Opportunities for flexibility exist across the energy system. This Information Paper provides an introduction to the concept of flexible electrical networks. It provides an overview of technical solutions that can be applied (by network and building designers, owners and operators), at either the network or built environment level, to increase flexibility in the energy system and assist the UK’s transition to a low carbon future.

It will be of particular interest to network and building designers, owners and operators. The techniques presented include recently trialled Distribution Network Operator (DNO)-led smart grid solutions that focus on increasing and enhancing the capability of existing network infrastructure in constrained areas.

The Information Paper also highlights built environment energy-efficiency opportunities that building designers, owners and operators can consider in order to save energy and reduce peak demand, while supporting wider network flexibility and efficiency.

1 Introduction

The Department of Energy and Climate Change (DECC) report Towards a smart energy system highlighted a number of challenges facing the UK’s energy system. It states: ‘most trajectories of energy demand and supply to 2050 anticipate significant new system challenges as we incorporate more low carbon generation, and meet increases in peak demand (typically 16:00 to 20:00 on winter weekdays), driven largely by the extent to which transport and heating become increasingly electrified’. The report highlights that under a range of future scenarios, peak demand is forecast to increase, and in some scenarios these increases could be very significant. In order to meet the increases in demand, DECC suggests that a large increase in low carbon generation is needed as well as a smart energy system that incorporates new forms of flexibility, smarter networks, energy storage, demand side response and increased interconnectivity. The report also highlighted that it may also involve a focus on energy-efficiency improvements which target peak demand.

It is anticipated that distribution networks will be required to connect and manage increasing levels of demand from electric vehicles, heat pumps and general load increases. The distribution networks will also need to manage increased distributed generation (eg large scale renewables) and other embedded generation (eg microgeneration at the built environment level). This growth of low carbon technology on the electrical network is widely expected to be rapid, in order to achieve ambitious climate change mitigation objectives. It is also expected to be localised, eg focussed on major centres of population or by geographical areas offering significant potential for distributed generation. As a result, DNOs are expected to have limited forward visibility to enable them to plan and implement network upgrades. This introduces a risk that the rate of change within some parts of the network may exceed the capability of DNOs to respond with traditional solutions. In addition, complexities associated with demand and generation profiles for low carbon technology have the potential
to significantly increase peak network flows and produce substantial voltage rises. Smarter, flexible network solutions are therefore required to deal with these issues as the rapid rate of change in how energy is generated, distributed, stored and used increases the risks associated with network integrity, as well as the quality of supply and service to customers.

2. What is a flexible network?

While a flexible network can take various forms, generally they are networks in which the novel use, or control, of existing network assets enables a cost-effective release of additional capacity headroom. Flexibility in headroom is an important aspect of a smart network, and this flexibility also presents other benefits including the possibility to defer or avoid costly traditional reinforcement.

2.1 A flexible network vs a traditional approach

Historically, network design practices (and reliability standards) have required that network design is based on worst-case assumptions with security being provided via redundancy in network assets. An example is shown in Figure 1.

Although there are benefits to this approach (such as security of supply), there are many downsides including significant redundancy in the energy system and therefore increased cost. Also, when dealing with increasing loads on constrained networks the traditional approach is to install additional capacity (ie building new substations, overhead lines and laying cables) which can be expensive, time consuming and disruptive. Therefore alternative, technically effective and economically efficient (flexible) solutions that enhance the utilisation of the existing network assets, can present significant benefits for network operators and customers.

One of the main drivers for flexible networks is to enable higher levels of low carbon technology to be accommodated while also enabling traditional reinforcements to be deferred until a greater degree of certainty on the nature of future loads can be established. The latter enables business decisions to be made without the risk of making inefficient network investment or stranded assets, eg installing additional capacity and then it not being fully utilised. The benefits of this flexible approach are presented in Figure 2.

Solutions that are faster and easier to deliver than traditional reinforcement will also be of significant value to a rapidly changing network. Research being delivered with the support of Ofgem’s network innovation\(^2\) theme is helping develop new, cost-effective and technically robust approaches that enable DNOs to:

- determine more accurately the capacity headroom while maintaining licence obligations
- exploit headroom in a safe, reliable and cost-effective manner
- provide incremental increases in headroom in a timely and cost-effective manner.

A number of evolving methods are available to exploit or increase capacity headroom. Some innovative measures are not yet sufficiently technically and/or economically proven whereas others are beginning to be implemented in ‘business as usual’ by UK DNOs. This Information Paper introduces four techniques, as recently developed, trialled and tested via the Flexible Networks for a Low Carbon Future project\(^3\). This project aimed to provide a 20% increase in network capacity in three constrained network areas via practical alternatives to costly traditional network upgrades. The project was co-funded by Ofgem under its network innovation theme via the Low Carbon Networks Fund\(^4\).

3. Enhanced network monitoring

Before introducing the flexible network techniques it is important to note that detailed network monitoring is a prerequisite for their application. Enhanced monitoring is greatly beneficial in improving knowledge of the distribution network, thereby enabling the ability to detect changes, extrapolate trends and identify appropriate responses.

