

Power System Modelling Data: Requirements, Sources and Challenges

Stephanie Hay, Anna Ferguson
TNEI Services
Stephanie.hay@tnei.co.uk

Paper 15 of 15, Part 3: IET Special Interest Publication for the Council for Science and Technology on
“Modelling Requirements of the GB Power System Resilience during the transition to Low Carbon Energy”



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

All three parts of this report are available from the IET website at:

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Stephanie.hay@tnei.co.uk

EXECUTIVE SUMMARY

Power system modelling forms a crucial part of the operation, management and planning of electricity networks. The value gained from power system modelling is in direct correlation with the quality and accuracy of the data and inputs used. As the industry shifts towards a low carbon future, there are a number of new data sources¹ to account for, such as smart meters, Phasor Measurement Units (PMU) and High Voltage Direct Current (HVDC) technologies, as well as renewable generation and dynamic demand.

This paper presents ongoing work and development projects focused on, or with an element of, modelling these and other data sources such that accuracy can be improved as the uncertainty of a more variable and less deterministic power system grows as a result of increasing penetrations of intermittent generation and other challenges. The current capability in the area of modelling data sources is described for both transmission and distribution, with each having a different portfolio of issues and objectives; the transmission network needs to model new HVDC and other transmission-specific technologies to manage the network within its statutory limits; while the distribution network must model a whole range of new low carbon technologies (LCT) with the objective of maximising capacity to connect generation.

An evaluation of the current capabilities and developments in data source modelling, with a view to identifying gaps and potential shortfalls out to 2030, highlights that there are improvements required for transmission network modelling data sources in order keep abreast of advancing changes, with issues of stability, visibility and sub-synchronous interactions at the forefront.

The key message for distribution networks is the sharing and dissemination of knowledge and results from the vast amount of Low Carbon Network Fund (LCNF) projects, and others, for the benefit of all. This coupled with the harmonisation of processes across DNOs for better alignment will facilitate the widespread adoption of modelling tools and techniques and accelerate progress to a low carbon future.


LV network modelling is also an area of concern with regards to data capture and single phase modelling. These are both recognised areas of improvement going forward.

1. BACKGROUND

The accurate modelling of existing and new data sources is crucial to the value gained from power system modelling. Traditionally, the most prominent data inputs to any modelling activities, whether it be for planning or operational purposes, were generation and demand profile models. Although this remains the case, there is now a much wider range of data sources in play on electricity networks owing to the deployment of new and smart technologies, including, but not limited to, STATCOMs, SVCs, FACTS (flexible AC transmission system) devices, power electronic devices, VSC-HVDC (voltage source converter) and solar PV inverters. The generation and demand profiles are also evolving as customer participation is being encouraged and generation is seen at all voltages on the networks right down to domestic level.

The shift in network operating philosophy, especially of distribution networks, to a more active (rather than reactive) approach is seeing them operating closer to their margins while also increasing in complexity.

¹The term 'data sources' in this paper refers to information sources for power system models which encompasses all manner of inputs which provide data to be used in a model/simulation.



As a result, the importance of well-defined and modelled data sources is growing and network operators are taking measures to include the modelling of data sources in their various development projects.

This increase in complexity is also giving rise to the need for modelling within a real-time simulator environment. This allows for equipment behaviour and performance to be assessed in the complex conditions of the actual network.

2. METHOD

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

Research has been performed to inform on the current position of modelling data sources, including ongoing projects on the subject. Stakeholder engagement has been another useful source of information on modelling data source capabilities, giving a network company perspective.

TNEI Services Ltd is also in a unique position to not only be involved in a number of the Low Carbon Network Fund (LCNF) projects, but also to be linked with IPSA Power, the software platform which is used extensively by network operators in GB for power system analysis modelling. Knowledge and lessons learned from power system modelling projects (LCNF and others) within the TNEI consultancy business has been a useful resource.

