BENEFITS OF LARGE SCALE URBAN DISTRIBUTION NETWORK AUTOMATION AND THEIR ROLE IN MEETING ENHANCED CUSTOMER EXPECTATION AND REGULATORY REGIMES

C M Walton and R. Friel

London Power Networks (LPN) UK

INTRODUCTION

Keywords: Remote Control, Automation, Security, Reliability, Condition Monitoring, Restoration, Telemetry, Worst Served Customers, Interruptions.

Multiple interruptions

The UK regulatory framework for electricity distribution has been continuously evolving since privatisation in 1990. In 1995 it was recognised by London Electricity that increasingly the regulatory would seek to put into place incentive systems that would reward improved levels of network performance delivered at lower cost. Recent developments in terms of frontier efficiency and competitive incentives between companies have further accelerated these trends.

London Electricity and LPN have developed and implemented a comprehensive distribution network automation system for managing large scale urban distribution networks. Remote control and telemetry has been installed at over 4000 substations of 5000 currently authorised and network automation is being progressively introduced. The paper considers the key drivers, lessons, benefits delivered and outlines the proposed future development of urban distribution.

The paper shows the correlation of progress of quality of supply statistics with the number of Remote Terminal Units installed by understanding what is happening on the network and taking a proactive approach. Operational savings are evident and the adoption of widespread Condition Monitoring is just beginning to deliver real benefits.

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At Medium voltage the number of customer minutes has already halved and will fall still further as further degrees of automation are fully commissioned. The percentage of customers restored at MV by remote control has risen steadily form from virtually zero to around 60%.

Customer satisfaction has improved considerably and complaints to the Regulator concerning MV faults have fallen to an all time low. The risks associated with major incidents have been bounded

The programmable logic within the RTU provides distributed intelligence capability that can be utilised either independently or in conjunction with the central control processor. LPN’s current network automation implementation includes a variety or network automation options that have the capability to substantial reduce sustained customer interruptions. Around 3% of interrupted customers are already being restored within 20 seconds and with the commissioning of sequenced switched automation during 2001 the level of restoration is expected to rise to approximately 50% within 60 seconds.

The paper consider some of the lessons learned concerning communications, project management, upgrading of existing MV switchgear, reliability and the management of telemetry data.

Network Automation is proving excellent for LPN’s circumstances it has proved flexible and reliable. It is delivering the planned benefits and more now. There is lots more potential still to come.
AVANTAGES DE L’AUTOMATISATION A GRANDE ECHELLE D’UN RESEAU DE DISTRIBUTION URBAIN ET SON ROLE DANS L’AMELIORATION DE LA SATISFACTION DU CLIENT ET UN REGIME REGLEMENTE

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INTRODUCTION :

Mots-clefs : Contrôle à distance, automatisation, sécurité, fiabilité, surveillance de l’état d’entretien, rétablissement, télémétrie, client le plus mal servi, interruption, interruptions multiples.

Au Royaume-Uni La réglementation sur la distribution de l’électricité a continuemment évolué depuis sa privatisation en 1990. En 1995, il était reconnu par London Electricity que de plus en plus, la réglementation chercherait à mettre en place un système qui récompenserait les entreprises ayant de bonnes performances tout en gardant un coût réduit pour le client. De récents développements en termes d’efficacité (performance et coût) et compétition entre les entreprises ont accéléré ces tendances.

London Electricity et LPN ont développé et mis en œuvre un système automatique qui permet de gérer de grands réseaux de distribution urbains. Des appareils de contrôle à distance et de télémétrie ont été installés dans approximativement 4000 des 5000 sous-stations actuellement autorisées et l’automatisation du réseau est progressivement mise en place. La présentation parle des idées clefs, leçons, bénéfices apportés et souligne les possibles développements futurs de la distribution de l’électricité dans un milieu urbain.

La présentation parle de la corrélation du progrès de la qualité de distribution avec le nombre d’appareils contrôlés à distance installés (RTU :
REMOTE TERMINAL UNITS)

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<tr>
<th>Moyenne-Tension existants, fiabilité et gestion des données télémétriques.</th>
<th>Amélioration</th>
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<td>L’automatisation du réseau s’est avérée excellente. Pour LPN, elle s’est révélée flexible, fiable, apporte les bénéfices prévus et laisse beaucoup d’espoir pour l’avenir. Un potentiel énorme est toujours à exploiter.</td>
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En Moyenne-Tension, le nombre de minutes perdues par client a déjà baissé de moitié et va continuer à baisser car l’automatisation du réseau se poursuit. Le pourcentage de client ayant eu un rétablissement de la moyenne tension à l’aide d’appareils contrôlés à distance a augmenté considérablement, passant de 0% à 60%.