Network monitoring data has traditionally consisted of relatively simple data associated with the monitoring of peak demands. Such monitoring is also commonly applied in a ‘fit and forget’ manner. Unfortunately, these approaches and systems are inadequate for effective network management as we move towards a smart grid. While enhanced network monitoring does not create any additional network capacity directly, the analysis of the data can assist in better decision making and more efficient use of existing assets. It is therefore a critical first step towards improved risk management and allowing operators to become more risk aware rather than simply risk averse.
Detailed network monitoring is a key factor in enabling:

- the identification of suitable applications for innovative network techniques
- the assessment of the potential performance of the techniques
- the evaluation of the performance of the techniques including assessment of the improvement and thus quantification of the costs and benefits of their application.

More detailed information on enhanced network monitoring is available in *Future energy monitoring network strategy*[^5], which was produced to disseminate knowledge from the Flexible Networks for a Low Carbon Future project[^3].

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<th>Benefits</th>
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<td>Energy efficiency</td>
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[^5]: Future energy monitoring network strategy
[^3]: Flexible Networks for a Low Carbon Future project

4 Innovative techniques

Four separate innovative techniques are explored below which offer the ability to increase capacity, enable greater connection of generators, or reduce customer demand (Table 1).

Figure 3 highlights the network locations where the techniques can be typically applied. Figure 4 shows the impact of each of the respective techniques on an indicative annualised load profile.

It should be noted that, with the exception of energy efficiency, these techniques focus on optimisation of the network operation and management i.e., they are network-based solutions in contrast to solely customer-based solutions (such as demand side management or other demand control techniques). While customer behaviour change is an important part of a wider low carbon network solution, value can equally be gained from improved utilisation and capacity release from network optimisation techniques.

![Figure 3: Network diagram showing locations where the flexible techniques are applied](image-url)

![Figure 4: The impacts of the techniques on a load and capacity](image-url)
Flexible network control concerns the use of controls to help re-balance network loading. This is achieved by using neighbouring network groups to support demand, via the integration of voltage regulation and power compensation equipment to release voltage constrained capacity. By applying these concepts flexibility can be improved so that, primarily, the 11 kV (and some 33 kV) network can be operated to enhance the existing network capacity. This can provide useful increments of network capacity, both relatively quickly and at reasonable cost. A range of flexible network control techniques exist, some of which make use of technology advances and cost reductions to allow deployment of approaches that may already be in use on the transmission and extra high voltage networks, at lower voltage levels. Other techniques focus on the specific issues that limit network capacity and aim to use better data and control to be able to reduce or remove the barrier.

While not an exhaustive list, innovative flexible network control techniques include:

- the development (and use) of packaged solutions for series voltage regulators and reactive power compensation
- implementing flexible network control on 11 kV networks
- the use of dynamic ratings on 33 kV networks

(see section 4.2)

Flexible network control via voltage regulators and reactive power compensators

Rural networks, or isolated urban networks, are often complex and difficult to reinforce due to long feeder lengths. These networks are also the ones that may be earlier adopters of low carbon technologies such as heat pumps and renewable generation due to their location and economic drivers (eg they may not be connected to the mains gas network). Often the network capacity limitation is due to the back-up capacity in the event of a network problem, rather than the normal intact network. Long 11 kV network feeders therefore tend to be voltage constrained rather than thermally constrained, and so the use of series voltage regulators, or in some circumstances reactive power compensation, can create useful levels of an incremental capacity in a relatively quick and low-cost manner.

Flexible network control on 11 kV networks

Incremental capacity can be created on the 11 kV (secondary) network by using flexible Network Control Points (NCPs) to link neighbouring groups (with spare capacity or different demand profiles) in order to dynamically transfer load between primary substations. For example, the use of automated 11 kV switches on secondary networks can provide the capability to dynamically transfer load between primary substations; historically it has generally been difficult to accurately quantify the benefits of this approach due to lack of robust data. Enhanced network monitoring and more specifically, improved secondary substation data monitoring (which can provide high resolution network data) is critical to evaluating and quantifying the benefits of this approach.

Overhead lines

Figure 5 shows the key weather-related (dynamic) variables that affect overhead conductor thermal performance.

Traditionally, DNOs have tended to apply (seasonal) static thermal ratings to overhead lines based on guidance within Engineering Recommendation P27[6] which makes a number of assumptions regarding ambient temperatures (winter = 2°C, spring/autumn = 9°C, summer = 20°C), wind speed (assumed to be a constant 0.5 m/s irrespective of season), solar radiation (no solar radiation is assumed irrespective of season) and design temperature of the conductor (50°C). While this conservative approach helps to protect the asset, available capacity can, under specific conditions, remain latent and unused within the system. As a result more innovative approaches are now being developed which provide dynamic ratings using an RTTR system.

4.1 Technique 1: Flexible network control

Implementing effective flexible network control also requires the dynamic control and actuation of transformer assets. This is typically via the substation central control units which marshal NCP data into the network operators control system (eg a SCADA system). The age and specification of plant is therefore a critical factor. Many older plant (with only very simple levels of control) will have restricted ability to integrate with the modern telecontrol required to implement flexible network control. The advent of computer processing in telecontrol is relatively recent when compared to the expected life of electrical plant on the distribution network.

If none of these restrictions applies, then it is likely to be possible to develop flexible network control that combines next generation telecontrol equipment with modern control algorithms necessary to release network capacity. Ideally, development of both of these aspects should be undertaken concurrently while considering limitations presented by either the software or hardware already in use. It is also likely to be critical to maintain backward compatibility with the current generation of telecontrol equipment.

