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CIGRE US National Committee
2016 Grid of the Future Symposium

Adapting Distribution Network Planning Practices and Design Standards to Accommodate Distributed Energy Resources

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SUMMARY

The integration of Distributed Energy Resources (DER) on distribution networks has grown rapidly around the world throughout the past decade. DER encompasses not only generation and demand customers, but also elements of storage and other controllable network devices, enabling the transition towards decarbonised electricity systems.

The long-established method of providing sufficient security of supply is conservative and deterministic whereby distribution networks are effectively over-designed to ensure enough capacity and redundancy is available to keep customers connected during contingency operation. DER can play a diverse and active role within distribution networks, enabling more efficient use of capacity and capital whilst not impacting network security. DER challenges the fundamental rules by which distribution networks have traditionally been planned and designed.

The connection of many DER assets to date has been using relatively bespoke technical and commercial arrangements. More recently, penetrations of DER have risen to such levels, and growth is expected to continue, that there is increasingly a focus on adapting the core practices of electricity distribution i.e. planning, design, operation, control and management processes, to accommodate and embed DER into "business as usual" (BAU).

Peak demand shifting and domestic generation management are two applications where DER can improve network capacity, reduce losses and network investment requirements. However, this requires a move to a more probabilistic approach to network planning and operation that considers the availability of various controllable loads and network assets. This is being actively explored by DNOs and in the current review of the UK distribution network security of supply standard.

KEYWORDS

Distribution Network –Distributed Energy Resources – Renewable Generation – Standards – Planning

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INTRODUCTION

Distribution networks have been, and for the most part are still, designed conservatively to comply with security of supply standards and ensure adequate redundancy such that peak demand can be met, even in contingency conditions (typically N-1 above low voltage). This practice has led to networks, especially at higher voltages e.g. 33 kV, only utilising up to half of the installed capacity of their assets in anticipation of mostly infrequent faults or planned maintenance. While security of supply remains paramount to distribution networks, the substantial increase in DER is driving the evolution of the associated standards to include provision for active (controllable) generation and demand customers in network planning activities, replacing the traditional passive philosophy of planning and operation.

The benefits of incorporating DER into planning and design standards are numerous. By allowing active network components to contribute to security of supply, existing network infrastructure and assets can be utilised more efficiently, reducing system losses and, in many instances, deferring capacity reinforcements. Such reinforcements are time-consuming, often very expensive and can also result in stranded assets if load growth is not realised. If reinforcements can be deferred or avoided through the use of DER then not only are network issues resolved more promptly, but significant cost savings can be made and passed onto customers and increased volumes of low carbon generation and demand can connect. Greater visibility of networks through more monitoring and control devices is another advantage. Embedding the consideration of DER into planning and design standards would also make it easier for future customers to connect due to greater clarity of technical and commercial arrangements.

This paper considers the adequacy of existing distribution network planning and design standards and examines how the integration of high volumes of DER is driving changes, recognising that fundamental change is ultimately what is required. Ongoing innovation work in the area by distribution network operators (DNO) supports the case. Recommendations on how standards and practices could be revised to accommodate more flexible operation of distribution networks are also explored through case studies which illustrate some of the features of DER and how they challenge existing practices. Whilst this is focused on the UK where we are actively supporting DNOs in better understanding and responding to the influence of DER on network design, it has many parallels for other countries where DER connection is increasing.

EXISTING PLANNING & DESIGN STANDARDS FOR DISTRIBUTION

Relevant Planning Standards

There are a number of planning and design standards that new connections to UK distribution networks e.g. DER, must comply with. The *G59 Engineering Recommendation for the Connection of Generating Plant to the Distribution Systems of Licensed Distribution Network Operators* [1] provides guidance on all of the requirements throughout the connection process. The document contains a list of planning and design standards which provide rules, limits and guidance for such aspects as security of supply (ER P2) [2], voltage fluctuations (ER P28) [3] and unbalance (ER P29) [4], power quality (ER G5) [5] and earthing (TS 41-24) [6]. The G59 (and the standards listed within) are applicable in the UK however there are equivalent standards and guidance in most countries with a developed electrical grid.

