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Existing Capabilities and Anticipated Challenges of Power System Modelling in the GB Network Companies

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About this report

The Institution of Engineering and Technology was commissioned by the Council of Science and Technology (CST) to research the emerging challenges for modelling electricity systems and how Britain's capabilities would need to be adapted to assess electricity system resilience as GB makes the transition to a low carbon electricity system.

This project commissioned, and received, fifteen individual papers from GB-based specialists of international standing in power system modelling. The authors of the papers worked with a wide stakeholder base of network companies, academics and others, who provided review and challenge. Professor Graham Ault CEng FIET was contracted to provide technical co-ordination and drafting. The emerging conclusions were further validated by means of an industry and academic workshop sponsored by Government Office for Science. The entire project was conducted under the direction of an independent steering committee composed of senior IET Fellows, two of whom were also CST nominees.

The report is composed of three parts:

- Part 1: Main report
- Part 2: Summary of Commissioned Papers
- Part 3: IET Special Interest Publication – Academic & Industry Papers

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EXECUTIVE SUMMARY

Power system modelling is used by all of the network companies, the System Operator (SO), Transmission Owners (TOs) and Distribution Network Owners/Operators (DNOs), to plan and operate their networks. The principal aims of this paper are to describe the current capabilities of the Great Britain (GB) network companies in the field of power system modelling, and identify known and anticipated challenges as the operational philosophy of networks evolve and the landscape of the power industry is drastically altered out to 2030.

The current position of the GB network operators is presented initially, which highlights differences in the modelling tools used by network operators for planning purposes. This is not perceived as a disadvantage; rather it is encouraging innovation with network operators undertaking new projects in a wide range of modelling aspects and tools. Operationally, there is alignment through the DNO companies whereby the majority use the same distribution management software however each system is customised to DNO preferences and requirements. The modelling tools used by the TOs for planning are becoming more aligned owing to the need to share data more frequently.

Through the evaluation of the power system modelling capabilities, and the identification of associated challenges, concerns and gaps presented in this paper, including data issues, harmonic analysis requirements and knowledge sharing between network operators, a number of conclusions and recommendations have been made. The most important requirement for the future of power system modelling is the availability, accuracy and alignment of data, including improvements to GIS (geographic information system) databases, such that valuable results can be offered. State estimation is an area cited for improvement and expansion as a supplement to the ability to provide this data, offering full network visibility based on a fraction of the information.

A key point for DNOs is to recognise that a wide range of issues experienced by and on transmission networks, will become issues for distribution networks in the coming years as distribution networks evolve from passive to active systems. Aspects of harmonic analysis, generation and demand forecasting, and risk modelling will all have to be considered more carefully for distribution network planning in the future. Operationally, the impact of changes to system strength, the introduction of sub-synchronous interactions and reverse power flows on the transmission system will have to be considered and monitored on distribution systems.

Alignment and harmonisation of processes is encouraged to promote innovation and facilitate knowledge sharing and dissemination; however care should be taken to avoid lock-in to solutions that stifle development and the rigidity this would bring.

1. BACKGROUND

The GB transmission system companies are National Grid (NGET), which is the SO for England, Wales and Scotland and the TO for England and Wales, and the two Scottish TOs, Scottish Hydro Electric Transmission (SHE-T) and Scottish Power Transmission (SPT). There are seven DNOs that cover the fourteen licence areas in GB. The six DNOs which operate the fourteen GB licence areas are Electricity North West (ENW), Northern Powergrid (NPG), UK Power Networks (UKPN), Western Power Distribution (WPD), Scottish Power Energy Networks (SPEN) and Scottish and Southern Energy Power Distribution (SSEPD).

Power system modelling broadly falls into two categories: modelling for planning purposes (long-term), and modelling for operational network management (short-term, real-time).

1.1 Modelling for Planning Purposes

Power systems are designed according to a set of criteria and standards including, but not limited to, the Grid Code [1], the Distribution Code [2], the SQSS (Security and Quality of Supply Standard) [3] and Engineering Recommendation (ER) P2/6, as well as various other Engineering Recommendations. In order to meet the required design criteria, standards and recommendations, all networks must undergo power system analysis. Power system analysis involves modelling the power system on a chosen software platform and performing any number of studies to test for compliance with the aforementioned criteria and standards. This type of modelling is carried out for long term planning purposes, to study outage and maintenance schedules, network reinforcement options and new generation or demand customer connections.

Within the field of power system analysis, there are further modelling subcategories; steady-state, fault level, dynamic[1] and harmonic being the main areas within which the most commonly undertaken studies fall. Modelling for each of these purposes can vary significantly, although ideally a minimum level of data consistency should be maintained across all three.

Power system analysis is the most common method employed for long-term planning, however a number of other modelling techniques may be deployed making use of electricity network analytical models, whole energy system models (which take account of parameters such as gas, heat and carbon as well as electricity), and economic models for the purposes of planning and scenario testing based on prospective outlooks.