Case study 1 (on page 12) presents additional considerations and findings following a flexible network control trial.

4.2 Technique 2: Real-Time Thermal Ratings

Historically, network operators have tended to apply a static rating to power lines and transformers in order to help protect the asset (and the wider system) by keeping the load on the assets under its static rating. More innovative approaches are, however, now available which provide dynamic ratings of assets using Real-Time Thermal Rating (RTTR) systems. RTTR systems are defined as a time-variant rating that can be practically exploited without damaging components or reducing their life expectancy. Actual measurements of asset conditions or key environmental conditions (eg wind speed, wind direction, ambient temperature and solar radiation) are input to steady-state thermal models before algorithms calculate the real-time dynamic thermal rating. For example, in overhead lines, RTTR systems can help provide a significant increase of transmission capacity compared to the static rating through the application of algorithms that take account of measured, real-time, conditions and/or forecast meteorological data.
Renewable generation (e.g., wind farms) is often located in rural locations where there is little or no spare capacity available on the network. Wind cooling, however, has a significant effect on the real-time rating. RTTR of overhead lines can therefore be particularly beneficial for wind farm connections since there is a correlation between the power output of wind farms at times of high wind speed, and the cooling effect of the wind on overhead line conductors. RTTR of overhead lines can therefore unlock extra capacity in the networks reducing reinforcement requirements and connection costs for generators.

A cost-effective approach to overhead line RTTR is to utilise a thermal state estimation model with system integrated sensors. The thermal state estimation model being based on heat balance equations within IEC TR 61597 Overhead electrical conductors – calculation methods for stranded bare conductors\[^7\], and CIGRE WG 22.12 Thermal behaviour of overhead conductors\[^8\]. A meshed network of weather stations, together with a detailed geographical model can then capture detailed weather parameters at specific locations and acts as inputs to the thermal model. Interpolation techniques can then be used to estimate the weather parameters at any location of the overhead line, and the RTTR at every location, or span, can be calculated and displayed within the distribution network control room. The span with the lowest rating can then be used as the limiting span for the RTTR circuit. To add protection, the ratings can be validated against a number of temperature sensors installed on the conductors (carefully selected to minimise the number and duration of outages required for equipment installation). Such an approach benefits the control room operators by giving them greater visibility of the actual thermal operating status of the network. It also ensures network integrity and that security of supply is not compromised. This gives increased confidence to DNOs to offer active network management solutions for prospective generation customers.

The key components of an RTTR system can be categorised as weather stations, monitoring equipment, communications equipment and information technology equipment.

To date, RTTR systems have typically been delivered via a consortium approach including, for example the DNO (or consultant acting on the DNO’s behalf), the weather station/monitoring equipment supplier, the communication solution provider and the information technology system supplier.

An example of a pole-mounted, meteorological and RTTR monitoring equipment installation can be seen in Figure 6. Tower and substation mounted solutions may also be required.

Case study 2 (on page 13) presents additional considerations and findings following overhead line RTTR system trials.

**Transformers**

Similar to overhead lines, traditional industry practice concerning transformer ratings also typically revolves around the use of fixed equipment ratings based on conservative seasonal conditions. Improved thermal management of transformer assets using real-time dynamic ratings can help to release additional network capacity. This could also potentially help avoid triggering unnecessary network reinforcement where there are relatively small levels of demand growth. National standards assign different thermal ratings to network assets during each operating scenario that takes into account both the representative equipment loading and typical ambient conditions. DNOs have typically adopted two approaches to this:

1. To ‘weather correct’ the demand to an Average Cold Spell (ACS) reference temperature, and then to use the rating of plant at this reference temperature. Typically, it is then assumed that if it is colder, demand will increase but at a slower rate than the increase in asset rating due to lower ambient temperature. However, this approach is difficult to apply to summer loadings and many network groups do not exhibit strong temperature dependency of demand.
2. To modify the rating to suit the season that the demand occurs within. Up to four seasons is most typical. Some DNOs have interpolated published ratings to give individual monthly ratings.

Some transformers may be suitable for careful, accurately controlled loading above its nameplate rating, thereby allowing additional transformer capacity to be realised. Similar to overhead lines, a dynamic RTTR system can be applied to such transformers although some DNOs are applying enhanced static thermal ratings to transformers as a quicker and more cost-effective intermediate solution.
The term enhanced thermal rating refers to a fixed enhanced rating (rather than a dynamic rating). The enhanced rating is typically determined through consideration of transformer-specific environmental and loading conditions. It is then verified through monitoring of the transformer duty temperature (Figure 7). Transformer condition assessments are also typically conducted in order to determine their suitability for enhanced loading. The condition assessment typically includes a number of activities as outlined below. Consideration of these condition-related factors can then be used to inform an estimation of the remaining life of the transformer asset, as this is a critical factor regarding suitability for enhanced loading.

Typical actions and consideration during a transformer condition assessment:

- collection and analysis of the available information on transformer characteristics, historic loading and historic through fault history
- detailed visual inspection
- thermographic inspection (Figure 8)
- online partial discharge measurement
- oil analysis (dissolved gases, quality, corrosiveness, furanic compounds)
- estimation of the remaining life on the basis of: furanic compounds in the oil and loading-guide calculation.