La satisfaction du client a augmenté considérablement et les plaintes au régulateur concernant les défaillances Moyenne-Tension sont historiquement au plus bas. Le risque associé avec les incidents majeurs a été limité en comprenant ce qui se passe sur le réseau et en adoptant une approche anticipée. Les économies opérationnelles sont évidentes et l’adoption de la surveillance de l’état d’entretien commence juste à apporter des bénéfices.

La logique programmable des RTU offre une intelligence distribuée qui peut être utilisée indépendamment ou en conjonction avec le processeur de control central. Les automatisations du réseau de LPN incluent une variété d’options qui sont susceptibles de réduire considérablement les coupures d’électricité. A peu près 3% des coupures sont déjà rétablies dans les 20 secondes. Avec la commande d’automatisations a commutation successive en 2001, le pourcentage de rétablissement dans les 60 secondes pourra atteindre 50%.

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INTRODUCTION

London Electricity and LPN have developed and implemented a comprehensive distribution network automation system for managing large scale urban distribution networks. Remote control and telemetry has been installed at over 4000 substations of 5000 currently authorised and plans for network automation are well advanced. The paper considers the key drivers, lessons, benefits delivered and outlines the proposed future development of urban distribution.

London’s predominant network assets comprise approximately:
- 2,000km EHV cables (above 11kV)
- 19,000km LV cables
- 8,000km MV cables
- 100 EHV/MV substations
- 13,000 distribution substations
- 2.1m customer connections

London’s Network is characterised by high load & customer density with high customer numbers per circuit, per km and per transformer. Fault rates are generally not proportional to route length but rather to customer density. Third party damage occurs everywhere.

London Environment
The cost and disruption of reinforcement cable laying is very high and Londoner’s don’t want their streets dug up. Added to which are traffic congestion, security arrangements and difficult plant access. The extensive urban re-development, requires resilient systems for the needs of a dynamic city.

REGULATORY FRAMEWORK

The UK regulatory framework for electricity distribution has been continuously evolving since privatisation in 1990. In 1995 it was recognised by London Electricity that increasingly the regulatory would seek to put into place incentive systems that would reward improved levels of network performance delivered at lower cost. Recent developments in terms of frontier efficiency and competitive incentives between companies have further accelerated these trends.

At the outset of developing it’s Technology Strategy, London Electricity recognised that the systems employed must have the flexibility and capability to respond to developing customer and regulatory issues.

Figure 1 above demonstrates the relationship between incidents, interruptions and customer minutes lost. This clearly shows that whilst by far the most incidents occur at low voltage, the medium voltage (MV) systems cause by far the most customer disruption. It comes to be of no surprise therefore that investment has initially centred on reducing the impact of MV system incidents and disruption.

REMOTE CONTROL

The first phase of the plan was to establish some 4000 MV/LV substations with remote control facilities to achieve the company’s quality of supply targets, particularly for Customer Minutes Lost and Restoration and to establish a sound base form which to develop full network automation facilities.

At peak some 40+Remote Terminal units (RTUs) were commissioned each week. A further 1000 units have since been authorised for completion during 2001/2 making London’s MV network automation scheme one of the largest in existence.
RISK CONTROL

risk = probability x consequence

Active Asset Management will include an assessment of the relative network risks, including the risk of ‘improbable’ events and implement appropriate risk control measures

Risk Control

MV Faults are infrequent but the consequences can be high. Remote Control bounds the risks of major events

by reducing the probability

Exercising switchgear reduces failure
Condition monitoring with remedial action
Automated securement of supplies

by reducing the consequences

Minimising number of customers affected
Knowing status of network and keeping customers advised
Restoration in seconds or minutes not hours

STRATEGY

The strategy for the programme was based on:
Understanding fault statistics and causation and executing remedial works for Worst Served Networks and known poor condition assets. Use of Remote Control to bound the remaining risks. A pilot 30 RTU system to gain first hand experience of the technology. Prioritising networks by substation performance with Outer London radial networks first and Central last

A structured and upgradeable standardised approach rather than circuit by circuit design. Slick installation & commissioning systems. Distributed AND centralised intelligence. Stand-alone central control system initially with full integration with main control systems after principle benefits delivered and systems proven.

