation). At a convenient location between the source circuit breaker and the NOP a third switching point is selected such that the CI risk on each side of this point is approximately equal (predicted fault rate x customer numbers). This point is called the sectionalising point.

* Strictly tele-control, i.e. switched from a remote site.
A large programme of work has recently been completed to ensure that all feeders have the requisite number of remote controlled switches. Typically on overhead networks, the ASP will consist of a pole mounted auto-reclosing circuit breaker (colloquially known as a gas-vacuum recloser, or GVR), and the NOP will consist of a similar item or a remote controlled switch (non fault breaking).

For underground networks, ring main units are used as ASPs and NOPs. These may be equipped with secondary protection (circuit breakers) guarding the second section of each feeder, or without secondary protection, in which case the entire feeder will be lost for a fault anywhere downstream of the source CB. In the latter case, automation will interrogate fault-passage indicators to ensure that the non-fault half of the feeder is restored within the requisite three minutes.

Hybrid (part overhead, part underground) systems will use a combination of pole mounted and ground mounted switchgear. The various configurations to be found on the EPN network are illustrated in Figure 1.

**Automation Scripts**

Ten generic combinations of switchgear are used on the system. For each generic type, a script of switching operations is applied, which carries out a sequence of checks and switching operations. The scripts are identified as ‘Type A’, ‘Type B’ etc and are populated with unique plant identifier codes which indicate which plant items should receive each switching instruction.

Scripts are triggered by the opening (or lockout) of a source circuit breaker. A ‘tripped’ event will begin the execution of a script unique to each trigger source. The scripts run on the central control system computer (using proprietary ENMAC™ software and UNIX shell scripts), and generate communication requests via our primary and secondary SCADA (Supervisory Control and Data Acquisition system) links to control or query plant in the field.

When an automation script runs, several safety checks are performed, including testing that automation is enabled for that feeder, and that other supporting circuits are in a normal configuration. During execution of an automation script, automation is disabled on all other circuits which would be dependent on the faulted circuit. In this way, cascade failures or script ‘race conditions’ are avoided. As the script progresses, a log file is generated which indicates to the control engineer the exact sequence of operations performed on the network. Another task of automation scripts involves load checking. The script stores a threshold value (amps) which can be safely moved across the NOP. If this proportion is greater than the threshold value, the script will not run.

Figure 2 below shows a flow chart detailing switching operations for one of the simpler (type A) scripts, which will run following a fault in the first section. Some details are omitted for clarity.

**Figure 2 – Flow diagram for Type A script**

![Flow diagram for Type A script](image-url)
OTHER TYPES OF SYSTEM USED ON THE EDF ENERGY NETWORKS

The three EDF Energy licensed networks of SPN, LPN and EPN have historically developed separately, and consequently their topologies and subtleties differ. Currently, the LPN and EPN networks use a centralised automation system, whereas the SPN network uses an autonomous system where devices communicate between themselves and only report back to the centralised operating system once the scheme has completed its sequence of operations. At the time of writing the EPN automation and control system is being applied in the SPN network.

The LPN automation system differs from the EPN system in that the primary (source) switchgear was originally not used for automated restoration, relying instead on one or more NOPs to restore supplies. The reason for this is that the system was originally designed to be a stand-alone system with no interface to the centralised control system (which is used for control of primary switchgear). LPN automation utilises a remote control infrastructure installed in 1998 which permits multiple methods of restoration from the same substation via secondary (distribution) switchgear. Automation was added to this for the first time in September 2001. A three zone teed LPN feeder model is shown in Figure 3 below [1]. ‘Loss of volts’ at the sectionalising point was initially taken as the trigger for automation operation. Recent developments of the system have enabled the linkage of the LPN automation system with the centralised controller, allowing automation to extend to control of primary switchgear. As a result, the ‘loss of volts’ trigger has now been complemented with the ‘trip of primary CB’ trigger. The main drivers for automation in the London area (as well as CI / CML targets) were the need to reduce the impact of faults, and secondarily, to reduce the requirement for manual switching which, due to congested roads, would otherwise delay restoration. For this reason, automation in the LPN area has been applied more intensively, with typically one in three substations being equipped with automated equipment.

Figure 3 – Typical London area automated feeder

PERFORMANCE OF THE AUTOMATION SYSTEM

Once remote control, and subsequently automation was installed on the LPN network, there was a marked decrease in CIs because it became possible to restore customer supplies within three minutes, whereas formerly there had been no mechanism in place to enable this. With the EPN system, such a marked ‘step change’ in performance was not predicted, partly because the number of automated switches per feeder was lower than that installed in London, and also because teed sections of network are not specifically included in automation. In addition, a significant proportion of source circuit breakers supplying the largely rural (and overhead) network are equipped with auto-reclose facilities (automatically restoring most customers following transient faults). The graph below shows the predicted and actual savings since installation of the scheme in 2003. Some faults, such as transient overhead-line faults, are cleared by auto-reclose facilities or (for earth faults) cleared by or held on arc suppression coils (Petersen coils). These faults traditionally do not contribute to CI/CMLs and are not influenced by automation unless they develop into continuous (sustained) faults.