It is also important to consider that the typical load profile could change in the future due to the impact of changing loads arising from, for example, low carbon technology or new connections. There are tools available that allow designers to calculate the enhanced rating of primary transformers, provided that the characteristics of the transformers, their load profile and the ambient temperature are known. This enables the enhanced rating of transformers to be recalculated should there be a significant change in the load profile in future.

Case study 3 (on page 14) presents additional considerations relating to the use of enhanced ratings for primary transformers.

4.3 Technique 3: Voltage optimisation

The UK low voltage (LV) limits were partially harmonised with European voltage limits in 1990, when the 240 V +/-6% and 230 V +/-6% voltage limits were harmonised to 230 V +10/-6%. In practice, no physical changes were generally made to actual voltage settings as the old limits were largely captured within the range of the new. The European voltage limits are 230 V +/-10%. Given that most UK domestic appliances have been manufactured to operate within the European voltage limits since 1990, there is a growing consensus within the UK industry that it may be time for the UK to consider the full adoption of the European voltage range of 230 V +/-10%. While such a change would require DNOs to make changes to their voltage control policies and settings, the resulting voltage reduction can help create additional network capacity for the connection of embedded generation, as well as reduce energy use for customers.

Optimising the network voltage can also help reduce peak demand through better voltage management. In addition, it is generally recognised that overall system headroom for generation can be increased through better optimisation of voltage set-points and permissible voltage ranges thereby enabling connections of more embedded generation. Historically, it was assumed in the UK that a 3% reduction in voltage would reduce demand for electricity (at least in the short term) by 5%. Recent observations of the behaviour of load in response to changes in network voltage, and knowledge of the changing mixture of loads (e.g. the growth in electronic equipment), have led to this assumption to be questioned. A review of recent research in this area (including the National Grid Operation Juniper tests), coupled with a trial which carried out a voltage reduction exercise on a discrete section of SP Energy Networks HV network (as outlined in case study 4 on page 15), presented the following findings:
• A reduction in voltage will generally result in a reduction in active power demand, with this reduction being larger over the short term than in the long term. In addition, the reduction achieved will depend on the types of load present (i.e., active/reactive mix), and therefore the reduction:
  – can vary between different parts of the distribution network
  – can vary between different seasons, and different times of day
  – can vary according to the ambient temperature.
• Reactive power demand will generally be reduced by a larger factor than active power demand.
• A reduction of 1% in active power demand in response to a 1% voltage reduction is a reasonable estimate. This reflects a direct energy saving for customers, where a 1% reduction in voltage can typically lead to a 1% reduction in energy consumption.
• A network voltage reduction does not generally seem to reduce the network current, therefore network copper losses (i.e., 2R losses in transformers, cables, and overhead lines) are not reduced by reducing the network nominal voltage.

The research also found that reduction of nominal network voltages at the primary substation was a more cost-effective, and flexible, method of accommodating increasing levels of embedded generation on the LV distribution network than changing the off-line tap settings of secondary transformers.

While there are the benefits listed above, it should also be considered that periods of high demand (typically occurring in winter evenings when PV generation will be negligible) could result in the voltage dropping below statutory limits at the ends of feeders. Furthermore, reducing the voltage set-point at the primary substation could cause voltage to drop below the statutory limit where large commercial/industrial loads are connected to HV or LV feeders, or where customers are connected directly to 11 kV where there is little or no embedded generation. The impact of voltage reduction in these scenarios needs to be better understood, and managed, although the research found that these barriers do not necessarily outweigh the overall benefits to customers of a general voltage reduction.

It may therefore not be sufficient for any new network voltage control strategy to simply be a new (lower) set-point voltage. Additional flexibility, such as the ability to apply seasonal settings, may be necessary. This would likely require additional network monitoring as well as greater network active management and control, e.g., remotely settable voltage control relays at primary substations. Finally, if voltage reduction is implemented widely by DNOs then the Grid Code requirement to provide voltage reduction as a means to achieve rapid load reduction may need to be reviewed, given that voltage reductions will be less effective than they have been historically.

Case study 4 (on page 15) presents additional considerations and findings in relation to creating generation headroom capacity via a voltage reduction trial.

### 4.4 Technique 4: Energy efficiency

While the previous techniques have all been network-led solutions, this section considers various demand-side (i.e., customer) measures which can simultaneously provide direct network benefits (such as creating network capacity) and customer benefits (such as lowering operating costs).

Customer energy efficiency offers significant potential for creating network capacity to reduce network constraint. The DECC impact assessment study,[11] undertaken in 2012 when considering the potential to develop an Electricity Demand Reduction (EDR)[12] Pilot, suggests there is approximately 26.2 TWh of peak EDR potential in the non-domestic and industrial sectors. It also reported that, even under conservative assumptions, there remains considerable potential for cost-effective EDR. A well-designed energy-efficiency campaign (that is specifically focused on reducing electrical power demand within targeted areas served by stressed network assets) can therefore serve as a useful means of increasing network flexibility while also benefiting customers by reducing their energy demand.

The majority of measures also have wider societal benefits such as reducing carbon emissions over the lifetime of the energy-efficiency intervention, i.e., not just at the same (peak) time that achieving increased capacity headroom is most advantageous to the network operator. An additional benefit that energy efficiency can provide is that it is likely to be a cost-effective means of freeing up capacity in scenarios where low headroom (e.g., kVA reductions in low hundreds) may be beneficial for network operators; for example, this could provide additional short-term capacity to help align with a longer term strategic plan, or to help defer the significant spend associated with upgrading of transformers.