Security of Supply

Perhaps the most important standard to review in the context of connecting increasing levels of DER is *Engineering Recommendation P2 Security of Supply*. The current version of the distribution network security of supply standard in the UK is Engineering Recommendation (ER) P2/6. It was published in 2006 and is a revision of P2/5 which was published in 1978. The revision does not revisit the analyses performed for P2/5, rather it was updated to account for a more diverse range of distributed generation (DG) types including landfill gas, CHP, waste to energy, wind and hydro. As such, the standard has effectively changed very little in almost four decades, yet distribution networks have evolved significantly in the last decade alone. The table below summarises the level of redundancy required for distribution networks based on Group Demand (estimated maximum demand at a grid supply point).

Table 1: UK Requirements for Network Redundancy [2]

Group Demand	Required Redundancy	
Up to 1 MW	N-0	No requirement
1 MW up to 60 MW	N-1	At least one additional circuit to supply demand for First Circuit Outage
Over 60 MW	N-2	At least two additional circuits to supply demand for First and Second Circuit Outages

P2/6, with support from Engineering Technical Report (ETR) 130 [7], makes allowances for intermittent and non-intermittent generation (wind, small hydro only) by assigning reliability values (F Factors) to DG based on size or "persistence". The reliability of non-intermittent generation is dependent on the number of units in a generating station while intermittent generation reliability is based on how long the generating station is required to be available and is irrespective of the number of units.

A combination of:

1. the requirements for system redundancy in the form of additional capacity; and
2. the conservative view of DG contribution to meeting demand,

has resulted in distribution circuits and transformers sized around twice the peak demand capacity requirement, where peak demand occurs, in some cases, for less than 1 hour per year; while locally available generation is not being accounted for and so capacity must be provided for generation sourced outside the local network area. Additionally, any demand growth beyond network capacity triggers material upgrades in asset ratings to ensure that this level of security of supply is maintained. Figure 1 below illustrates the requirements for redundancy in the security of supply standards which are based on worst case (N-1) conditions.

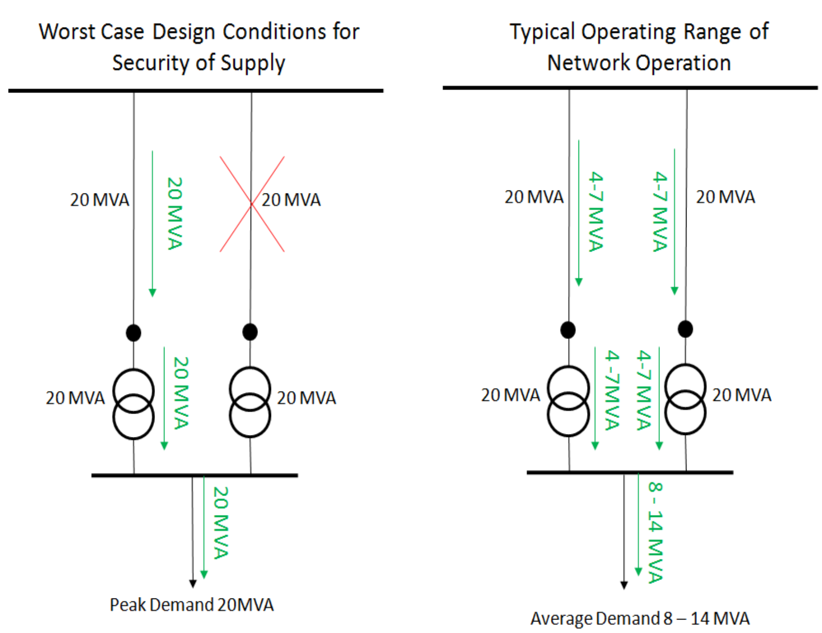

Figure 1: Comparison of Worst Case (N-1) vs. Typical Operating Conditions for Distribution Network Design

The current security of supply methodology is deterministic and based on peak demand rather than the demand profile. A capacity assessment will then identify any areas where reinforcement is required based on forecasted peak demand. Implementing a more probabilistic methodology has the potential to utilise existing capacity more effectively through better understanding of how different types of DG and DER could contribute to meeting demand. This prospect has been examined extensively in the ongoing review of the ER P2 standard [8] where the benefits and challenges of implementing more probabilistic methodologies are measured.