1.2 Short Term and Operational Modelling

There are a number of modelling tools available to the network operators for relatively short-term planning purposes e.g. generation and demand forecast models and market models. This allows the networks to be balanced and operated efficiently and cost-effectively on day-, week- or month-ahead timescales.

[1]The term 'dynamic' refers to both transient and dynamic disturbances and/or studies throughout this paper.

Generation and demand forecasting is critical to network operators such that the system can be balanced effectively. Generally this is done by the transmission system operator; however there is a trend towards this being required, or at least advisory, at distribution voltages as penetrations of distributed generation (DG) increase. Generation forecasting is carried out based on seasonal, time and weather information, and demand forecasting is broadly based on historical patterns (but is also dependent on seasonal, time and weather information). Within the GB network companies, forecasting is generally undertaken using models created and developed internally.

The real time operation and management of power systems is carried out on software platforms known as Network Management Systems (NMS). These NMSs are utilised at both transmission and distribution voltages, and are operated from within the control centres. The management of the power system is achieved through interaction with the topology models built within the NMS which are linked to the ICT (information and communication technology) and SCADA (supervisory control and data acquisition) infrastructure out on the network which updates measurements and the status of equipment in real time.

2. METHOD

The data and evidence for this paper has been collected through desk based research, stakeholder engagement and TNEI's experience through recent projects.

Stakeholder engagement has been the main source of information on existing power system modelling capabilities in the network companies. Discussions were held with the SO, TOs and DNOs. This has provided valuable insight into the present position of modelling capabilities and also the different approaches used by different companies depending on their network needs.

Desk based research has been carried out to establish current projects and R&D in the area of power system modelling, such as Ofgem-incentivised projects and academic research.

Future and emerging challenges have been addressed with a combination of the two methods, with network companies keen to see developments in a number of areas. TNEIs power system modelling experience has also helped to inform the assessment of potential gaps in modelling capability, alongside other sources.

3. CURRENT POWER SYSTEM MODELLING CAPABILITY

This section describes the current power system modelling landscape within GB network companies and includes information on what modelling tools are used, and for what purpose, the inputs that are used and how the outputs inform decision making.

3.1 Distribution Networks

3.1.1 Long and Short Term Planning

3.1.1.1 Power System Analysis

The power system modelling tools and techniques used by the network operators are not uniform and are dependent on how each of the companies has evolved and grown over the years. The software package used for power system modelling is also highly dependent on the voltage level of the network, with certain capabilities being more suited to lower voltage networks than high voltage networks (and vice versa). The table below provides an overview of the planning software used by DNOs organised by voltage level.

Voltage Level (applicable number of DNO regions)	Power System Analysis Software (used by number of DNO regions)
Below 11 kV (14)	DINIS (2), PSS Adept/PSS Sincal (2), WinDebut (4), No modelling (6)
11 kV (14)	DINIS (8), PSS Adept/PSS Sincal (2), GROND (2), IPSA (1), DIgSILENT (1)
33 kV (14)	DINIS (1), IPSA (3), PSS/E (6), DIgSILENT (4)
132 kV (12)	DINIS (1), IPSA (3), PSS/E (5), DIgSILENT (3)

Table 1: Planning Software Used by DNOs.

It is evident from Table 1 that the DNOs have different preferences regarding the software they use (or request consultants to use) for performing power system analysis. At voltages below 11 kV (LV (low voltage)), some network areas are not modelled at all, while others are modelled using either DINIS [4], WinDebut [5] or PSS Adept/PSS Sincal [6]. At 11 kV (HV (high voltage)), the majority of DNOs use DINIS to model their networks. DINIS is popular at the lower voltages as this software is capable of studying unbalanced networks, a common characteristic at LV, and one which is becoming more prevalent. A few other regions are modelled in PSS Adept/PSS Sincal, Win Debut, IPSA [7], DIgSILENT Power Factory [8] and GROND [9]. At 33 kV (EHV (extra high voltage)), there is an even mix of PSS/E [10], IPSA, DINIS and DIgSILENT Power Factory used to model the networks, and this is also the case at 132 kV (EHV).

The power system analysis studies carried out on the networks up to and including 132 kV encompass load flow, fault level, voltage step, transient and harmonic studies. On the whole, the DNOs perform the three former analyses internally, while transient and harmonics are often outsourced to consultants (not always, and more so harmonic studies than transient studies). These studies are carried out for the purposes of outage planning, maintenance, network reinforcement and new connection assessments. Matlab [11] and OpenDSS [12] are other software packages used for specific power systems analysis.

3.1.1.2 Forecasting

For other types of analyses, such as forecasting and economic modelling, there is a range of work ongoing within the DNO companies. All of the DNO companies interviewed make use of their own demand forecasting tool, developed internally, and most are taking steps to continually improve the accuracy of the forecasting. One of the DNOs also makes use of a generation forecasting tool, again developed internally, for the purposes of constraint arrangements.