In many cases, measures to reduce peak demand will also result in a reduction in overall energy use, bringing benefits to both the DNO and electricity consumers, although it is vital to appreciate that these benefits are likely to be at different scales and times. For example, customers are typically interested in interventions that provide the highest energy reduction for lowest cost (i.e., £ spent/kWh of energy saved), whereas DNOs are generally interested in interventions that provide the highest load reduction during peak periods for the lowest cost (i.e., £ spent/kVA peak reduction). It is therefore critically important to identify opportunities that are mutually beneficial.

DNOs must also appreciate that customers are much more likely to be interested in reducing energy than simply shifting loads out with the peak period as this would typically not reduce their operating costs. Additionally, in most cases, shifting or limiting load may well be detrimental to customers as it may result in them having to reduce their service level (e.g., reduce their output capacity or manufacturing capability). Another important consideration is that annual energy savings (accumulated over the year) will often not directly correspond to the load reduction over the peak period in which the DNO is predominantly interested in. As a result, there is often no synchronous, or mutually significant, benefit to both parties during peak periods. Careful consideration is therefore needed to understand the nature and magnitude of the customer benefits so that mutually beneficial solutions and delivery models can be developed.

Potential approaches to tackling these issues could include incentivising customers to reduce peak loads, or for the Government or electricity industry operators to undertake a bidding process for demand reduction, or to purchase capacity from customers (or groups of customers, e.g., via aggregators). For example, DECC has recently piloted an EDR auction[12]. The EDR is a competition where organisations bid to receive financial support to implement energy-efficiency projects that deliver electricity savings at peak times, by installing more efficient equipment or increasing the efficiency of selected existing electrical systems. EDR will test whether projects that deliver lasting electricity savings at peak times could, in the future, compete for funding with generation, demand-side response and storage in the UK’s Capacity Market[13].

It is also worth noting that the Government’s Energy Savings Opportunity Scheme (ESOS) (a mandatory energy assessment and energy saving identification scheme for organisations in
the UK that meet the qualification criteria as dictated within the ESOS Regulations 2014[14] requires large undertakings[15] to carry out an ESOS assessment and identify energy saving opportunities. ESOS helps large organisations better understand what energy-efficiency opportunities their buildings and sites present. ESOS assessments include an audit of the energy used by their buildings, industrial processes and transport, as well as identify cost-effective energy saving measures. DECC estimates that the ESOS regulation will require around 9400 eligible companies (and their parent groups) to carry out an ESOS assessment meaning more than 200,000 buildings and 10,000 industrial plants will be assessed. DECC estimates that this covers over a third of total UK energy consumption.

The introduction of schemes like EDR and ESOS are a good start. However, there is much more to be done before householders, businesses and industry are adequately informed, equipped or incentivised to tackle the peak load problem at a big enough scale to make significant difference. Technology advances (eg advanced controls, demand side response technologies, energy storage in buildings or at the community stage) will help ease the transition. However, it will undoubtedly also require significant consumer education along with changes in current policy and/or significant financial drivers (eg dynamic time-of-use electricity tariffs, incentive schemes, new commercial arrangements). The energy retail, energy networks, industrial and built environment sectors therefore all have an equally important role to play in facilitating the development, and uptake, of suitable demand-side energy efficiency and peak reduction measures and vehicles as the UK moves to a low carbon future.

Case study 5 (on page 16) presents additional considerations relating to energy efficiency.

**Interventions**

Research undertaken by BRE within the Flexible Networks for a Low Carbon Future project[3] identified the following hierarchy of energy-efficiency measures as typically offering the best £ spent/kVA peak load reduction, potential:

- (non-essential) load shedding
- voltage reduction (at DNO substation level)
- low energy lamp replacements
- installing variable speed drives on motors
- energy system controls upgrades eg improving heating ventilation and air conditioning (HVAC) controls, installing occupancy linked ventilation controls, local air conditioning/chiller plant controls, installing comfort cooling controls, installing/upgrading Building Energy Management Systems (BEMS)
- lighting control upgrades with light fitting and lamp replacements.

While the above hierarchy can be used as a guide, it should be noted that the £ spent/kVA peak reductions are likely to vary significantly depending on the building type, use, scale and specification of the intervention measure. It is therefore essential for robust energy audits to be completed when considering the relative merits of various energy-efficiency interventions. Reducing voltage at DNO transformers was found to be a significantly more cost-effective approach than carrying out traditional energy-efficiency interventions within buildings (although DNOs are generally adverse to reducing voltages right across their network for various reasons as discussed earlier).

The conventional energy-efficiency measures investigated were also found to typically require prohibitively expensive investment (when considered versus conventional network reinforcement costs); however, it should be noted that each intervention will achieve annual energy cost savings for each building as well as presenting an EDR potential for the network. Payback periods for the interventions (based on energy cost savings alone) were typically found to range from one to eight years. This means that there is likely to be significant scope to implement interventions in partnership with end-users. For example, capital costs could be split between the network operator and the building owner or other beneficiaries, making the interventions more cost-effective from both the DNO and customer perspective.