DER CHALLENGES AND OPPORTUNITIES

In the context of short- and long-term network planning and design, the main challenges and opportunities for distribution networks presented by the connection of DER include:

- Responsive generation and demand which may alter peak load, removing the predictability of demand profiles in the planning processes but adding flexibility;
- Decentralised network controllable devices e.g. energy storage, actively managing network parameters in real-time and utilising network assets more efficiently; and
- Intermittent and distributed generation that is not always visible to the network operator in the control centre which makes daily operational management and control more challenging;
- Each type of DER is potentially operating and responding to varied commercial triggers and instructions.

The capabilities of DER, in the context of their real-time operation and control, are starkly different to the long-term planning approach taken by distribution network/system operators. Capacity and redundancy are ensured well in advance and according to peak loading forecasts. However, by embracing the capabilities of DER, networks can be planned, designed and ultimately operated much more efficiently.

Case Studies

The following case studies are examples of how different applications of DER challenge existing standards. Early outcomes of ongoing work by UK DNOs including a review of the current P2 standard [8] are presented where relevant alongside the case studies.

1. Peak Demand Shifting

Peak demand shifting can be achieved in a number of ways; through responsive demand, the use of storage or the implementation of small-scale or domestic generation. As described in the previous section, peak demand is the main indicator used to assess capacity (and redundancy) requirements of networks according to ER P2/6, and demand growth will trigger upgrades once network capacity is reached. As such, if peak demand can be "reduced" locally through:

- Shifting – using smart meters or appliances to schedule consumption at off-peak times;
- Levelling – using storage to produce/consume energy to keep demand level; or
- Displacement – using domestic or local generation to serve demand.

Conversely, smart control of demand can be exploited to "absorb" solar and wind generation at times of peak production (if storage is unavailable). Peak Demand Shifting can not only defer capacity upgrades but could also create opportunity for more DER customers to connect in the same network area.

UK Power Networks' (UKPN) Low Carbon London (LCL) project is a good example of how flexible demand can be used to defer reinforcement [9]. The project also looked at how DG can contribute to security of supply [10] which is discussed later in the paper. LCL carried out various trials using industrial and commercial demand response both as a short-term operational tool and as a longer-term alternative to network reinforcement.

With the inclusion of DER, and specifically peak demand shifting, there needs to be more visibility of what the demand profile consists of i.e. demand, DG, storage, electric vehicles, in order to better understand and forecast power flows at lower voltages. Potential adaptations to existing standards to incorporate flexible demand could include a revised methodology for calculating and forecasting capacity requirements at different substation levels i.e. primary, secondary substations.

2. Domestic Generation Management

Increasingly, households and businesses are deploying distributed generation “behind the meter” whereby any generation not consumed in the household/business is exported back to the grid. Since the low voltage network was not designed for reverse power flows exporting to the grid, novel methods of maximising self-consumption and reducing overall export were researched and trialled in the Northern Powergrid Customer Led Network Revolution (CLNR) innovation project. The solar PV trials monitored 93 domestic customers with either:

- No intervention;
- Automatic load balancing which diverts excess PV generation to hot water storage; or
- An In-House Display (IHD) which notified customers of generation exceeding their consumption to encourage them to manually increase it.

The aim was to benchmark and assess whether automatic or manual intervention is more suitable to manage excess generation export at LV [11]. The approaches used in this trial indicated that there was no visible additional benefit to automatic intervention however, the sample size was relatively small.