Graph 1 – Predicted, potential and actual performance benefit from automation.

Initial forecasts of performance within the East of England area made some assumptions about the availability of automated feeders. These were:

- At any one time, a number of feeders will be disabled due to maintenance and planned outages;
- Automation will be disabled on a number of feeders as a result of faults on neighbouring feeders or substations;
- Automation will be disabled on some sites due to abnormal running arrangements and/or capacity limitations;
- Communications failures and plant defects will cause a number of scripts to be disabled or abort;
- Typical fault rates will apply.

The graph above shows the forecast performance of automation on the EPN system, together with the actual and potential savings which would have resulted from perfect operation of all automation schemes. A forecast increased trend in CI savings reflects the continual addition of automation scripts to the network into 2005.
As of week ending 5th December 2004 8.89 CI per 100 connected customers (CI/100cc) have been saved since the first automation scripts were commissioned. This is lower than initially forecast, as a consequence of a delayed roll-out period (of the order of three months, which can be seen in Graph 1) and other factors described below.

Table 1 – Number of scripts commissioned to date

<table>
<thead>
<tr>
<th>Script Type</th>
<th>Scripts commissioned to 5th Dec 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>483</td>
</tr>
<tr>
<td>B1</td>
<td>58</td>
</tr>
<tr>
<td>C + Cmod†</td>
<td>118 + 705</td>
</tr>
<tr>
<td>D</td>
<td>185</td>
</tr>
<tr>
<td>E1</td>
<td>21</td>
</tr>
<tr>
<td>E2</td>
<td>31</td>
</tr>
<tr>
<td>F1</td>
<td>13</td>
</tr>
<tr>
<td>F2</td>
<td>9</td>
</tr>
<tr>
<td>F3</td>
<td>20</td>
</tr>
</tbody>
</table>

When planned work or a fault occurs on a feeder, it is necessary to disable automatic scripts on that feeder, and all feeders which may interact with it. Work on higher voltage systems, or any abnormal network configuration, requires automation to be disabled. In practice a hierarchical system of automation enablement flags is used, and automation is inhibited if one of the sibling or parent flags are set to inhibit. This allows one master flag to be set to disable area-wide automation. The flags are displayed on the network control diagram, and the automation controller can disable automation on a global or local scale. Wide-scale disablement is used on rare occasions where the amount of communications traffic generated during times of high fault activity would have an adverse effect on control system performance (typically ‘exceptional events’ caused by storms).

Results of initial review

A review of automation performance following the first year of operation (Month ending 29/02/2004) identified that 1257 faults occurred on circuits with automation schemes (approximately 36% of all 11kV faults). 378 of these faults were correctly cleared by downstream network circuit breakers and sectionalisers which prevented the primary source circuit breaker tripping and triggering the automation schemes. Customers connected upstream of these secondary devices did not have their supplies interrupted. There were 322 events where an automation scheme could have operated. 61% of these schemes operated successfully and restored supplies to customers connected downstream of the sectionalising device saving 3.3 CI/100cc.

There were 69 schemes that were disabled when the fault occurred and 57 schemes that failed to operate, resulting in the loss of a potential saving of 1.73 CI/100cc. The table below gives reasons for the disablement of these scripts.

Table 2 – Reasons for disabling automation

<table>
<thead>
<tr>
<th>Disabled due to</th>
<th>Number disabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault outages</td>
<td>25</td>
</tr>
<tr>
<td>Load Transfer</td>
<td>5</td>
</tr>
<tr>
<td>Planned outages</td>
<td>14</td>
</tr>
<tr>
<td>Other</td>
<td>25</td>
</tr>
</tbody>
</table>

The 57 schemes which failed to operate are largely attributed to plant or communications failures.

Outstanding defects on the network, or special operating conditions applied for safety reasons may require numerous scripts to be disabled. At the end of the review period, it was estimated that an additional saving of 1.07 CI/100cc could have been achieved by rectifying all outstanding faults or defects on the 11kV network.

Communications failures – devices failing to respond when queried or commanded – result in scripts aborting. The EPN system uses a combination of radio, private wire and EDF Energy’s own copper pilot cables for communication to grid and primary substations (i.e. those with 132kV or 33kV in-feed), and uses the Paknet™ system for control of secondary switchgear which is installed on the 11kV network remote from a grid or primary substation.

Other reasons for incorrect automation operation may occur from protection grading (for example if a primary CB locks out following a fault which occurs downstream of a pole mounted auto-recloser). In this example, the fault would be assumed to be in the first half of a feeder whereas it is actually in the second half. Such a failing would result in a fault being transferred across the NOP and tripping the second (donor) feeder. Such an occurrence would be recognised by a control engineer and supplies restored. A similar scenario can result from the failure of a fault passage indicator. Such failings highlight the need for inspection and maintenance on the automated network.

At the end of the 2003/4 regulatory year (1st April – 31st March), 2.1M out of 3.42M customers were connected to circuits with automation schemes (62%). The success rates of each type of automation script are shown below.