Figure 9 shows some example energy systems offering peak reduction potential. Table 2 has been created to help identify potential peak load reduction opportunities by building type.

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*Figure 9: Example energy systems offering peak reduction potential*
<table>
<thead>
<tr>
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<td>Schools</td>
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<td>Catering</td>
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<td>Hospitals</td>
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<td>Care homes</td>
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<td>Hotels</td>
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<td>Museum/galleries</td>
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<td></td>
<td>Conference facilities</td>
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<td>Theatres/cinemas</td>
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<td>Libraries</td>
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<td>Industrial buildings</td>
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<td>Replacement heating for electric resistance heating</td>
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Table 2: Example energy systems offering peak reduction potential
5 Where to apply these techniques

This Information Paper has presented a number of flexible network techniques, but where can these be applied for maximum benefit?

The following innovative techniques can present opportunities on demand constrained networks:

- improved network analysis techniques
- enhanced thermal ratings for primary transformers
- RTTR for overhead lines
- flexible network control enhanced with voltage regulators
- customer energy efficiency
- voltage optimisation.

The following innovative techniques can present opportunities on generation constrained networks:

- improved network analysis techniques
- RTTR for overhead lines
- voltage optimisation.

Further information on potential applications, including budget costs and potential capacity gains, is presented in Figure 10.

<table>
<thead>
<tr>
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<th>Flexible solution</th>
<th>Approximate cost</th>
<th>Approximate benefit</th>
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<td>Enhanced thermal rating</td>
<td>£15 – 30 k</td>
<td>10 – 14%</td>
<td>Transformer needs health check and temperature monitoring</td>
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<td>Overhead line reaching maximum capacity?</td>
<td>Dynamic rating</td>
<td>£90 k</td>
<td>10 – 14%</td>
<td>Dependent on wind speed, so suited for wind generation. However, flexibility of load is needed for other scenarios</td>
</tr>
<tr>
<td>Primary substation or 11 kV group at capacity?</td>
<td>Flexible network control</td>
<td>£190 k</td>
<td>6 – 17%</td>
<td>Requires spare capacity or mirror load profiles on adjacent groups or feeders</td>
</tr>
<tr>
<td>Long 11 kV feeder difficult to backfeed?</td>
<td>Voltage regulators</td>
<td>£140 k</td>
<td>5 – 15%</td>
<td>Assumes capacity is available from back-feeding primary</td>
</tr>
<tr>
<td>Concentrated small-scale electricity generation/PV?</td>
<td>Voltage optimisation</td>
<td>£15 – 30 k</td>
<td>10 – 25%</td>
<td>Requires modern AVC relay and monitoring of supply voltage at points across the local network</td>
</tr>
<tr>
<td>No capacity at secondary substations?</td>
<td>Enhanced network monitoring</td>
<td>£0.5 – 2.5 k per substation</td>
<td>0 – 20%</td>
<td>Provides an accurate load measurement/profile to determine the capacity and reinforcement needed</td>
</tr>
</tbody>
</table>

**Figure 10:** Applying the network-led techniques to different network scenarios
6 Conclusions

In the future the UK electricity distribution network will serve a vastly different role than that for which it was designed over 50 years ago. With the decarbonisation of transport and heating and a proliferation of distributed generation, the energy landscape is changing at a rate that could not have been imagined when the network was created. DECC predicts a demand growth of 1 to 2% per annum, meaning that demand for electricity will increase significantly by 2050. This increase could be manageable if the load is spread evenly. However, the growth of low carbon technology on the network is likely to be rapid, localised and with limited forward visibility to allow network operators to plan and implement network upgrades.

UK network operators currently manage their systems conservatively, using parameters and controls typically developed for an outdated picture of generation and demand. They also tend to lack network visibility (especially on the 11 kV and LV network) and in the absence of good quality data they must continue to take low risk decisions to ensure the network is not overloaded and to ensure security of supply. The traditional solution to dealing with more load has been to build new assets (new substations, overhead lines and cables) but this is time consuming, costly and energy and carbon intensive. Furthermore, it doesn’t enable network operators to respond quickly to new and changing demands. For these reasons new, smarter, more flexible network solutions are needed which offer a truly innovative approach to maximising the capacity headroom available on the network while working network assets more efficiently.

This Information Paper has introduced a number of measures that, with network monitoring and good engineering, can help realise significant network capacity headroom. This is hugely important as our networks become increasingly constrained, but also because it enables networks to move towards becoming a true enabler of a low carbon future, facilitating new technologies and delivering lower cost renewable connections for the wider benefit of all – a network that is more fit for the future.
Case studies

Case study 1: Flexible network control

SP Energy Networks recently developed and deployed network switching points on two trial areas of their 11 kV network (with similar load issues but with different network topologies). The aim was to trial transferring load between adjacent substations in order to maximise the capacity of the group. A three stage approach was applied:

1. improve visibility to understand what is happening on the network
2. improve the controllability of the network
3. add ‘intelligence’ to capitalise on the advances of advanced network management systems and next generation telecontrol equipment.

Key requirements included:

- reduced physical size of control equipment
- increased capacity for the NCPs
- upgraded radio-telemetry system (with sufficient bandwidth to transmit analogue data)
- ability to recover analogue data from field devices.