Early work in the review of ER P2 has identified some limitations of the standard relevant, including no explicit consideration of “prosumers” i.e. domestic customers who produce and consume electricity. Also, demand is only considered in >1 MW groups. Potential adaptations could include more detailed identification of demand groups and include provisions for domestic generators to encourage the more active role of consumers in generation management across the network.

Big Data

As a result of increased monitoring requirements for more flexible loads and controllable devices on the grid, “Big Data” will be an important aspect of future distribution networks in the context of operation. However it can also be exploited to improve various aspects of network planning and design. More accurate monitoring of generation and demand will improve understanding of network behaviour and load forecasting. It will also enable a more probabilistic methodology to be employed to security of supply capacity assessments as well as improved selection of solutions when capacity is reached.

EVOLUTION OF DISTRIBUTION STANDARDS

A number of UK DNOs, as part of their innovation projects, have already carried out exploratory work on how DER (distributed generation, storage, electric vehicles, demand response etc) could contribute to and improve existing security of supply standards. UKPN’s LCL project looked both at how DG and responsive demand could be addressed in the context of security of supply [9], [10]. Northern Powergrid, as part of their Customer Led Network Revolution (CLNR) project have conducted a review of P2/6 and ETR130 with a view to advise on updated F Factors for different types of generation and the methodology for assessing DG contribution to security of supply [12].

Recognising that the UK security of supply standard is based on deterministic load behaviour, and is no longer fit for purpose, a fundamental review of the Engineering Recommendation P2 is in progress, commissioned by the Energy Networks Association. Early outcomes of this review have been published in [8] and a number of reform options have been presented:

- Retaining P2/6 without revision;
- Retaining deterministic planning standard but includes improvements to account for non-network solutions i.e. DER;
- Implementing a non-deterministic planning standard;
- Implementing a non-deterministic planning standard but retaining some deterministic elements for minimum reliability; and
- Abolition of the planning standard if other regulatory framework is in place.

Incorporating DER solutions into the standard could improve productive efficiency however it is recognised that it is difficult to pre-determine DER contributions when assessing reliability, work is ongoing.

In Europe, ENTSO-E (European Network of Transmission System Operators for Electricity) has published a portfolio of network codes which are currently going through the process of becoming legally binding [13]. These network codes aim to facilitate harmonisation, integration and efficiency of the European electricity market. Although these codes are focused on the transmission network, the connection of large industrial loads and distribution networks is considered in the "Demand Connection Code" [14] which considers Demand Side Response from these entities and allows the TSO to place requirements on this to maintain network security.

The Electric Power Research Institute (EPRI) is very active in the area of DER research and they have a wide portfolio of research findings. They have carried out various research, developments and trials in the area to gain a better understanding of the challenges associated with integration of DER. For example, in association with Con Edison, they conducted an investigation into whether DER could help achieve improved reliability on a network [15]. Their Smart Grid demonstration initiative has also studied DER in relation to its interoperability and integration with a view to standardising them as part of BAU [16].

IEEE 2030 "Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System, and End-Use Applications and Loads" [17] was published in 2011 and provides guidelines on the integration of smart grid technology and associated IT with the power system. Further guidance was published in 2015 on the connection of energy storage systems (2030.2) and there is work ongoing relating to the connection of electric-sourced transportation (e.g. electric vehicles) (2030.1).

CONCLUSIONS

It is evident that for distribution networks to evolve and integrate DER effectively, the associated technical standards must also evolve. This has been recognised by stakeholders and a variety of work is being carried out to determine the changes required to maximise the opportunities that DER offers for more efficient network planning and design. Peak demand shifting and domestic generation management are two applications where DER can improve network capacity, reduce losses and network investment requirements.

The existing focus in the UK on a single annual peak demand value and N-1, at high voltage, does not consider the benefits that can be provided by an increasing volume of controllable customer loads and network assets on the network. Also, there is increasingly domestic and small-scale generation that is available to provide local supply albeit with consideration of probabilistic characteristics and/or manage generation export during low demand times. Focused analysis of the large volumes of data that are becoming available across all voltage levels will provide further evidence and justification for future adaptation of network planning standards to better incorporate DER.

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