3.1.1.3 Development Projects with Modelling

Some examples of ongoing collaborative modelling projects include the FALCON project, Flexible Plug & Play, New Thames Valley Vision, Flexible Networks, Customer Led Network Revolution and Capacity to Customers. These are all Low Carbon Network Fund (LCNF) Tier 2 projects and contain modelling aspects specific to the DNO areas. Each of the projects, described below, has some aspect of modelling which facilitates the transition to low carbon networks. Knowledge sharing is one of the philosophies of the LCNF, with one of the objectives when competing for LCNF funding is for the projects to be scalable and replicable across GB.

The FALCON project [13] is a WPD project deploying smart interventions on the HV network and novel commercial arrangements with customers. Data from these trials will be used to develop an investment tool to model where these techniques can be deployed efficiently across the whole HV network.

Flexible Plug & Play [14] is a UKPN project trialling ways to improve the control of the EHV network to connect increased volumes of wind or other intermittent generation. The project will trial an open communications platform and develop an investment model for connecting renewable generation to the distribution system.

The New Thames Valley Vision [15] is a large SSE project which is primarily focused on developing a tool to help forecast where low carbon technologies might connect to the network. The project also trials network monitoring, energy storage and novel commercial arrangements with large customers.

Flexible Networks [16] is a SPEN project investigating how to obtain extra capacity from the existing HV network in three separate locations by co-ordinating innovative engineering practices. The project also looks to encourage large customers to improve their energy efficiency.

The Customer Led Network Revolution [17] is a NPG project that brings together the trialling of smart meters and customer-side interactions with new network technologies. NPG is working in partnership with British Gas and Durham University (amongst others).

Capacity to Customers [18] is an ENW project that trials new operational techniques to release latent capacity within the existing HV network. This capacity is provided to ensure security of supply when network outages occur. The project will utilise this capacity by combining network automation and 'interruptible' contracts with large customers.

Many more tools and models are being developed and used in a collaborative manner as part of the Low Carbon Network Fund, or similar. For instance, each of the DNO companies interviewed have been involved with the Smart Grid Forum Work Stream 3 "Transform" model at some stage (development, to form business plan, to use). This is a tool for long-term appraisal of distribution network reinforcement expenditure driven by low carbon technologies (LCT).

The upcoming Smart Grid Forum Work Stream 7 project will involve more detailed electrical power system analysis (using nodal network models) of the electricity system of 2030, with particular focus on the distribution networks, their design and, critically, their operation. It has been proposed that the models of this work be made available to parties, other than those carrying out the work, to carry out further studies.

In addition to UK institutions, there are a number of working groups in relevant international organisations like CIGRE and CIRED where distribution network modelling is discussed in the context of smart grids and the use of modelling for the preparation and transition of networks to these from their current state.

3.1.2 Operational

In the case of all but one of the DNOs, the GB distribution networks are operated and managed using the GE products ENMAC or PowerOn Fusion [19] (where PowerOn Fusion is an upgraded and rebranded version of ENMAC), while the other DNO performs its real-time management through the Thales Network Management System [20]. The modelling itself is achieved using connectivity and equipment data information from one or more of the NMS databases, e.g. GIS, and keeping it up to date using the SCADA and communications network, whereby the real time data from the remote terminal units (RTU) and network measurement points is sent back to the control centre and into the NMS where it updates the connectivity diagram of the network. The connectivity diagram is the main interface used by the control engineers to engage with the network.

The GE PowerOn Fusion DMS (distribution management system) is a powerful tool and each of the DNOs has customised their product for use, with most exploiting the internal scripting facilities to implement automation. The types of automation deployed include intertrip, load transfer, generation constraint, supply restoration, auto-reclose and sequence switching. An additional appeal of the GE PowerOn Fusion product is its alignment with Ofgem reporting styles which makes the reporting process much easier and more efficient. The Thales NMS is also highly adaptable in terms of automation.

3.2 Transmission Networks

3.2.1 Long and Short Term Planning

3.2.1.1 Power System Analysis

The software platforms used by the GB transmission network owners and operators for planning purposes are DIgSILENT Power Factory and PSS/E.

As is the case with the DNOs, the TOs also have different preferences regarding the software they use (or request consultants to use) for performing power system analysis, however there is better alignment as data sharing is more prevalent between the TOs and the SO. They use the analysis software for the same studies, which includes all of the studies listed above (Section 3.1.1.1 as carried out by DNOs) for the purposes of contingency analysis, outage planning, network reinforcement and new connection assessments.

The transmission companies make use of other power system analysis software, mainly for validation purposes.

PSCAD [21] and AMT [22] are used to carry out and/or validate (consultant) work on transformer energisation and sub synchronous resonance studies. They make use of PSCAD and Matlab for validation of operator/manufacturer models of equipment such as HVDC (high voltage direct current).

NGET also has a unique responsibility, as the GB transmission SO, to carry out additional studies in accordance with the SQSS guidelines when there is a new connection, and these centre on transient and voltage stability, and frequency.