3. CURRENT POWER SYSTEM MODELLING CAPABILITY

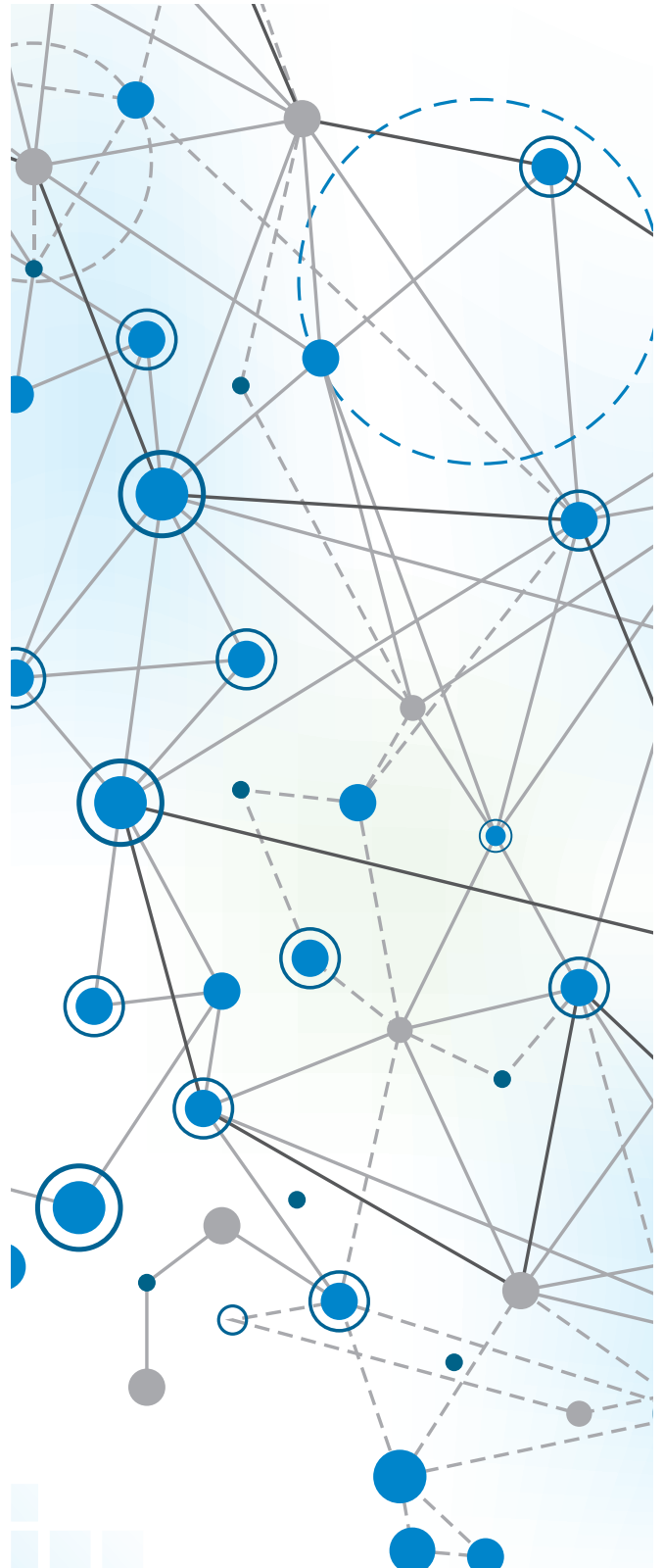
As increasing amounts of low carbon and smart technologies are deployed onto the electricity networks in Great Britain (GB), it is important that their adaptation into modelling software is made a priority amongst other associated activities. The following sections detail a variety of projects which highlight the work currently being undertaken in this area.

3.1 Development Projects in Data Source Modelling at Transmission

Accurate modelling of data sources for the transmission network is important to ensure it can be balanced and managed to within its statutory limits. National Grid Electricity Transmission (NGET), as the GB System Operator (SO) is responsible for this and as such, has commissioned a number of projects which focus on, or have an element of, data source model development.

Table 1 opposite summarises the ongoing projects concerned with the development and practice of modelling data sources. These projects relate to the modelling of demand, PMUs, sub-synchronous interactions and real time data sources. Another key area is modelling associated with the visibility of renewable

energy on the transmission networks, including the exchange of information between distribution and transmission networks. Many of these projects are wider in scope than the modelling and data aspects, but within each project these areas have been identified and are described further below.



Category	Title	Budget	Years	Modelling Data Sources
Modelling of Demand	Development of Dynamic Demand Models in DlgSILENT Power Factory	£268k	2014- 2016	Dynamic demand models are being developed in DlgSILENT to represent the industrial load service. The project includes the investigation of feasibility, reliability and predictability.
Modelling of Demand	Electricity Demand Archetype Model 2 (EDAM2)	£299k	2013-2014	Inclusion of industrial and commercial demand to extend EDAM1 model.
Stability/ Modelling of Phasor Measurement Units	Developments in Protection and Control	£685k	2008- 2011	Includes laboratory scenario testing against a system model and pilot deployment on the transmission systems in the UK and Ireland to track network stability issues.
Stability/ Modelling of Sub-synchronous Interactions	Investigation of Sub-Synchronous Between Wind Turbine Generators and Series Capacitors	£271k	2014-2016	Modelling of dynamic interactions between series capacitors and large wind farm generators, and identify controls to mitigate impact of interactions
Stability/ Modelling real time data sources	EPRI Research Collaboration on Grid Operations and Control	£4,244k	2013-2015	Development of tools to enable system operators to use real time data to assess the system, manage the grid and restore the system in the event of an outage.
Stability/ Visibility	Scalable Computational Tools and Infrastructure for Interoperable and Secure Control of Power System	£126k	2012-2016	Development and deployment of standards such as the Common Information Model to enable power system data exchange between network operators.
Visibility of renewable generation	Modelling of Embedded Generation with Distribution Networks and Assessing the Impact	£42k	2012-2014	Investigating candidate techniques to determine nature and magnitude of impact of distributed generation on transmission demand.
Visibility of renewable generation	Visualization of Renewable Energy Models	£120k	2013-2017	Development of prototypes for visualising wind and solar generation on the transmission networks.

Table 1: National Grid Innovation Projects featuring Data Source Modelling.

3.1.1 Modelling of Demand

As the GB SO, NGET needs to continually balance generation and demand. Accurate forecasts of electricity demand and the rate of change of demand during the day are therefore essential. Electricity demand profiles are changing due to current and predicted increased uptake in technologies such as electric vehicles and heat pumps. NGET also makes use of ancillary services for demand and generation to help to balance the system.

