ACTIVE NETWORK MANAGEMENT FACILITATING THE CONNECTION OF DISTRIBUTED GENERATION AND ENHANCING SECURITY OF SUPPLY IN DENSE URBAN DISTRIBUTION NETWORKS

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ABSTRACT

The Low Carbon London (LCL) project has explored the impact of a wide range of low carbon technologies, including Active Network Management (ANM), on London’s electricity distribution network. This paper focuses on how ANM could enhance security of supply and facilitate the connection of additional distributed generation (DG). The outcomes illustrate the potential benefits of using ANM in urban networks and provide guidelines and recommendations for implementation.

INTRODUCTION

UK Power Networks, who owns and operates the urban electricity distribution network within London as the Distribution Network Operator (DNO), has now completed the £28.3-million Low Carbon London (LCL) project (2010-2014). The project has been partially funded by Ofgem, the UK’s energy regulator, through the Low Carbon Network Fund (LCNF).

The learning, insights and data from all the LCL trials have been collated and analysed to understand how the outcomes could be replicated in other large cities. These learnings are captured in an integrated set of learning reports, which will be publicly available online [1]. The reports present a comprehensive analysis offering a practical guide for DNOs on the implementation of smart grids for the electricity distribution network.

Urban networks present particular challenges, such as security of supply and fault level constraints, due to their dense concentration of demand and increasing distributed generation (DG). Five ANM systems, supplied by project partner Smarter Grid Solutions, provided the real-time, deterministic, autonomous control required to tackle these challenges. Details on ANM can be found in references [2] and [3], including the high-level ANM architecture used in LCL.

The paper is organised in two sections, each addressing one of the major objectives for ANM in the LCL project:

- Understand how ANM could enhance security of supply on the distribution network with the support of DG [4].
- Inform how ANM could facilitate the connection of additional DG to urban networks like London [5].

ANM ENHANCING SECURITY OF SUPPLY

Growth in distributed generation

In recent years, there has been a steep growth of DG connected to distribution networks, including in the London electricity distribution network. As shown in Figure 1, the capacity of large-scale DG (above 16 A per phase) now installed in London is around 1.2 GW (c. 20% of maximum demand). Small-scale DG (below 16 A per phase) accounts for around 8 MW in London, consisting of c. 2,700 generators with over 98% being photovoltaic (PV). A combination of factors, including targets for 25% of energy in London to come from decentralised sources by 2025, means further growth in DG is expected.

Figure 1: Large-scale DG (above 16 A per phase) capacity connected to the London network
The diversity of DG and its utilisation in London has changed in the last 10 years, with a large proportion being currently diesel and combined heat and power (CHP) plants, mainly installed in office buildings or other in-building applications. Urban networks typically host CHP, diesel and small-scale PV, making the DG mix very different from rural areas, where wind and large-scale PV predominate.

As part of the LCL DG monitoring trial, the project instrumented 15 DG sites, covering both CHP and PV large-scale generators. DG output profiles have been derived using these sources and enhanced by other data sets, producing profiles that can inform industry guidelines and can help DNOs better understand the behaviour of the DG connected to their networks.

Two types of CHPs have been identified based on their operation:
- Cyclically operated CHPs, which tend to be located within sites with a defined occupancy based on opening hours (e.g. leisure centres and offices).
- Continuously operated CHPs, which tend to be located on sites that are occupied 24 hours a day (e.g. large industrial sites or hospitals).

Figure 2 provides an example generation profile for a typical cyclic CHP in the summer, where CHPs switch on between 04:30 and 07:00 in the morning and switch off between 19:30 and 00:30 in the evening. This variability translates into an availability profile based on the portfolio observed. The power output profile is based only on the CHPs that are running. CHP plants are heat-led and typically sized to run at 80-90% of capacity. This means flexibility in electricity production is normally limited to 10-20% of rating, unless effective means of managing heat is available.

**Management of DG**

The following approaches for enhancing the contribution of DG to security of supply have been explored:

- Passive management of DG is based on monitoring only to improve visibility and understanding of DG behaviour and thereby better inform network planning and operation decisions. 
- Active management of DG is based on monitoring and controlling generators to enhance the expected availability of DG and thereby recognise higher contribution factors when assessing security of supply. The aim is to match DG operation with times of peak demand and thereby support network operations during planned or unplanned outages.

In recent years, significant progress has been made across the industry with 'constrain-off' (curtailment) methods to provide access for additional DG to constrained distribution networks more quickly and cost-effectively. This paper examines the feasibility of using ANM to issue 'constrain-on' signals to DG situated on urban networks for enhancing their contribution to security of supply and maintaining the existing network within the safety limits. Figure 3 illustrates how ANM can keep the power flow in the network below the limit by 'constraining on' DG when it would have switched off and thereby preventing the import power flow from breaching limits.