3.2.1.2 Forecasting, Economic and Energy System Modelling

NGET carries out forecasting for system balancing. This is carried out using the Energy Forecasting System, an internally developed package, rather than commercial software platforms, which allows for continual improvement and maintenance.

NGET produce a set of Future Energy Scenarios [23] (which are reviewed and updated every year) which provides the GB with four potential whole energy system scenarios; Low Carbon Life, Gone Green, No Progression and Slow Progression. The scenarios account for electricity, gas, transport and heat, and reflect the energy "trilema" of sustainability, affordability and security of supply factors, and provide credible outlooks to 2035 and 2050. The GB TOs all use these scenarios to perform studies.

3.2.1.3 Development Projects for Modelling

There are a number of Ofgem-incentivised development projects ongoing which are focused on transmission networks. Two current Network Innovation Competition (NIC) projects are VISOR and MTTE.

VISOR (Visualisation of Real Time System Dynamics using Enhanced Monitoring) is a NIC project which is led by SPT [24]. This project will use enhanced monitoring techniques (phasor measurements units (PMU)) to provide a number of benefits associated with the secure integration of new technologies onto the transmission network and also provide visibility of system voltage and stability limits.

MTTE (Multi-Terminal Test Environment) is a test environment for HVDC systems being developed by SHE-T [25]. This project will establish a facility to model, demonstrate and test multi-terminal and multi-vendor HVDC transmission solutions.

All three GB TOs (NGET, SPT and SHE-T) are partners in each of these NIC projects, and this partnership encourages knowledge sharing and dissemination across GB companies. There are also a number of recent applications for NIC funding which are currently under review by Ofgem.

wholeSEM (Whole Systems Energy Modelling) is a research consortium which has been formed to address the need for quantitative whole energy system models of the UK. Presently, the modelling of power systems is fragmented and reactive and there is seen to be a need for more aligned models and modelling strategy for policy impact and technology development [26].

There are a number of working groups in relevant international institutions like CIGRE and CENELEC where transmission network modelling is discussed and input into models for HVDC grids, long cable systems or dynamic modelling of intermittent generation and interconnected energy systems are studied. This allows TOs and SOs from around the world to compare methodologies and share best practice.

3.2.2 Operational

As explained in Section 3, the GB transmission arrangements see NGET as TO in England and Wales, and SPTL and SHE-T as the TOs of their respective Scottish areas. NGET also assume the role of SO for the whole GB transmission system. The distinction, from an operational perspective, comes as NGET, as the SO, is responsible for system balancing and the power flows around the GB transmission system and in keeping within the statutory operating margins, while SPTL and SHE-T and NGET as TOs are responsible for the day-to-day operation and maintenance of their transmission assets. The TOs and SO make use of Energy Management Systems (EMS) to carry out these tasks.

SO/TO	Software
National Grid Electricity Transmission	GE PowerOn Reliance
SHE Transmission	GE PowerOn Reliance
SP Transmission	ENMAC

Table 2: Operational Software Used by TOs.

Table 2 shows that NGET use the GE product PowerOn Reliance [27], which is part of the same product range as the PowerOn Fusion tool used in the DNO control rooms but is more suited to management of transmission networks. SHE-T use the ENMAC tool and SPT use the Alstom (previously Areva T&D) e-terra product [28].

As is the case with the DMS platforms in use on the distribution networks, the EMS platforms used by the TOs for operation and management of their networks are reliant on the SCADA and communications infrastructure to keep these systems up to date with real time data and measurements. The visibility available of the transmission networks is far superior to that on the distribution networks, mainly because of the criticality and more active nature of the system, but also because there are considerably fewer assets to monitor.

The transmission companies also use their EMS to implement automation and control schemes, including dynamic thermal ratings and other smart controls.

4. MODELLING CHALLENGES

There are a number of modelling challenges facing the industry as the networks themselves undergo significant changes in areas such as system inertia, fault levels, generation mix and load characteristics, amongst others. Below describes some of the challenges articulated by the network operators.

4.1 Visibility of Information between the SO and DNOs

NGET does not have real-time visibility of connected DG. Enabling NGET to have visibility of this generation would improve their operational timescale forecasting, leading to greater efficiency in system balancing and scheduling of reserves.

A recent project between WPD and NGET established a real time link between their SCADA systems using the ICCP (Inter-Control Centre Communications Protocol) to enable data on either system to be transferred between systems in real time. The CLASS project (Customer Led Active System Services) with ENW has also established an ICCP link to enable services on the ENW system to be made visible and called off using the NGET SCADA system. Although still under development, both of these projects are indicative of a trend towards establishing connectivity between NGET and the DNOs for real-time data exchange.

From the DNO perspective, each of the DNOs who contributed to this paper expressed an interest in gaining better visibility of the transmission network through the linking of their DMS and SCADA networks, if appropriate security measures were implemented and the benefits to the distribution companies could be clearly defined. Cyber security is a key consideration in rolling this out, given the critical nature of these systems.