NGET has two ongoing projects that have elements of the modelling of demand. The first of these is the development of dynamic demand models in DIgSILENT Power Factory power system analysis software [11]. Dynamic demand technologies can be exploited to mitigate a drop in system frequency by rapidly reducing demand however, there are issues surrounding the technical feasibility of this approach to frequency control. This project will therefore develop dynamic demand models in DIgSILENT to represent the industrial dynamic demand service (primary and secondary frequency response) provided to the GB system and integrate them into the GB dynamic system model and the service will be investigated for feasibility, predictability and reliability.

The EDAM2 project is looking to enable NGET to produce more accurate demand forecasts by extending the existing EDAM1 model (which accounted only for residential demand) to also include industrial and commercial demand [12] to obtain a daily profile. It will consider demand at a national level and, if this is successful, evaluate demand by geographic area.

3.1.2 System Stability and Reliability

NGET has a number of projects involving modelling data sources that are related to the understanding of system stability. One of the objectives of the “Developments in Protection and Control” project is to evaluate the technology, functionality, performance, interoperability and application of PMUs. This involves scenario testing against a system model and pilot deployment on the UK transmission systems [3]. One of the expected benefits is to enable a better understanding of system stability, particularly on the England-Scotland interface.

Another project concerned with stability is the “Investigation of Sub-Synchronous Between Wind Turbine Generators and Series Capacitors” [4] project. Series compensation is being used on the England-Scotland boundary to enhance the transfer capability of the interconnectors; however, an associated risk is the

potential occurrence of Sub-Synchronous Interactions (SSI), which can lead to generator failure. If not properly managed, this could initiate system instability, disconnection of load, and ultimately system break-up. This project therefore involves modelling of wind turbine generators alongside series compensation in the GB system to assess and highlight potential SSI issues and establish mitigation strategies. MATLAB and Simulink are being used for this modelling work, where standard IEEE benchmark models are not considered to be suitable to provide accurate representations of SSI in the system so specific models for WTGs and series capacitors are being developed for this project.

The “EPRI Research Collaboration on Grid Operations and Control” project is also concerned with secure and efficient transmission system balancing [5]. This project is looking to produce situational awareness tools for system operators which will incorporate new sources of real-time data, such as that available from synchrophasor (synchronised PMU) measurements, asset health sensors and forecasts of future load and variable renewable output levels. These tools will assist in managing the grid through extreme events and restoring the system in the event of an outage.

3.1.3 Visibility

As the penetration of renewable energy generation on the networks increases, a key concern is the lack of visibility that NGET has of many of these generation sources. As a result, system operation, balancing and forecasting are less accurate, more expensive and less efficient. Recognising this, a number of innovation projects that seek to increase the visibility i.e. real-time data and operational information, of these sources have been initiated.

The “Scalable Computation Tools and Infrastructure for Interoperable and Secure Control of Power System” project is looking to develop and deploy emerging industry standards such as the Common Information Model (CIM) to enable data exchange between electrical network operators [6]. This could help to facilitate the exchange of information between the distribution network operators (DNO) and the SO for example, or even between the European Transmission System Operators on a larger scale. The project includes the use of modelling methods such as Real Time Digital Simulation (RTDS). To note here, an EU project, Smart Grid Architecture Model (SGAM), which was initiated as a facilitator to the interoperability of power systems in the context of the

Smart Grid [7], could potentially play a role in this NGET project, and indeed other DNO projects, further down the line.

“Modelling of Embedded Generation within Distribution Networks and Assessing the Impact” is a project that is specifically looking at the collective impact of distributed generation (DG) on the load profiles seen by the transmission system in order to reduced load forecasting errors [8].

Finally, “Visualization of Renewable Energy Models” is looking to understand and display the variability in renewable energy output to enable the transmission system to be operated more efficiently [9]. Prototype models of renewable energy sources will be developed and these will be incorporated into real time operation in order to enable system operation to take account of these sources. Training facilities will be used to test the effectiveness of the new process in making real time decisions.

3.1.4 Future Energy Scenarios for Transmission

NGET produce a set of Future Energy Scenarios for GB (reviewed on an annual basis) encompassing 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 provide credible outlooks to 2035 and 2050. The Future Energy Scenarios provide models of various data sources inclusive of energy demand (residential and commercial), heat pumps and electric vehicles. These scenarios and models are available to the GB transmission owners (TO) to perform network analysis.

3.1.5 ENTSO-E

NGET, as the GB SO, are involved in the ENTSO-E (European Network for Transmission System Operators for Electricity). Through this, they are involved in the development of generic models such as wind turbine models, which NGET use in their modelling activities. The Network Modelling and Data Working Group of the ENTSO-E are charged with creating and developing Power System scenario models out to 2020. The ENTSO-E also has a statistical database which encompasses data from all of the participant countries and comprises production, consumption and exchange (interconnection) profiles which can be accessed and used for modelling purposes.