Population of remotely controlled switchgear

Main Substations networks were selected for remote control with distribution substation being automated at 1:4 or 1:2 population depending on the level of assessed risk. Double actuator Ring Main Units (RMU) were selected for flexibility and network automation development. This simple approach has proved to be very powerful in that it is easy to upgrade from 1:4 to 1:2 to 1:1, needs very little planning or administration and is very resilient for networks that are constantly changing and evolving.

Where the first section of circuit from the Main Substation to the first distribution substation is particularly long and on a higher risk networks, then the first unit has also been automated so that a fault on the first section of cable can be isolated and all supplies can be restored quickly by remote switching.

Telemetry

Comprehensive control & telemetry including:

<table>
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<tr>
<td>Voltage</td>
<td>MV switching &amp; status</td>
</tr>
<tr>
<td>Load</td>
<td>LV switching</td>
</tr>
<tr>
<td>Temperature</td>
<td>EFPI &amp; DEFPI alarms</td>
</tr>
<tr>
<td>Harmonics</td>
<td>Programmable Logic</td>
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<tr>
<td>Out of balance</td>
<td>Automated Battery test</td>
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<tr>
<td>LV Disturbance</td>
<td>Remote software download</td>
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<tr>
<td>Security access</td>
<td>Radio</td>
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<tr>
<td>Condition monitoring</td>
<td>PSTN</td>
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Fibre

MV SWITCHGEAR AUTOMATION

Ring main units (RMUs)
The cost of delivering enhanced MV switchgear functionality have been minimised by the three R’s:

- Retrofit of SF6 units without actuators
- Refurbishment of selected oil RMUs
- Replacement of unsuitable switchgear

In each case a standardised plug & socket specification for RTU connection has been adopted. Suppliers test and field staff commission against a standard test box

Refurbishment can extend the life oil RMUs, particularly for those sites where the cable and plant access routes are tortuous. Actuators and oil temperature monitoring/alarm facilities have been developed for a variety of RMUs and nearly a thousand such conversions have already been successfully completed:

Main substation telecontrol

It has also been necessary, as a parallel project competing for MV circuit access, to install telecontrol and telemetry facilities on 1700 feeders at 100 main substation sites. Again the 3 R’s principle has been employed. The system is fully integrated with the main control graphics system providing real time control and loading

QUALITY OF SUPPLY RESULTS

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<tr>
<td>Overall Restoration in 3 hrs (%)</td>
<td>81.1</td>
<td>84.5</td>
<td>3.4 percentage points</td>
</tr>
<tr>
<td>Reliability (faults per 100km)</td>
<td>17.1</td>
<td>15.0</td>
<td>12.4%</td>
</tr>
<tr>
<td>Worst Served Customers (groups)</td>
<td>65*</td>
<td>23</td>
<td>64.6%</td>
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The results of the programme have produced very significant improvement in all of the standard rolling year reporting measures:

SAIDI (MV Customer Minutes Lost)

![SAIDI Graph]

PRITM (EHV/MV % restored in 30 minutes)

![PRITM Graph]

SAIFI (Frequency of interruptions)-- Sectionaliser and auto-changeover (Flip flop) benefits are just beginning with an estimated 3% reduction in interruption for 2000. Trials of sequenced switched automation from Spring 2001 are expected to result in a substantial reductions (up to 50%) in sustained outages where commissioned.

Customer complaints to OFGEM concerning MV faults have fallen steadily to an all time low eg none at all in some months since October 99 despite typically 30 MV faults.

Remote control system performance

Inevitably there have been a range of commissioning issues but overall the system delivers high performance and reliability.

- 25 minute commissioning (6-10 new sites a day)
- 20 Second operation (30-40 routine operational controls a day) 99.94% reliability (with very few failures in service)

The reliability of the dial up telephone modem sites is good but relatively slow (30seconds). There have been some line faults and line negotiation with telcos operators can be fraught. The 3500 radio sites have proved fast, efficient and generally very reliable. Some initial tuning was necessary to optimise performance which now peaks at 10% of proven message capacity. Occasional problems have been encountered with vandalism of aerials and close parking of high sided vehicles can cause delays whilst an alternative transmitter is sought.