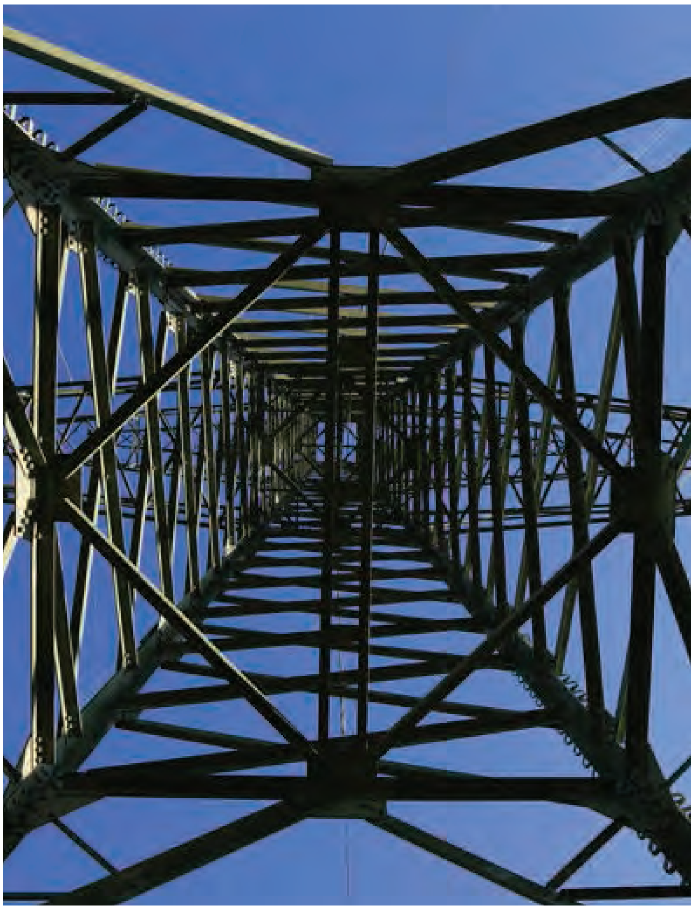
The DNO networks would look for access to operational data from the transmission network, such as transmission outages and phase angle information. This would aid the DNOs operation of their networks and help to manage system abnormalities. In return, NGET would gain access to useful information as noted above. The ‘depth’ (into the distribution network) to which they would require to go would depend on the nature of the objective i.e. the level of detail and information would differ from a state estimation perspective to a DG forecasting exercise.

4.2 Wind Forecasting

Presently, NGET carry out forecasting of load and renewable generation for the purpose of system balancing in their forecasting tool, the Energy Forecasting System. Forecasting of renewables was integrated into this system following a research project which developed a number of forecasting algorithms. The system and its algorithms are continually maintained and improved with a view to enhancing accuracy. Some improvements to the NGET wind power forecasting capability are being sought through a number of initiatives, including the development of wind direction sensitive models for every wind farm, improved modelling of high wind speed shutdown, and changes to the way wind farm power curves are modelled.

As the proportion of renewable generation connected to the network grows, the accuracy of forecasting it will become crucial to operating an efficient network. More accurate wind forecasting can reduce reserve requirements, resulting in reduced system operation costs and, potentially, reduced curtailment costs.

Generation forecasting is not something that DNOs have traditionally undertaken, however this is rapidly becoming a concern for DNOs, especially those experiencing major growth of solar PV farms across their networks.



There is one DNO who is looking at wind forecasting for the purposes of constrained smart arrangements, looking to reduce constraining wind generation where possible. Integrating hour-, day- and week-ahead weather forecasting with outage planning will facilitate minimisation of constraints through load transfer. Another useful type of generation forecasting for DNOs currently, is cited as a connection forecast i.e. what generation will connect to networks including information on what type of generation, where it will connect and when.

4.3 Harmonics

NGET recently changed the way in which they handle harmonic data and how it is supplied to developers connecting generation to the transmission network. NGET are required to provide background harmonic data (harmonic impedance at the Point of Connection (PoC) or surrounding network harmonic information) to potential connections. Previously, harmonic data was provided by NGET to the generation developer for the PoC in the form of impedance loci. The impedance loci would account for a number of network running arrangements required to be tested. This process would generally take a National Grid engineer up to four weeks to complete. In order to reduce inefficiencies such as this, the generation developer is now provided with a reduced network of the surrounding area such that the impedance loci are able to be calculated by them (or tasked consultants) for the different running arrangements.

This will change the way in which harmonic assessments are undertaken and managed in the hopes of providing more accurate data, studies and results as concerns over harmonic impacts grow.

4.4 Review of P2/6 Security of Supply Standard

Engineering Recommendation P2/6 is the principal standard governing distribution network security of supply design. A review of ER P2/6 has been proposed and a DPCR (distribution price control review) Working Group has been formed. As part of the scope, the Working Group will review perceived deficiencies in the current arrangements and consider future requirements for the standard. This will include recognition of changes in technologies, changes in customer behaviour, the impact of smart grids and the impact of EU network codes. Modifications to the P2/6 Standard would greatly impact power system design, modelling and studies carried out in future.