3.2 HVDC and FACTS Modelling Activities

A major focus for transmission networks is the increasing deployment of HVDC technologies. Despite the large number of HVDC links already in operation across the world, there remains a substantial amount of research and development to be carried out both on the technology itself, and also on methods and impacts of its integration with the existing AC networks. Dynamic assessment is possible using power system analysis software such as PSCAD and other electromagnetic transient (EMT) analysis software, however there is also increasing attention to the simulation of HVDC behaviour, impacts and interactions in real-time.

Scottish Hydro Electric Transmission (SHE-T), together with NGET and Scottish Power Transmission (SPT), are working to establish a GB-centric collaborative facility to enable the planning, development and testing of HVDC transmission solutions [10]. The facility is called the Multi-Terminal Test Environment (MTTE) for HVDC Systems and will include real-time simulation capabilities for HVDC technologies with the main objectives of supporting the transmission planning of HVDC schemes, facilitating the deployment of multi-terminal HVDC solutions, and training of planning and operational engineers in the field. Modelling of new HVDC technologies is also a key advantage of the facility as the role of HVDC on GB networks in future is expected to be significant.

Again in GB, the Power Network Demonstration Centre (PNDC), a venture between the University of Strathclyde, Scottish Enterprise, the Scottish Funding Council, SSE and SP, has a core research theme dedicated to power electronics systems including HVDC and FACTS development.

Internationally, ABB, one of the main (worldwide) manufacturers and suppliers of HVDC technology, has set up an HVDC Grid Simulation Center. The facility has state-of-the-art simulation equipment which is capable of simulating multi-terminal HVDC grid with several unsynchronised AC systems in order to test and verify control and protection strategies for the DC grid in real time using RTDS racks [11]. The HVDC components are modelled in the RTDS on PB5 processor cards and the VSC-HVDC converters are modelled inside small time-step sub-networks. The performance of the RTDS models are verified against results from existing (and verified) PSCAD-EMTDC models.

Rt , the French transmission owner and operator, has also built an HVDC test facility which incorporates HVDC and FACTS devices modelled in the EMT simulation tool, EMTP-RV, with the Opal-RT HYPERSIM real-time simulator [12]. The French transmission network has a variety of HVDC links including with the UK, Spain and Italy, as well as a number of SVCs FACTS devices in operation and their main challenge is to study the performance of their hybrid AC/DC grid to verify transient/dynamic behaviour as well as DC protection schemes.

3.3 Developments in Data Source Modelling at Distribution

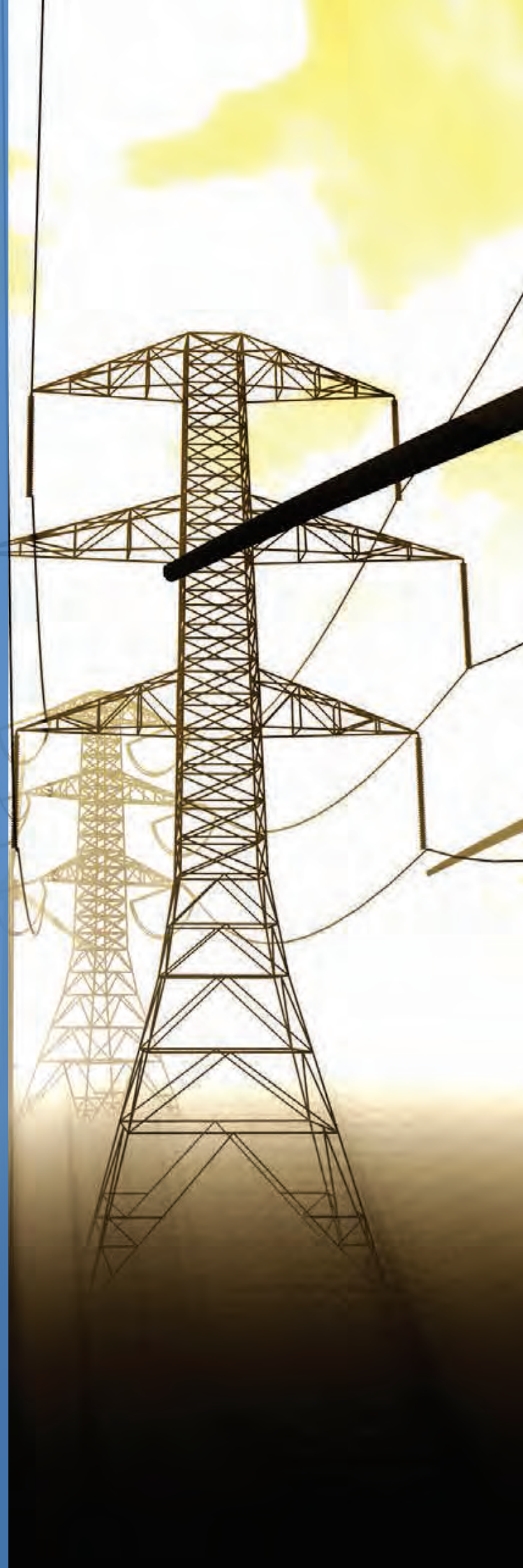
Accurate modelling of data sources for distribution networks is growing in importance as the DNOs focus their efforts on maximising available capacity to connect generation and manage new demands such as Heat Pumps and EV charging. The following sections detail relevant projects where the modelling of data sources is considered.