NETWORK AUTOMATION

The programmable logic within the RTU provides distributed intelligence capability that can be utilised either independently or in conjunction with the central control processor. LPN’s current network automation implementation includes:

Parasitic Load Trip Unit (PLTU)

In the central area of London the LV network runs in a fused mesh supplied by several MV feeders such that loss of a single MV feeder should not cause loss of supply. If large MV point loads are connected to such meshed groups then the operation of the LV networks can be compromised under MV fault conditions.

The PLTU detects the loss of one or more MV phases and enables non critical MV loads to be automatically disconnected, preserving the integrity of the LV mesh from high levels of through current. The PLTU has enabled MV point loads connected to such mesh networks with standard Ring Main Unit switchgear and without the need for complex protection systems.

The PLTU can be combined with the Flip Flop auto-change logic to transfer supplies to alternative feeders within about 20 seconds. Several hundred installations such have been completed each producing significant capital cost savings for customers and LPN alike. Performance has been excellent.

Sectionalisers

Because of the density of housing in some parts of London, some MV feeders can have up to 4000 customers interrupted per 11kV feeder fault compared to an LPN average of 1650 (and a UK average of 520). For some of these feeders with very high customer numbers and higher than average fault rates, additional sectionalising circuit breakers have been introduced part way along feeders. RTUs provide circuit breaker control, inhibit and status indication. The advantage is that only those customers beyond the sectionaliser are interrupted for faults at the remote end of the feeder. However, for faults at the beginning of the feeder, sectionalisers add nothing beyond another remotely controllable switch point.

The use of sectionalisers has so far been limited by the availability of suitably sized and costed switchgear to fit within existing substations and the knowledge that for most circuits sequence switched automation will soon provide a more comprehensive and lower cost automation solution using standard switchgear.
Options to expand sectionalisation into fully meshed MV networks with adaptive protection and logic control have attractions for higher risk, high customer number networks. Technical options have been explored and scoped but will not be deployed unless there are clear business benefits from doing so.

**Flip Flop auto changeover**
Most of LPN’s MV feeders are normally run radial but usually have at least two Normally Open MV switching points that can be used to transfer load to other feeders. On average at least one of the distribution substations supplied by each feeder will have an alternative supply available when its normal source is faulty. The Flip Flop logic within the RTU logic detects if there has been a loss of supply on all three LV phases for more than 5 seconds (to allow for MSS autoclose operations), opens the MV switch towards the faulty section of MV cable and then closes the MV switch to the alternative feeder supply.

If LV supplies are restored then the RTU reports successful operation to the control centre. Should LV supplies not be restored (because the alternative feeder is also dead) then the RTU logic restores the initial operation arrangements automatically. Some 700 substations at Normal Open points have had the flip flop logic commissioned. The logic disabled remotely whilst routine switching is being undertaken and re-enabled again on completion.

This simple form of network automation has proved to be remarkably effective, currently restoring 5-10 distribution substations a month within 20 seconds and reducing overall sustained interruption by at least 3%, a figure than should progressively rise to around 7% at an incremental cost of the logic scripting.

**Simple Sequenced Switched Automation**
A combination of central and distributed intelligence is being developed for LPN for commissioning in Spring 2001. These trials will to begin the process of large scale automation of radial systems though the use of simple predetermined switching sequences to restore supplies following a MV fault.

A substation toward the centre of the feeder, has its internal RTU logic selected such that if it senses loss of supply on all 3 LV phases for more than 5 seconds it automatically opens a pre-selected MV switch to divide the feeder into two sections. On receipt of confirmation of the switch opening and the Earth Fault Passage indicator the central controller can automatically decide which Normal Open Point to an alternative feeder to close.

Assuming that half the customer are located on either side of the centrally selected substation then typically 50% of MV supplies should be restored in under 60 seconds.

**Automation switching time**
In practice there is only a very limited amount of logical switching that can take place within the UK’s Transient Interruption time of 60 seconds.

Following representations from the UK industry it has been agreed that from April 2001 OFGEM will adopt the 3 minute Short interruption time of the European Norm BS EN 50160:1995 which has been specifically set to facilitate effective network automation. This change in standards opens the possibilities that much more can be accomplished by extended sequences of MV switching. It is expected that changes to the centralised software enhancements will open the possibility of progressively enabling the proportion of MV supplies this to be restored automatically to be raised to at least 75% within 3minutes where implemented. Further more sophisticated approaches using Artificial Intelligence and more remotely controlled switching points have the potential to produce still better and faster results.