4.5 Modelling of HVDC and FACTS

The use of HVDC for bulk transmission over long lines, interconnection of asynchronous grids and offshore wind farm connections has brought to light the need for more detailed modelling of the HVDC elements themselves, as well as their interaction with the HVAC systems. VSC (voltage source converter) technology is the current state-of-the-art in HVDC technology (VSC-HVDC), and it is also used in many FACTS (flexible AC transmission system) devices such as STATCOMs.

Power electronic devices, such as VSCs, are also becoming prevalent on distribution networks, both as the interfacing technology between the network and generation and LCT, as well as part of the overall distribution network architecture with the implementation of technology such as storage system converters and soft open points.

As they are more widely deployed on GB networks, it will become increasingly important that the VSC-HVDC, FACTS and other power electronic devices are accounted for and modelled accurately for analysis, in addition to the more established Current Source Converter HVDC technology. Further to this, it will be important to ensure ‘appropriate’ models are developed, for instance, a very detailed model may not be suitable for use in a whole-system stability study, such that it may be required to develop a range of models for one technology to ensure it can be used for a variety of purposes.

4.6 Understanding of IT and Communications

A better understanding of the IT and communications systems with respect to their role in the successful operation of future power systems is seen as a requirement. Power networks are already highly reliant on the communication and IT systems to operate and to be managed effectively. For distribution networks with increasing levels of automation, control schemes, active management and smart grid technologies in operation, the capability of the communications infrastructure will require careful consideration. It will be important to assess the capabilities and requirements of the communication systems in terms of resilience, data volumes and latency. Interoperability of decentralised controls and technologies will also become an important consideration to ensure devices can communicate with each other and bandwidth is used efficiently.

Designing new communications infrastructure against common standards and protocols will be paramount to ensuring this interoperability is successfully achieved.

The way in which communications and IT technologies develop over the next 10-15 years will play a large part in determining the architecture of power systems networks in the future.

4.7 Dynamic Modelling at Distribution Voltages

Dynamic modelling (stability) for power system analysis is not commonly carried out on distribution networks, owing to their traditionally passive operational philosophy and limited levels of DG. Increasing levels of generation and a shift towards a more active operating approach however, gives more cause for the dynamic (and even real-time in the future) study of distribution networks. There are a number of challenges associated with this, including the availability of correct dynamic data for existing DG, and the accuracy of dynamic models for distribution network plant and whether these incorporate information such as time constants for temperature rise (i.e. for dynamic rating) or the dynamic behaviour of DG under rapid rates of change of frequency or voltage dips (both of which are likely to become more severe due to lower levels of synchronous generation infeed to the transmission system. The capability of personnel to build and run dynamic power system models is a further concern in this particular area.

4.8 Evolution of Power System Modelling

With the evolution of power systems, it stands to reason that the modelling of power systems should also evolve.

Presently, distribution system design is carried out for 'worst case' scenarios, or at operating extremes (maximum generation/minimum demand, minimum generation/maximum demand) to ensure the networks will operate under the full range of possible conditions. Future distribution networks however, will be operated more in real-time so there will be a wider range of 'network stress' scenarios to consider. A more statistical approach to planning and design studies, with a reasonable number of likely scenarios studied to provide a holistic view of the network, will become common.

Similarly, more and more probabilistic modelling tools are being developed, as opposed to the deterministic modelling tools currently in use, for example, the Scenario Information Model (SIM) created in IPSA as part of the FALCON project provides a number of solutions to a probabilistic input scenario. There is also probabilistic modelling in the SPEN Flexible Networks project in terms of load forecasting for primary substations, definition of annual maximum demand, and definition of minimum daily demand profile and the characterisation of LV voltage. This modelling was carried out in Microsoft Excel in VBA (visual basic) as bespoke applications. Probabilistic modelling is seen as a valuable tool for future power systems as it allows for the modelling of uncertainty and changeability, as is characteristic of networks with volumes of intermittent generation.

It has also been suggested that power system modelling of distribution networks may need to evolve from the traditional hierarchical approach (modelling according to voltage level) to a more regional approach in future. This would provide a better understanding and view of the power system and its operation on an area by area basis, potentially improving efficiencies.

Contingency analysis will become increasingly more important on distribution networks owing to their developing complexity and active operational characteristics. There will be a wide range of possible generation, demand and outage conditions to consider, and contingency analysis will ascertain the actions that network operators must take to maintain system integrity against a range of 'what if' scenarios.

As described in Section 4.7 above, there will also be a shift in the modelling of distribution networks from static to more dynamic focused analysis as penetrations of DG continue to increase.