3.3.1 Tier 1 LCNF Projects

A number of DNO Tier 1 LCNF projects have aspects of modelling data sources. The Electricity North West (ENW) Low Voltage Integrated Automation (LoVIA) developed and trialled new applications of voltage control for LV (low voltage) networks [13]. Through this work, electrical models of a number of technologies were developed including an on-load tap change distribution transformer and LV capacitors.

The Scottish & Southern Energy (SSE) Honeywell I&C ADR project demonstrated the use of automated demand response (ADR) technology to reduce the demand on the network at peak times [14]. The ADR modelling included the development and calibration of thermal models of buildings. This technology will also be trialled in the New Thames Valley Vision (TVV) project (see Table 2 below).

The Distribution Network Visibility (DNV) tool, developed by UK Power Networks (UKPN) provides an improved view of the distribution network on an operational timescale by retrieving more and better data from the networks using remote terminal units (RTU) [15]. This data is also collected with a view to providing meaningful demand profile models around the network which is then used to inform on reinforcement plans and generation connections.



3.3.2 Tier 2 LCNF Projects

Table 2 below lists a number of DNO Tier 2 LCNF projects which have aspects of modelling data sources [16]. The majority of these projects are looking at alternative solutions to traditional reinforcement in order to free up capacity on the LV and HV (high voltage) distribution networks to connect increasing levels of renewable generation as economically as possible. Correctly modelling data sources is crucial to the value that these projects will offer.

DNO	Title	Budget/ Years	Data Source Aspects	Description
ENW	Capacity to Customers (C2C) [17]	£9,597k 2012-2014	Demand Models	Trialling new operational techniques to release latent capacity within the HV network by combining network automation with “interruptible” contracts with large customers.
ENW	Customer Load Active System Services (CLASS) [18]	£7,800k 2012-2015	Collection of Power Quality and Voltage Data	Exploring the relationship between voltage and demand – provide DNOs with knowledge to use voltage control to manage network constraints.
ENW	Smart Street [19]	£11,476k 2014-2017	LCT Generation and Demand Models	Trialling interconnection and voltage management on LV networks. Utilising real time optimisation software and integrating capacitors, on load tap changers and automation to manage voltage.
Northern Powergrid (NPG)	Customer-Led Network Revolution [20]	£52,620k 2011-2014	Analysis of Smart Meter Data, LCT Generation and Demand Profiles	Trialling of smart meters and customer interactions with new network technologies. Development of NPADDS decision support tool.
SP Energy Networks (SPEN)	Flexible Networks for a Low Carbon Future [21]	£5,625k 2012-2014	Voltage Regulator Model	Looking to obtain extra capacity from HV network in three separate locations through the use of voltage regulators.
SSE	New Thames Valley Vision [22]	£27,230k 2012-2017	Demand Models, ADR models, Energy Storage Models	Developing a tool to help forecast where low carbon technologies might connect to the network. Trials network monitoring, energy storage and novel commercial arrangements with large customers. Modelling facilitated using Common Interface Model (CIM).
SSE	My Electric Avenue (Innovation Squared) [23]	£9,083k 2013-2015	EV Charging Models	Facilitating connection of EV (electric vehicle) chargers to LV network with the aim to give a low cost, easy to implement alternative to network reinforcement.

DNO	Title	Budget/ Years	Data Source Aspects	Description
SSE	Solent Achieving Value from Efficiency (SAVE) [24]	££10,338k 2014-2018	Customer Receptiveness Models	Trialling and establishing energy efficient measures to manage peak demand as an alternative to network reinforcement. Development of tools to assess a particular network's suitability for demand reduction through energy efficiency measures.
UKPN	Flexible Plug and Play [25]	££9,700k 2012-2014	Quad Booster Model	Trialling ways to improve control of EHV (extra high voltage) network to connect increased wind generation.
UKPN	Low Carbon London [26]	£28,300k 2011-2014	Derivation of Load Profiles	Exploring technical and commercial innovations to integrate low carbon technologies. One objective is "increase modelling robustness" with an emphasis on using modelling to derive load profiles.
Western Power Distribution (WPD)	FALCON [27]	£12,400k 2011-2015	Intervention Technique Models (e.g. demand side management, Storage)	Deploying smart interventions on the HV network and novel commercial arrangements with customers. Data used to develop investment tool (Scenario Investment Model – SIM) to model where techniques can be deployed efficiently across HV network.
WPD	FlexDGrid [28]	£15,184k 2012-2017	Fault Level Mitigation Technology Models	Developing new fault level assessment processes, real-time monitoring of fault levels and deployment of alternative mitigation solutions to reduce cost and time to connect DG.
WPD	LV Templates for a Low Carbon Future [29]	£9,017k 2010-2013	Templates of Domestic Generation/ Demand Models	Assessing impact of low carbon, demand-side technologies connected to the LV network.
WPD	Low Carbon Hub [30]	£3,527k 2011-2015	Dynamic Rating Plug-In, DStatcom Model	Investigating how network technologies can increase the capacity of wind generation that can be connected to a rural distribution network.

Table 2: Tier 2 LCNF Projects Featuring Data Source Modelling.

Regarding the modelling of data sources for distribution networks, there are two areas that are particularly applicable: The widespread modelling of various new technologies such as voltage regulators, smart meters, PV installations which may be developed as plug-ins for power systems analysis software.