**Reliability & condition monitoring**
In order to optimise the use and life of expensive power system assets, RTUs have been provided with significant condition monitoring capability.

Some options to be considered include:
- Transformer use of life
- Transformer oil temperature & condition
- Switchgear oil temperature
- Partial discharge of MV switchgear & cables
- LV fault analysis

**LESSONS**

**Value for money**
Evaluation of the initial 30 RTU Pilot scheme showed how much more value we could get from a longer term vision than simple single actuator remote control system. This led to the development of an overriding and coherent technology strategy which has proved invaluable.

Throughout the programme further opportunities for getting more value have emerged. The timing of such upgrades needs careful consideration to maximise benefits whilst minimising the costs and risks of making enhancements on a live operational system. Getting the system right before fully integrating with existing main control systems has significantly speeded up change management and reduced overall project and operational risks significantly.
Programme efficiency
A major programme has to be slick, if costs and downtime are to be minimised, some key learning points in driving efficiency have been:

- Hardware - Simulator box to prove product conformity
- Software - Version control and rigorous checking of parameter limits
- Processes - Make it slick and easy to do right first time
- Assets - Manage the version and status of the assets
- Architecture - Simple rules empower field staff
- Substation data-points - Standard templates save time

Project management
The project has been a huge multi-contractor project executed with very few project managers.
Experience shows there to be an overwhelming case for a dedicated and empowered project delivery team.
Prioritising networks to deliver maximum performance improvement first, can conflict with efficient project execution and circuit access constraints and some flexibility is essential.
Resource scheduling of multiple sites and contractors with significant operational constraints is complex and if not well managed can prove critical.
Phasing the technical challenges and risks has been essential to maintain progress eg avoid all the difficult sites being left to last!
Consistency of purpose and investment really is essential to the efficient execution of such a project and the delivery of maximum benefits.

Lessons from experience
Efficient and reliable communications really are critical to efficient operation, commissioning and future automation. The EMC environment proved tougher that had been anticipated and distribution transformer switching surges in particular.
Active control room alarm and condition monitoring information systems will become more and more important as distributed intelligence becomes widespread in order to manage the volume of data and communications.
The importance of an efficient remote software upgrade capability cannot be understated as any change which requires visiting 1000’s of substations is very bad news indeed.
Simple and fast commissioning procedures are essential, and new processes and training will be required. Control staff take on and do more and more routine switching (virtually all switching schedules now include at least 25% remote operations). Well honed procedures enable field and control staff to reap the benefits from both remote control and telemetry

LESSONS IN BENEFITS
Customer satisfaction has improved considerably and OFGEM complaints concerning MV faults have fallen to an all time low. The risks associated with major incidents have been bounded by better understanding what is happening on the network and taking a proactive approach. Operational savings are evident and the adoption of widespread Condition Monitoring is just beginning to deliver real benefits. There is scope for developing MSS transfer capability and exploiting differences in the seasonal loading patterns.
Significant economies in project execution and contractor management have come through consistency and scale.
The system has provided a sound foundation for next generation of Smart network design, optimisation and management. Exploiting the full range of potential benefits is dependent upon being able to invest in a consistent and timely manner.

APPLICATION TO CENTRAL LONDON
The next major phase that has recently commenced is the move into the Interconnected LV networks of Central London where there are very different objectives and issues to address.
For interconnected networks the objective is bounding risk of long outages (cascades) by securing supplies by switching immediately after an MV fault and before, rather than after losing customer supplies.
Remote control of LV Circuit Breakers provided for Reverse Power protection is necessary (using the 3 R’s approach ). Even higher utilisation of transformers and circuits then becomes possible thereby reducing the need for costly and disruptive conventional cable & substation reinforcement. Radio is not generally viable as most substations are located deep within buildings and most sites are using dial up telephone lines.

SUMMARY
Network Automation is proving excellent for LPN’s circumstances it has proved flexible and reliable. It is delivering the planned benefits and more now. There is clearly lots more potential still to come.

It is to be expected that urban distribution systems of the future will be designed to operated by Smart systems running under Artificial Intelligence, optimising running arrangements, asset condition & losses. Real time condition monitoring will be standard and customer expectations will be still higher. Remote control & automation of LV systems will be normal in the continuing drive for frontier efficiency and competitive advantage.