A process was then developed to assess flexible network control solutions, as follows:

- assess available capacity at adjacent primary substations
- identify 11 kV circuits that could be used to achieve the transfers (made possible via enhanced network monitoring)
- conduct analysis to rule out various transfer options, followed by a load flow analysis to examine the detailed effects on network loading and voltages. Figure A shows an example analysis.

The following practical considerations should also be considered:

- requirements for appropriate electrical protection of the reconfigured network
- transferring load to adjacent substations may place them in a worse load index position
- customers may become aware of switching transients if switching is carried out frequently.

The flexible network control solution (which involved moving a number of different normally open points) was trialed and resulted in a successful release of 6% and 11% headroom in the two separate trial areas.

The process also enabled the DNO to learn of wider business implications and requirements regarding network reconfiguration. Mechanisms have been put in place enabling the technique to be rolled out into the DNO’s business as usual processes enabling them to defer reinforcement projects at a number of locations resulting in savings for customers.

This technique is expected to be highly replicable for other DNOs.

Figure A: Flexible network analysis output (image courtesy of University of Strathclyde)
Case study 2: Overhead line RTTR system

As part of an earlier research and development project\cite{9} SP Energy Networks successfully designed and installed a RTTR system for overhead lines, cables and power transformers on a trial network in North Wales (90 km of 132 kV network). The project included the development, prototyping and validation of an active thermal controller – which combined RTTR systems with a distributed generation output control system.

The research reported the range of theoretical average uplifts that could potentially be achieved through deployment of overhead line RTTR systems (at the trial location) as 1.70 to 2.53 times the static summer rating. Additionally, the theoretical additional annual energy yield from distributed generation that could potentially be accommodated through deployment of the RTTR system was estimated between 20% and 54%. In practice, the average uplifts ranged from 1.24 to 1.55 times the static summer rating, which presented a potential additional annual energy yield range of between 10% and 44%. The exploitable headroom and energy yield achieved were lower than the theoretical values as the RTTR system had to factor in a number of practical constraints such as cable ratings and protection equipment ratings.

While these results are highly encouraging, and demonstrate the potential merit of RTTR systems, it should be borne in mind that these uplifts are site (and network loading) specific and may not be achievable elsewhere.

Additional research completed within the Flexible Networks for a Low Carbon Future project\cite{3} on two 33 kV circuits in the St Andrews areas (Figures B and C) presented an average uplift above static ratings of between 1.10 and 1.12. Notably, this research also found that there were times when the RTTR drops below the static rating due to the actual weather conditions being less favourable than the assumptions used to calculate the static rating. These instances did not coincide with periods of high demand, although this may not always be the case elsewhere.

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**Figure B:** Conductor/pole configuration on the trial RTTR 33 kV overhead line (image courtesy of WSP UK Ltd)

**Figure C:** Conductor temperature snapshot across the trial RTTR 33 kV overhead line (image courtesy of WSP UK Ltd)
### Case study 3: Enhanced rating of primary transformers

Analysis by SP Energy Networks during the Flexible Networks for a Low Carbon Future project[3] revealed that assets in the trial areas effectively limit the increase in capacity available from the transformers to well below the level that would require a closed loop RTTR system to be deployed. As a result, the DNO developed a technique that allows them to assign enhanced ratings to primary transformers using transformer condition assessment and modelling techniques (based on historical load profile and ambient temperature data).

The results of this assessment concluded that some primary transformers were in fact suitable for careful enhanced loading. A thermal model of the transformers was therefore developed which included creating future load patterns, based on actual load patterns, to simulate and verify a safe increase in loading. The findings of the assessment concluded that peak loadings could be increased above nameplate rating by 30% while maintaining an expected technical lifetime of 40 years. The application of this technique resulted in capacity increases of between 10% and 14% in three separate areas undergoing trial.

This technique has now been adopted by the DNO and is being applied as standard, using a five-step process as outlined below. This enables the DNO to defer reinforcement projects at a number of locations resulting in savings for customers. The application of this technique is likely to be highly replicable for other DNOs.

The five-step process used for the implementation of enhanced ratings for primary transformers was as follows:

1. new ratings are calculated using an Enhanced Transformer Rating Tool
2. assess that the ratings of associated assets are sufficient
3. transformers must be condition assessed before an enhanced rating is applied
4. transformers must have a temperature monitor installed and have this connected to the overarching control system
5. the enhanced rating should be reviewed (eg bi-annually) for the actual duty cycle imposed.
One of the objectives of the Flexible Networks for a Low Carbon Future project[3] was to explore the potential for greater uptake of embedded generation through voltage optimisation. The business and economic case for better management of network voltages was assessed through a network voltage reduction trial on an area of network with a relatively high penetration of domestic PV installations (~320 kW of installed PV generation capacity). Voltage can approach, and potentially exceed, statutory limits (due to over voltage) when high PV uptake is present. This is especially true when installations are ‘clustered’ (e.g. a large social housing scheme or similar) so such a network was specifically chosen for the trial to provide a double benefit of being able to observe both the peak load reduction and the generation headroom enhancement.

The trial comprised a voltage reduction at the primary substation transformer of 3%. The effect on HV and LV network currents, voltages and power flows was recorded via extensive primary and secondary substation monitoring equipment. This allowed a detailed analysis and comparison of load before, during and after the period of the experiment. The effect of PV generation can be seen clearly in Figure D, where an LV feeder experiences power flows in the conventional direction (up to 60 Amps) in the evening when no PV is exporting, and reverse power flow (up to 40 Amps) during the day when PV generation reaches its maximum.