Data requirements to carry out this modelling, in particular data required to accurately undertake unbalanced power systems analysis for the LV networks.

3.3.3 Smart Grid Forum Scenarios

The DECC (Department for Energy and Climate Change) and Ofgem Smart Grid Forum was set up to facilitate and support the electricity networks as they work towards decarbonisation [31]. A number of the work streams are concerned with modelling and have elements of data source modelling, including LCTs and smart appliances.

Work Stream 1 was involved in the development of shared assumptions and scenarios regarding the need for additional distribution network capacity. Work Stream 3 then used the outputs and findings from Work Stream 1 and the “Transform” model was borne from this. Transform is a statistical tool that models the costs and benefits of smart developments of the GB distribution system. This was DNO-led and the results from the modelling activities were used by many DNOs and by Ofgem to inform and assess RII0-ED1 business plans.

The upcoming Work Stream 7 will take this work further through examination and power system analysis of the network solutions suggested by the Transform model. Work Stream 7 will focus on how these network solutions will operate in practice and model how the system components will interact, both on the distribution networks themselves, as well as with the transmission system, and with smart domestic appliances.

3.4 Data Source Modelling Working Groups

There are a number of international working groups concerned with the development of models for generation sources. There is the current CIGRE/CIREN Joint Working Group (JWG) C4/C6.35 on the “Modelling and dynamic performance of inverter based generation in power system transmission and distribution studies” which is looking to develop PV generation models for use in system studies [32]. This JWG is building upon and complimenting work already carried out by the CIGRE WG C4.601 on the dynamic modelling of wind turbines. The IEC TC88 WG27 on “Wind Turbines – Electrical Simulation Models for Wind Power Generation” and the WECC (Western Electricity Coordinating Council) Renewable Energy Modelling Task Force in the USA are also contributing to providing dynamic models for renewable energy sources.

4. EVALUATION OF MODELLING CAPABILITY AND GAPS

This section provides an evaluation of the existing data source modelling capabilities presented in Section 4 for the GB transmission and distribution networks, and also identifies any gaps and potential shortfalls both currently and in the future.

4.1 Transmission Network Modelling

The current developments in the modelling of data sources for the GB transmission network are focused on three main areas; demand modelling, system stability and reliability and visibility. NGET must keep abreast of the ongoing changes to the demand profile of networks which is taking/will take place with the adoption of technologies such as heat pumps and electric vehicles in order that effective system balancing can be carried out. The modelling challenges associated with these objectives are being addressed by NGET through a number of Ofgem-incentivised projects. Alongside this, software developers must take measures to ensure their users benefit from the outcomes of these projects by developing their tools and platforms such that they are capable of utilising data from these sources.

The deployment of technologies such as PMUs, and the study of SSI, indicates that the transmission companies are taking advancing measures to obtain a better view of their networks. There have been related developments in modelling of data sources such as series compensation equipment and wind turbines.

Visibility of distribution networks is also an area for improvement as DG penetrations rise, so much so that there is currently an ongoing debate looking at the increasing levels of ‘cross-system’ interactions and the potential need for a System Architect. The role of the System Architect would be to achieve this cross-system technical integration in increasingly complex future networks [33], and presumably data modelling and consistency would be a key area for any standards or protocols prompted by this work.

4.2 HVDC and FACTS Modelling

The modelling and analysis of HVDC and FACTS equipment at transmission is not only developing in EMT power system analysis platforms, but it is also moving into real-time in order that the performance and behaviour of this equipment and its control/protection can be understood when it is operating in the highly complex conditions of the actual network. ABB and Rte have both developed real-time simulation environments with a view to tackling some of the anticipated challenges of deploying HVDC and FACTS devices, such as protection, control and integration with existing HVAC systems. SHE-T is also building a MTTE for HVDC Systems which will house a real-time test environment for GB-centric HVDC projects.

The complexity of these real-time modelling environments means consideration should also be given to user capabilities and knowledge retention with regards to

utilities being able to manage, run and interpret such models.

4.3 Harmonisation and Sharing of Model Development

Many of the ongoing projects described in Section 4 above include development of models of new technology that can be plugged into power system analysis tools, both for transmission and distribution networks. For example, the SPEN “Flexible Networks for a Low Carbon Future” Tier 2 LCNF project involves the development of a voltage regulator model in IPSA. One of the deliverables will be a fully tested model and the provision of associated block diagrams. These block diagrams can then be used to implement the model into other software packages such as DlgSILENT PowerFactory. Similarly, the UKPN “Flexible Plug and Play” project includes the development of a quad booster model in DlgSILENT and the WPD FALCON project contains the development of dynamic equipment models, such as transformers.

It will be important to continue to develop accurate models that can easily be incorporated into power system analysis software as the technologies deployed continue to develop. It is equally important that the models are suitably tested, can be shared between different DNOs and can be implemented in the different modelling software used by DNOs. Additionally, sharing the models and results with the SO, with facilities to aggregate or treat statistically, will benefit the study of the wider national network.