4.9 Reliability Modelling and Risk Management

Reliability modelling and associated risk management (such as that carried out at transmission) of distribution networks will become increasingly important as more and more technology is added, with the objective of achieving the optimum cost-risk trade-off. Characteristic future distribution networks will have some, if not all, of the following; ICT technology, smart controls and devices, demand side participation, energy storage, electric vehicles and renewable generation integration. All of these elements have risk factors associated with them, such as the failure risk of the ICT equipment, the interoperability of smart controls and devices, the uncertainty of demand response, the availability of energy storage, the uptake and charging patterns for electric vehicles, and the intermittent nature of renewable energy production. As such, risk modelling will become a more integral part of the modelling process.

5. EVALUATION OF MODELLING CAPABILITY AND GAPS

The evaluation of the modelling capability of GB power companies, with significant input from the TOs and DNOs, has led to the identification of gaps and potential future shortfalls in the modelling capabilities currently in use. A wide range of identifiable gaps were cited across the companies. Some notions were common across all companies, while there are other areas with specific needs that have to be addressed.

5.1 Data Availability and Accuracy

The most commonly identified gap for future modelling at distribution voltages is the availability and quality of data; data pertaining to the actual network and its operation, such as cable and transformer impedances and fault levels. This issue is also seen as one of the most critical shortfalls in modelling and must be addressed with the overall aim of improving models.

5.1.1 Steady State Data and Modelling

The need for more, and more accurate data is especially pronounced at lower voltages (11 kV and below) whereby, historically, the level of monitoring installed on these networks has been limited owing to their passive operating nature and well understood patterns of demand. In respect of retrieving this level of detail in data, it is recognised that the retrofitting of monitoring is unlikely to be cost effective to achieve and would also be highly demanding to manage and maintain, such that DNOs are also keen to see improvements in state estimation of distribution networks alongside this to fill the gaps.

5.1.2 Dynamic Data and Modelling

As described in Section 4.7, there is now an increasing need for dynamic analysis at distribution voltage levels, and the shortfall in this case is two-fold; the accessibility of dynamic data of existing plant, and in turn, the capability for dynamic modelling at these voltage levels. Dynamic data for connected plant (e.g. transient and sub-transient reactances) could prove cumbersome to retrieve. Going forward, the provision of dynamic data from distribution connected generators to the DNOs should be common practice.

Potential gaps in the modelling capability from both software and human perspectives are also apparent here. It will be important for DNOs to recognise if they have the appropriate software (e.g. licences) as well as personnel able to produce and process dynamic models.

5.1.3 Harmonic Data and Modelling

The study of harmonics has always been a complex task, and the introduction of large amounts of power electronic equipment to the power system makes it all the more so. Power electronics, such as those found in wind turbine converters, VSC-HVDC systems, STATCOM and SVC reactive compensation equipment, heat pumps and solar PV inverters, have a notable impact on the power quality. ER G5/4 defines harmonic distortion level limits and all new connections must ensure that these levels are not exceeded as a result of the equipment they are connecting; if necessary an appropriately specified harmonic filter must be fitted. Harmonic filters can prove costly, so the emphasis on the accuracy of harmonic analysis is increasing, that is both the accuracy of the harmonic impact of new equipment and knowledge of their characteristics, and also the accuracy of the existing background voltage distortion levels around the network.

5.1.4 Data Sharing between Network Operators

Collective agreement by the DNOs and the TOs deems data sharing between transmission and distribution networks a key area for improvement for the mutual benefit of all parties. Currently, it is a Grid Code requirement that NGET and DNOs exchange information twice per year (once from the DNOs to NGET and once from NGET to the DNOs i.e. the week 28 and 42 submissions). NGET also exchange data with the Scottish TOs (SPT and SHE-T) periodically. A number of factors hinder the efficacy of the exchange processes; data from DNOs in many different formats, and processing of data received is time consuming (sometimes up to 6 months) as a result. This in turn slows the process of using the data for any beneficial purpose. As a remedial action, several network companies have embarked on a project to implement a Common Information Model (CIM) which will streamline the problems of data inconsistency, and accelerate processing time as well as benefits.

5.1.5 GIS Data

Many DNOs expressed a keen interest in improving their GIS database and modelling, interfacing it with the power systems modelling tools, even to the extent that it can be used as the main repository of system data used across planning and operational modelling.

5.2 Skills Gap and Evolution of Modelling

There will be a definite and enhanced need for personnel with expertise and skills in power system modelling in the future. Additionally, in relation to skills, with the evolution of power system modelling tools described above in Section 4.8, is the ability of the current personnel to adapt. In the case of the evolution from deterministic to probabilistic modelling, a procedure for handling multiple scenarios should be implemented rather than leaving results open to interpretation if more than one plausible 'solution' is available.

5.3 Integrating Modelling Platforms

The power system is made up of a number of networks; the electrical network, the communications network, the protection/control network. Traditionally, these networks are all modelled and studied separately, for instance load flow and fault levels studies are conducted in a different software package from that of a protection coordination study despite the studies being interdependent i.e. protection studies are dependent on accurate assessments of fault current to ensure appropriate sensitivity, stability, discrimination and coordination. As these networks become more complex and operating margins decrease, a shift towards modelling these networks together has been suggested. The ETRAN software package has developed the capability to perform simulations on two separate analysis software models (from PSS/E and PSCAD) in a hybrid simulation environment. Learning from this could facilitate the development of more capabilities in integrated modelling.