Table 3 – Summary of automation script types

<table>
<thead>
<tr>
<th>Script type</th>
<th>No.</th>
<th>Custs ’000.</th>
<th>Ops</th>
<th>No Ops</th>
<th>CI Saved</th>
<th>% success</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>463</td>
<td>550</td>
<td>115</td>
<td>84</td>
<td>53425</td>
<td>58</td>
</tr>
<tr>
<td>B</td>
<td>57</td>
<td>76</td>
<td>6</td>
<td>3</td>
<td>3742</td>
<td>70</td>
</tr>
<tr>
<td>C</td>
<td>696</td>
<td>945</td>
<td>52</td>
<td>22</td>
<td>36145</td>
<td>71</td>
</tr>
<tr>
<td>D</td>
<td>179</td>
<td>371</td>
<td>17</td>
<td>9</td>
<td>15020</td>
<td>67</td>
</tr>
<tr>
<td>E1</td>
<td>21</td>
<td>38</td>
<td>1</td>
<td>90</td>
<td>784</td>
<td>67</td>
</tr>
<tr>
<td>E2</td>
<td>28</td>
<td>43</td>
<td>4</td>
<td>4139</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>12</td>
<td>24</td>
<td>1</td>
<td>784</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>14</td>
<td>28</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

† Modified version of type C
THE FUTURE

Automation on the EPN network at the current time is able to restore on average half the number of customers on each faulted circuit within three minutes. In order to optimise the restoration of customers and to accurately determine the fault location, a control engineer (and often several field staff) will be required. Where sufficient benefit can be demonstrated, it is a future goal to further divide circuits into more automated zones, so that automation scripts can restore more customers without an operator’s interaction. More elaborate scripts are being trialled to employ more detailed logic than the existing two or three zone scripts. Future improvements include the use of more than one NOP, as well as control of transformer or bus section circuit breakers to control fault levels in certain circumstances.

Due to the higher number of communications transactions between ENMAC and the switchgear, and the latency associated with each transaction, reaching the 3 minute restoration period with more complex scripts will be a real challenge. Nevertheless, there are benefits to be had in terms of customer minutes lost, and for modest additional outlay this will be a cost effective means of further improving network performance. Developments in communications are occurring continually, and will in time begin to reap benefits on our networks.

Additional applications

In addition to improvements for 11kV automation, applications can be found for automation on the higher voltage networks in EPN, beginning initially with 33kV and moving towards 132kV. Similar schemes can readily be implemented on the SPN network. In LPN, it is anticipated that automation will be applied to the Central London high load density network. This is an interconnected LV system and will require complex scripts and some network restructuring to implement effective automated switching.

Automation scripts also offer benefits in that they can be used to back-up normal protection operation; for instance Neutral Voltage displacement relays at primary substations fed by overhead lines will send an ‘inter-trip signal’ to the source CB if there is a fault causing displacement of the incoming phase-earth voltages. The automation scheme can send a backup trip signal which will operate the source CB if a fault or other reason has delayed the normal communication signals.

It should be noted that at no time will centralised automation be used in a safety critical role, i.e. its operation is used to support switching and never as a primary protection mechanism.

Automating load transfers away from substations following the loss of one transformer (a fault trip of an incoming feeder, or a fault internal to the transformer itself) is a cost effective means of maintaining security of supplies at heavily loaded substations, provided that adequate transfer capacity exists.

This option allows the short term emergency ratings of transformers and plant to be fully utilised during the switching duration. A risk of this approach is that should a script be unable to complete, large loads may exist on the remaining transformer(s), requiring rapid intervention from the control engineer to avoid a winding temperature trip of the remaining transformer(s).

CONCLUSIONS

Automation to date has served to save some 8.89 CI/100cc in 22 months across the EPN network, at very small cost over and above that required to install automated switchgear. No other investment plan to date has been able to achieve a similar performance improvement for such modest cost. As the CI savings continue, moderate investment will be needed to maintain existing automation schemes, offering an attractive CI saved/E value.

Automation has shown that there are a number of weaknesses on the network, as a result of communications failures, outstanding defects, or other reasons. As part of the assessment process, feeders have been identified which have transfer capacity bottlenecks caused by small section conductor or component ratings. The roll-out of automation has highlighted these weaknesses, allowing them to be incorporated in the future work plan for the network. Addressing these issues is part of the ongoing installation process, and exciting opportunities for automation have been identified as a result.

It is an eventual goal to achieve almost complete coverage of the EPN network with working automation schemes. For the short to medium term, automation will be installed on those feeders where most benefit will be derived, provided that the benefit justifies the cost. This will mean installation of additional automation on automated feeders in latter years, with some feeders (e.g. single customers) being left with no automation schemes at all.

Installation of automation on the East of England network has provided great improvements in network performance, and is expected to bring reductions in operating costs as it becomes more established on the network. As a direct consequence of automation, customers will benefit from a more efficient and secure network for years to come.

ACKNOWLEDGEMENTS

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REFERENCES