Detailed modelling of the network was also undertaken to quantify the increased capacity headroom due to voltage reduction. The model considered actual solar irradiance measurements (from the local area) and was validated with load and voltage profiles measured at secondary substations, and voltage measured at a number of LV customers. Voltage reduction tests were completed at two different times of year (January and June) to encompass a seasonal range of loads and the trial resulted in no adverse effects on the customers’ supply.

The project concluded that there is a case for voltage reduction in terms of wider LV network voltage management to enable further uptake of embedded generation and to reduce existing voltages more generally. It also concluded that network voltage reduction can provide significant additional generation capacity headroom for the LV network (with a 2% voltage reduction enabling a further 90% of PV generation by kW to be connected). SP Energy Networks suggests that such a reduction should be unlikely to lead to under voltages during peak demand winter conditions, although further study is recommended. The localised trial identified that there was generally about 6% voltage legroom during typical high demand conditions (based on LV customer voltage measurements towards the ends of LV feeders within the trial).

SP Energy Networks plans to build on this research and undertake wider trials focused on reducing the network nominal voltage. Should this introduce isolated under-voltage issues, then they will consider the merits of various mitigation measures (such as restoring the original voltage set-point in LV problem areas, or applying seasonal voltage settings) and network interventions (such as 11 kV in-line voltage regulators or STATCOMs) to resolve LV issues.

Figure D: Bi-directional current flows on an LV feeder that includes PV (image courtesy of SP Power Systems Ltd)
The Flexible Networks for a Low Carbon Future project[^2] sought to assess the potential for realising additional headroom capacity through the identification, development and assessment of peak demand reducing energy-efficiency opportunities in customer’s premises (that could simultaneously benefit customers and contribute to network flexibility). To deliver this, BRE developed and implemented a stakeholder engagement process and engaged with customers to gain knowledge of their site energy characteristics. Thereafter, opportunities for reducing peak demand were investigated and assessed. At the same time, potential delivery mechanisms for realising the interventions was researched and developed (including consideration of funding, procurement options and delivery partners).

BRE also developed a number of modelling tools in order to predict and understand peak demands and electrical loading of the trial networks. The models were later used to model distinct substations, as well as analysing the impact (in terms of peak load reduction, capital cost, energy and carbon saving) of implementing feasible energy-efficiency intervention scenarios on the trial networks.

**Stakeholder engagement**

The research concluded that Industrial & Commercial energy efficiency presents significant opportunity for peak load reductions. However, there are significant barriers to realising the potential in practice. Key conclusions and learnings included:

- Energy efficiency was unfortunately not high on the agenda for some organisations, particularly small businesses and in particular those who rented premises (who typically considered energy-efficiency improvements to be a landlord’s responsibility).
- Lack of knowledge and resource, and disruption to business activities were highlighted as significant internal barriers to progressing interventions.
- Industrial & Commercial organisations generally demanded a payback of two to five years on energy-related projects funded in-house. Longer payback is likely to be acceptable where external funding contributes to project costs.
- A cooperative approach with energy retailers in the implementation of customer energy-efficiency measures was found to work well.

**BRE modelling tools – electricity peak demand modelling**

Preliminary energy models (including winter peak profiles) were prepared by BRE in order to understand the anticipated electricity demands, load profiles and customer/building make-up on the trial networks. This was essential in order to better understand the network and aid project planning prior to the introduction of advanced network monitoring. The BRE models worked on a bottom-up approach ie they established robust estimates from limited input information (ie the number, type, nature and location of connected loads) with the BRE model deriving individual building loads. Figure E shows an example aggregated output.

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[^2]: Flexible electrical networks for a low carbon future

Case study 5: Energy efficiency (contd)

**BRE modelling tools – intervention planning**

Further models were also developed to assess the impact of feasible energy-efficiency interventions (that could reduce, or modify, electricity demand patterns), as well as provide a means of visualising and estimating the energy saving and peak load saving potential, and cost, of groups of interventions. Figure F shows an example output from the BRE intervention modelling tool. Figure G shows an example output from the BRE intervention investment analysis tool.

The tools allow users to explore different levels of investment across a mixture of energy-efficiency interventions and to explore the overall impact on demand by adjusting certain variables (e.g., the proportion of investment in each of the trial areas and the relative spend for each potential intervention type). This enables a budget cost (and feasible intervention mix based on the number and types of building in each area) to be arrived at for any given percentage reduction in peak demand, or alternatively, a means of calculating what percentage reduction in peak demand could be achieved by applying a practical, feasible, and cost-effective mix of interventions for a specific budget.

**Modelling – applications**

This type of modelling approach has applications as either an intervention planning assessment tool, or a network planning tool (which can provide early knowledge on the anticipated demand of new developments or where existing development is undergoing refurbishment e.g., assessing the impact of increased take-up of heat pumps). Equally, it can be applied at a larger scale to help understand the aggregated impact of a large scale rollout of the modelled energy-efficiency interventions. Such an approach can equally be applied to any part of the UK, and at smaller or larger scale than applied within the project.

![Figure F: Intervention modelling tool – demand profile output (sample)](image_url)

![Figure G: Intervention investment analysis tool (sample)](image_url)
References


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