The shape of the substation demand profile can be important in determining which approach is suitable. An ‘n’ shape load (Figure 4, left) is typical of central London areas (e.g. commercial offices) with an afternoon peak, while the ‘m’ shape profile (Figure 4, right) is characteristic of residential areas with morning and evening peaks. If there is high confidence that DG will operate through the day and help meet an ‘n’ shape peak, then passive management may be sufficient. Alternatively, with an ‘m’ shape profile, active management may better provide the necessary certainty that the DG turns on early enough and stays on late enough to satisfy both peaks.

Installing full-scale monitoring or active control in all substations is not required and would eventually present diminishing returns for a DNO. Additionally, it will be
Figure 4: Average network load curve at two primary substations in London

Table 1: Contribution of DG to security of supply for one substation in the London network

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<thead>
<tr>
<th></th>
<th>Active management</th>
<th>Passive management for maximum DG able to connect</th>
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</thead>
<tbody>
<tr>
<td>Existing DG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM capacity</td>
<td>13.92 MW</td>
<td>31.68 MW</td>
</tr>
<tr>
<td>Contribution to security of supply</td>
<td>10.45 MW</td>
<td>24.19 MW</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Maximum DG able to connect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM capacity</td>
<td>20.43 MW</td>
<td></td>
</tr>
<tr>
<td>Contribution to security of supply</td>
<td>7.27 MW</td>
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Contribution of DG to security of supply

An increasing level of DG distorts conventional measurement of demand, masking the true underlying load. However, growth in DG provides new opportunities for enhancing security of supply. The Engineering Technical Recommendations (ETR) 130 and 131 [6] [7], which provide a guideline on how to assess security of supply, was followed to demonstrate in three London case studies how DG can contribute to security of supply, based on the current regulation on security of supply in the UK (Engineering Recommendation P2/6 [8]).

The analysis suggests that the contribution of DG to security of supply is substation and approach specific. Table 1 presents an example of the results for one substation in the London network, showing how different capacities of DG could be connected using different approaches and how this resulted in different levels of contribution to security of supply.

The contribution that DG can make to security of supply can be greatly enhanced by using ANM to control the dispatch of that capacity, essentially using the DG as a form of Demand Side Response (DSR). This additional contribution to security of supply can lead to deferral of reinforcement spend, providing more value to the DNO and its customers. In some of the case studies, that value can be significant (e.g. up to £441k at one of the studied substations). However, the benefit available varies greatly according to the specific substation, and will depend on factors like the number of generators that require ANM equipment to be fitted and the types and configurations of the monitoring equipment required.

ANM FACILITATING DG CONNECTIONS

The barriers to connections in urban areas are most often associated with fault levels, rather than thermal or voltage constraints. ANM can facilitate additional capacity for DG under fault level constraints based on two principles:

- Network reconfiguration; and
- Status of short-term parallel (STP) generation.

Modelling methodology

The methodology followed in the LCL project consisted of a high-level review of the fault level headroom based on the two principles above, as illustrated in Figure 5.
Recognising the network reconfiguration

This applies to cases where the fault level headroom is different based on changes in network configuration (i.e. in outage conditions) and the binding constraint is given by the abnormal N-1 conditions due to the decreased fault level headroom triggered by the reconfiguration of the network. ANM could provide access to the difference in fault level headroom between the intact and the N-1 conditions. That difference determines the maximum capacity that could be connected under this principle by disconnecting the flexible DG when in the abnormal condition. ANM would monitor both the network configuration and the DG that contributes to the substation with the fault level constraint.

The LCL analysis compares the feasible DG capacity calculated for the normal network conditions with the value calculated for the worst-case conditions. The worst-case conditions currently set the limit on firmly connected DG. ANM would facilitate the connection of additional capacity up to the limit given by the normal conditions.

Since the disconnection would only be enforced under particular network reconfigurations during outage conditions, the curtailment of ANM-enabled DG would be very low. Based on typical measures such as a 20% probability of a fault on any given circuit in any one year and an average time for fault repair of 48 hours, a rough estimate is that DG enabled by ANM in this way might expect to be disconnected for less than 10 hours per year.

ANM provides added flexibility and integration compared to other traditional methods, such as automatic reconnection and easy reconfiguration of parameters.

Recognising the status of STP generation

DG with a short-term parallel (STP) connection starts generating power in island mode after loss of mains supply and only connects to the network for a very short period (i.e. between 1 and 5 minutes), switching off after mains power has been fully restored. DG with a long-term parallel (LTP) connection can connect to the network for an unlimited time, at any time, subject to control room approval. The current split in London is around 80% LTP and 20% STP, with most of the STP being diesel back-up generators.

Where generation has an STP connection, and has therefore been assigned fault level capacity, ANM can facilitate the connection of additional DG to use that capacity when the STP is not connected. The restriction imposed by ANM is to disconnect the additional DG when the STP DG is online.