5.4 Voltage Management of Distribution Networks

Modelling and study of the voltage profile across the distribution networks particularly at LV where monitoring is very limited is an area of rising importance to DNOs as increasing amounts of generation connect and bi-directional power flows become more prevalent. Smart metering data such as hh average rms voltage will become increasingly important to determining automatic voltage control set points (or distribution transformer fixed tap positions).

5.5 Statistical and Probabilistic Tools for Modelling

Stakeholder opinion strongly suggests a need for more statistical and probabilistic modelling to be carried out, although not necessarily as replacement of the deterministic modelling tools used presently. As described in Section 4.8, networks are generally studied for 'worst case' and/or the operational extremes; however there is now a greater need to view the wider range of 'network stress' scenarios and assess network behaviour under these conditions.

5.6 Usability of Tools

One concern raised by the network operators detailed how there is a potential gap in the usability of tools developed and how well they would integrate into processes on a daily basis. The exercise of taking a modelling tool from the environment from within which it is produced into the day-to-day operation is something that should be considered in the development process.

6. CONCLUSIONS AND RECOMMENDATIONS

Throughout the stakeholder engagement, a wide variety of concerns, challenges and potential gaps have been put forward by the GB power companies and these have been captured throughout this paper. It is clear however, through the discussions with the networks companies that they share a number of common concerns and these are highlighted further in this conclusion section with recommendations on ways forward to address these issues.

6.1 More and Better Data for Modelling

The key message throughout the interactions and discussions with the network companies was the need for more, and more accurate, data for use in modelling, both for planning and operation. There are a number of ways in which the network companies have expressed interest in improving their data and visibility of the distribution networks.

6.1.1 Integration of GIS Database with Modelling

A popular notion amongst the DNOs is the improvement of their GIS database such that it can be integrated better with modelling, and potentially be used as the central repository for network data and parameters. It is understood that the task of integrating the GIS with the planning and/or operational modelling systems would be considerable. However, as many DNOs expressed a keenness to align their planning and operational modelling, the potential long-term benefits of this may be worth the effort. Where previously analysis involving the full digitisation and integration of the GIS with modelling systems may not have had a sufficiently high cost-benefit, revisiting this and performing a cost vs. benefit analysis taking account of future enhanced modelling requirements would be a useful step in this process.

6.1.2 State Estimation of Distribution Networks

Utilisation of state estimation on distribution networks could prove effective in supplementing the lack of monitoring data, with operators being provided with a reasonable view of the whole network based on what can be inferred from measurements over a limited subset of the network. Smart meter data, providing information on voltage, real and reactive power import/export, voltage sags/swells, and outages, will be of particular importance to understand the performance and constraints on LV networks which are presently unmeasured.

The FALCON and Customer-Led Network Revolution LCNF projects have elements of state estimation for distribution networks under development; however these are aimed at solving specific problems and so further development would need to be carried out to produce state estimation tools suitable for whole-network modelling.

6.2 Harmonic Analysis

Harmonic analysis is definitely an area of growing concern for the majority of network companies with the increase in power electronic equipment being connected. Improvements in the quality and accuracy of the background harmonic data used for connection studies would benefit the management of harmonic distortion levels around the network. The provision of detailed information on the characteristics of the equipment connecting, for instance, the DG power converters and their behaviour under different loading conditions (including harmonic distortion and power factor) is also required to be understood, and indeed to be modelled.

6.3 Transmission Issues to become Distribution Issues

Another key message to come from the engagement with stakeholders is the need to recognise that many issues dealt with at transmission level will become issues at distribution voltages in the coming years. In terms of planning, these issues include detailed harmonic analysis, generation, including renewable, forecasting, and reliability/risk modelling. Awareness of this will allow preparatory measures to be taken to meet these challenges and tools; techniques and lessons learned can hopefully be translated from transmission down to distribution networks.

From an operational perspective, there are a number of technical issues which primarily impact the transmission system but have residual impacts on distribution systems. These include a fall in system strength (fault level and inertia), increasing levels of harmonics (including sub-synchronous/inter-harmonics), and reverse reactive power flows. The impacts of these transmission system issues can be felt on the distribution system by affecting DG stability, protection coordination, voltage levels and voltage quality. It is therefore important that these be accounted for in operational modelling activities.

6.4 Standardisation vs. Innovation

It is evident that there are differences across the network operators in terms of the modelling tools that they utilise for planning purposes. Standardisation of the modelling tools and processes used is not necessarily encouraged as too much uniformity can stifle innovation, which is presently thriving in a number of different software platforms to meet a variety of network requirements. Rather a level of harmonisation in the processes undertaken for modelling would keep a certain consistency without hindering progression. This would also aid the eventual convergence of modelling capabilities in the future.

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