4.3.1 Transparency of Dynamic Models

Concerns over data sharing has been, and continues to be, an issue for equipment suppliers e.g. wind turbine manufacturers, HVDC and FACTS device suppliers, such that generic or ‘black box’ models, such as those described in Section 4.4 developed as part of working groups, are provided for the purpose of performing studies and analysis. This practice hinders the ability to understand the interactions of the equipment being installed on networks in the necessary level of detail. Going forward, there will be a greater need for transparency of the dynamic models produced and provided by manufacturers and suppliers.

4.4 Data and Modelling of LV Networks

Many of the new low carbon technologies, such as PV installations, heat pumps and electric vehicle chargers, are being installed at domestic level, i.e. on single phases. Accurate modelling of voltage unbalance is therefore increasing in importance. DlgSILENT is able to model and

study phase unbalance, and this functionality is currently being developed in IPSA software, to be released shortly. However, a key issue is that sufficient data is often not available to produce accurate modelling results, for example, for one DNO approximately 20% of its cable data (length, type) is unknown. Customer installations such as Feed in Tariff (FiT) PV installations are also not well captured or recorded and data is often missing.

Another problem that arises when it comes to modelling small-scale generation installations is that, depending on its size, Engineering Recommendation (ER) G83 does not necessitate that the customer informs the DNO of its connection thus increasing the uncertainty of modelling these devices. It also increases the uncertainty of LV modelling as a whole owing to the DNO being unaware of what and where these connections are and assuming balanced modelling where the reality is much different.

Harmonic modelling of LV networks will also become more important and tools will be required that allow DNOs to understand waveform distortion and harmonic penetrations, and to design of remedial measures, such as filters.

4.4.1 Detailed Load Modelling

In the future, it may be necessary to produce and utilise models with more detailed operational traits at LV, for instance, the thermal characteristics of equipment in order to understand real-time ratings, or the charging capabilities and patterns of electric vehicles.

4.5 DNO Requests for Data Source Modelling Developments

Engagement with the GB DNOs revealed that the majority have a keen interest in obtaining smart meter data if the cost is justifiable. Their main objective would be to determine realistic load profiles to produce useful demand models for planning, and indeed operational purposes. Last year, a French DNO, ERDF, presented work undertaken in the area of creating value from the large volumes of smart meter data for better understanding and management of their LV networks. The ERABLE tool [34] sees individual load curves obtained from smart meters imported into DlgSILENT Power Factory and then used to perform studies on the LV networks e.g. phase-balancing.

Information from other derived data sources, such as state estimation, is also of interest to DNOs. They also stated that solar PV array, electric vehicle and heat pump usage patterns would be very useful in future, again to enable them to create representative generation and demand models.

In addition, there are a variety of other technologies which are now being connected on distribution networks, such as filters and capacitors. Where previously these have not been present on distribution networks, they are now required to manage some of the impacts of DG, and as such, these need to be modelled.

Harmonic data is also an important data source to model as increasing amounts of power electronic-based technology is deployed.

5. CONCLUSIONS AND RECOMMENDATIONS

The following sections offer some conclusions and recommendations based on the findings presented in this paper.

5.1 Improvements for Transmission System Operation

More accurate demand profiles which reflect the changing patterns of domestic and commercial consumption and production of electricity are necessary for the SO to carry out effective system balancing. Liaison with the DNOs and access to results of their work on demand modelling (e.g. from the projects described in Section 3.3) would be a useful resource in this process.

Another key recommendation in order that effective system balancing can take place is an improvement in the visibility of DG by the transmission operators, providing more information for forecasting. Better telemetry and monitoring of DG sites, and access to this data by the SO, would also go a long way to achieving this on operational timescales.

5.1.1 Cross-System Modelling in an Operational Context

Sections 3.1 and 3.3 detailed the data source modelling activities at transmission and distribution network voltage levels, and although there is some activity of modelling distribution demand in transmission models (mostly large demand centres such as industrial or commercial operations), Section 5.1 has demonstrated there is now a case for better representation of the distribution system in transmission modelling (and vice versa) for operational purposes. Consideration should be given to the real-time data exchange of topology arrangement and network operating conditions, as well as the additional DG telemetry described above.

5.2 HVDC and FACTS Modelling

Internationally, work on HVDC and FACTS modelling is going in a positive direction as more focus is being placed

on understanding their performance and behaviour in complex, real-time environments. The verification and test procedures of the ABB and Rté platform results with those of dynamic EMT modelling, described in Section 3.2, is also a positive approach to aligning data, performance and results across the various HVDC modelling domains.

In GB, the collaborative real-time MTTE facility will facilitate deployment of HVDC technologies, and accelerate progress to low carbon networks in GB by providing a useful environment to model and test existing and new HVDC technologies. Ongoing R&D (research and development) at the PNDC facility also contributes to the GB progress on HVDC and FACTS modelling and development.

5.3 Harmonisation and Sharing of Model Developments

As described in Section 3.3, there are a large number of projects ongoing in developing data source models for distribution network modelling activities. These models are being conceived, designed and built in a variety of different modelling software packages. As stated in Section 4.3, it is important not only that these models continue to be developed, but also that the DNOs are able to share and disseminate these models across a variety of DNOs (and the SO) and software platforms. It is therefore suggested that there should be a harmonised approach for the development and deployment of these software models.