The LCL analysis quantifies the fault level headroom that ANM could release by considering the total capacity of STP DG. The released capacity for additional DG is assumed equal to the capacity of existing STP generation (i.e. the contribution of new DG to fault level is assumed the same as the existing STP). If new DG had a lower fault level contribution (e.g. new PV compared to existing STP diesel), the capacity released for additional DG could be higher. Given that released capacity is proportional to the capacity of STP that is monitored, the greatest gains are to be achieved by monitoring the largest STP generators (or those with the highest expected fault level contribution).

Since the disconnection would only be enforced for the short period the STP DG is online after an outage, the curtailment of ANM-enabled DG would be very low. A typical operating regime for an STP generator may see it being tested once a month and run in parallel with the network for 5 minutes. Therefore, a rough estimate is that DG enabled by ANM in this way might expect to be disconnected for less than one hour per year.

This type of flexible connection is also possible using other traditional solutions but ANM offers advantages in dealing with more complex situations because of its inherent configurability and the flexibility to manage different types of constraints on a single platform.

Results for fault level headroom under ANM

All 114 primary substations in the London network were assessed in terms of fault levels and ANM-enabled capacity for additional DG, as per the modelling methodology and assumptions described above. The potential benefit of ANM for the two principles outlined above are summarised in Table 2. Note that there is only partial overlap in the substations where capacity is unlocked. This analysis indicates that up to an additional 619 MW of DG could be connected across 88 primary substations if ANM was fully implemented in London, representing a significant increase in the total potential DG capacity.

<table>
<thead>
<tr>
<th>Table 2: ANM-enabled DG capacity unlocked by recognising network reconfiguration and STP generation</th>
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<tr>
<td>Using ANM to recognise network reconfiguration</td>
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<tr>
<td>---------------------------------------------------------------</td>
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<tr>
<td>Number of substations where additional headroom can be accessed</td>
</tr>
<tr>
<td>Total acceptable new DG capacity</td>
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<tr>
<td>Average acceptable new DG capacity per substation</td>
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CONCLUSIONS AND NEXT STEPS

The Low Carbon London (LCL) project provides results of interest and relevance to Distribution Network Operators (DNOs) everywhere facing the dual challenges of growth in distributed generation (DG) and demand. The emphasis of this report was on enhancing the security of supply in the network through the use of DG and on facilitating additional DG connections under fault level constraints due to the characteristics of dense urban networks. The business implications of active network management (ANM) are also valid where it is used to mitigate thermal or voltage constraints.

While existing levels of DG may currently be too low in many network areas to provide a robust contribution to security of supply, future DG growth will create notable opportunities for cost savings in network development. Installing additional monitoring will enable DNOs to identify the true underlying demand and provide the data required to justify recognising a contribution to security of supply from DG and plan the network accordingly.

ANM can help to improve network visibility and control. Network operators can use the additional data and flexibility for improving network performance and development, including the connection of new generation or load. ANM not only allows more DG to connect but can also enhance the contribution to security of supply made by new or existing DG. ANM can thereby help to reduce the overall costs of maintaining a secure network.

Small-scale DG can have a large impact on the network, including an increase in the masked underlying demand or power quality problems. Its expected volume make them hard to monitor and its specific regulation imply it cannot be controlled. Network planning and operation must take account of this growth. For example, UK Power Networks is forecasting an average of almost 45 MW of new PV connecting at low voltage in London every year during the next regulation period (ED1) from 2015 to 2023.

ANM represents a fundamental shift in network planning and operation. Facilitating the connection of DG is the first major step in the transition from a primarily passive DNO to the future vision of a Distribution System Operator (DSO). The learning from the LCL project makes a valuable contribution to this transition.

The benefit of additional DG connections accrues firstly to the DG developer/owner through facilitating additional connections to the network. The benefit to DNOs is linked to the specific regulations as incentives on, for example, customer service or the deferral of network reinforcement expenditure.

Given the difficulty (experienced and overcome through the LCL trials) of applying ANM to existing generation sites, a pro-active approach needs to be taken by DNOs when new DG installations are connected to the network. DNOs should track existing and future DG on the network to understand its impact and prepare for emerging opportunities in network management. DNOs should also explore how the outcomes of the LCL project can be applied to their particular network areas.

The new approaches developed to assess the benefits of ANM should be explored in collaboration with software providers and users, promoting a consistent approach across DNOs. Analysis tools and methods are already being shared across DNOs in the UK.

Technical guidelines and regulation should be reviewed industry-wide to enhance the security of supply based on current and expected DG penetration and modern utilisation profiles. All the relevant stakeholders should be involved so that both customers and network operator can benefit from the use of ANM to facilitate new DG connections and enhance network performance.

REFERENCES


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