Improved transparency of dynamic models produced and provided by manufacturers and suppliers of equipment such as wind turbines and HVDC/FACTS equipment, is also a key recommendation. This will promote a better understanding of the operation and interactions of this equipment with the network on a detailed level, compared to that which is achieved through the simulation and analysis of generic and 'black box' models (although these remain important for large-system modelling such as that which would be undertaken on European level by ENTSO-E).

5.4 Data and Modelling of LV Networks

There is the recognition that modelling of the LV networks will become more prevalent. In order to progress with single phase modelling, it will be important to improve databases and methods of data capture.

Also, understanding the sensitivity of the analysis to missing data could help to prioritise areas of data improvement.

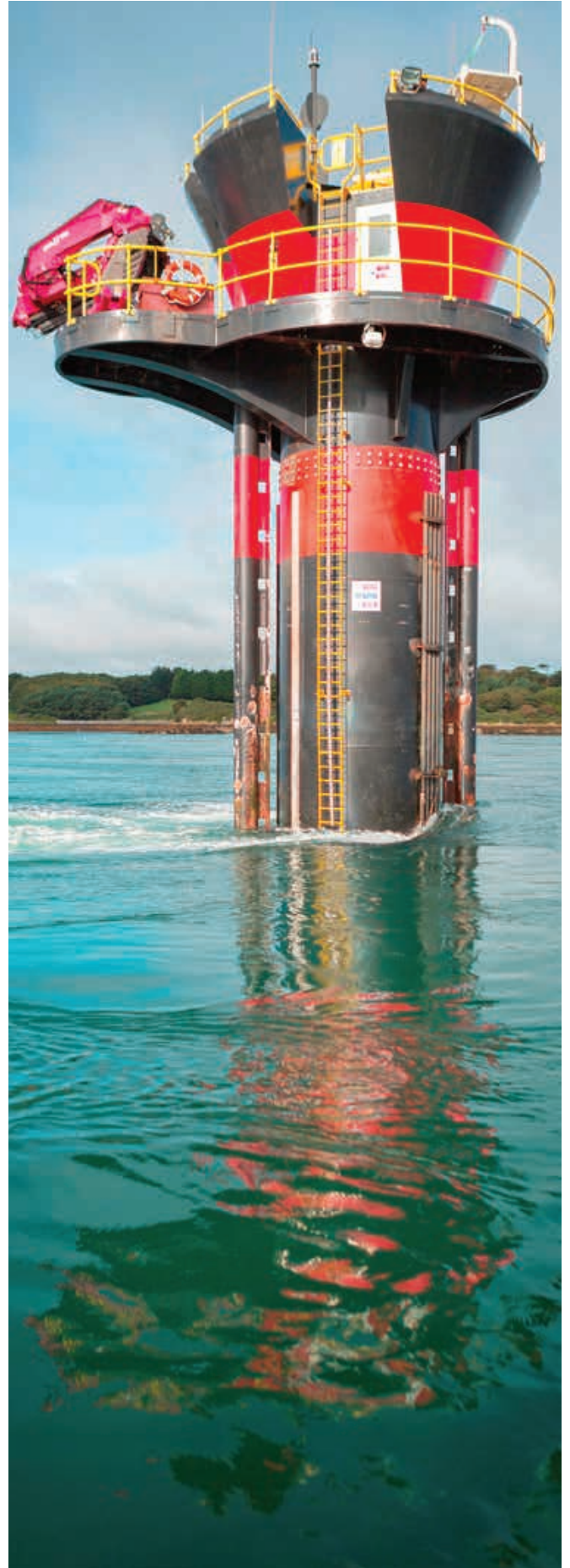
An increase in key area monitoring to improve accuracy and reduce modelling uncertainties is one recommendation to overcome the challenges faced with LV modelling. Another is the potential need for socio-economic analysis when addressing the modelling of demand. Demand profiles can vary considerably between feeders, often as a result of decisions made by customers depending on their circumstances. In general, the overall load profile for an area of network is known, however greater awareness and visibility of specific feeders would provide information on conditions such as reverse power flows at customer level, which in turn could be affecting protection and equipment.

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The Institution of
Engineering and Technology

IET Offices

London*

Savoy Place
2 Savoy Place
London
WC2R 0BL
United Kingdom
www.theiet.org

Stevenage

Michael Faraday House
Six Hills Way
Stevenage Herts
SG1 2AY
United Kingdom
T: +44 (0)1438 313311
F: +44 (0)1438 765526
E: postmaster@theiet.org
www.theiet.org

Beijing

Suite G/10F
China Merchants Tower
No.118 Jianguo Road
Chaoyang District
Beijing China
100022
T: +86 10 6566 4687
F: +86 10 6566 4647
E: china@theiet.org
www.theiet.org.cn

Hong Kong

4412-13 Cosco Tower
183 Queen's Road
Central
Hong Kong
T: +852 2521 2140
F: +852 2778 1711

Bangalore

Unit No 405 & 406
4th Floor, West Wing
Raheja Towers
M. G. Road
Bangalore 560001
India
T: +91 80 4089 2222
E: india@theiet.in
www.theiet.in

New Jersey

379 Thornall Street
Edison NJ 08837
USA
T: +1 (732) 321 5575
F: +1 (732) 321 5702

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