DEVELOPING AND ENHANCING BUSINESS PROCESSES TO ENABLE HIGHER LEVELS OF TSO-DSO INTERACTION

A Z M Shahriar MUTTALIB
Brunel University London, UK
a.muttalib@brunel.ac.uk

G. A. TAYLOR
Brunel University London, UK
gareth.taylor@brunel.ac.uk

M. E. BRADLEY
National Grid, UK
martin.bradley@nationalgrid.com

ABSTRACT

As a consequence of the progressive evolution of smart grid functionality, distribution systems are transitioning towards more active network management and are therefore posing significant challenges to the transmission system operators. The conventional approach of planning and operating the transmission and distribution systems, as virtually separate entities with limited coordination, will no longer be applicable in the near future. In this paper, a strategy has been proposed for the operational planning procedure to adapt the dynamic distribution system equivalents. The strategy has been demonstrated using a fully detailed offline model of the complete transmission system of Great Britain as operated by National Grid. The proposed system modelling approach, with limited but robust visibility of the relevant systems, needs to be supported by revising and refining the business framework that will enable higher levels of Transmission System Operator – Distribution System Operator interaction.

INTRODUCTION

As a consequence of greater decentralized operation in power networks, growing integration of highly distributed renewable energy systems and the development of Active Distribution Networks (ADNs), there now exists a requirement for higher levels of Transmission System Operator – Distribution System Operator (TSO-DSO) interaction. The continual capturing and acquisition of network element updates at the distribution level, including Low Voltage (LV), for accurate representation at the transmission level poses significant computational as well as data acquisition challenges. Furthermore, it has to be operationally justifiable for a TSO, National Grid (NG) in this case, to collect detailed data for network elements at the distribution level, including LV, in order to ensure that the benefits outweigh the costs. When considering the complexity and effort of building a highly detailed model, the validation of such a network representation is also an additional burden. Consequently, it can be argued from a business process perspective that it is unrealistic to represent distribution networks in such a highly detailed manner. A more practical approach is to have manageable models that can simulate the outcome of an event with a reasonable and acceptable degree of accuracy. Such a modelling approach can be achieved by defining the correct model depth combined with the use of appropriately defined and enhanced network equivalents. In this paper, the main contributions are:

i. To identify the present network modelling challenges and to relate them with the technical capabilities which dynamic network reduction can offer. The objective was to address NG's network modelling business requirement.
ii. To propose a modelling strategy for facilitating higher TSO-DSO interaction.
It is beyond the scope of this paper to explain or quantify any financial benefit of the proposed strategy.

IDENTIFICATION OF NG'S OFFLINE NETWORK MODELLING CHALLENGES

Considering the increasing complexity described above, Transmission System Operators can no longer run the network effectively based on their current approach. It is necessary to amend the regulatory framework and planning assumptions to adapt to the forthcoming changes in network management. To cope with the future trend, NG as Great Britain (GB) Transmission System Operator will need to have:
• Active participation of different stakeholders.
• Exploration of alternative approaches and adoption of new methods and strategies.
• Consideration of ADNs in planning procedures.
• Integration of various state-of-art developments to enhance and optimize the short term planning and real time operation.
• Coordination of the different platforms.

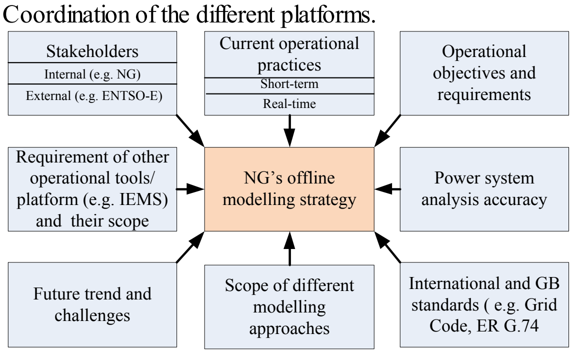

Figure.1. Influences on NG's offline modelling strategy

We have performed surveys of NG stakeholders in order to recognize the shortcomings with the current offline network modelling approach and identified different influences on NG's offline modelling strategy as shown in figure. 1. Furthermore, nine key issues have been pointed out for NG's offline network modelling:
i. Structural issues e.g. discrepancy in the model depths.
ii. Poor scalability as LV networks are expanding and becoming more active.
iii. Static load representation.
iv. Large volumes of data exchange, both internal and external.
v. High manual intervention.
vi. Infrequent updates to LV data (mostly annual)
vii. Extensive validation procedures required.

viii. Reliance on apportionment of loads to LV points.
ix. Extensive modelling of LV networks for which NG has no operational accountability.

NG uses DIgSILENT PowerFactory as its offline analysis package, also known as Off-Line Transmission Analysis or "OLTA".

Optimal depth of the offline model

Model "depth" here means the number of low voltage tiers and the extent of their detail that are represented below the transmission system. The optimal depth of the model is driven by the business requirements; the primary requirement is accuracy of the analysis results, and sufficient LV network elements (e.g. 132kV) must be included to ensure acceptable accuracy in studies such as Load Flow (LF), Fault Level Analysis (FLA), Contingency Analysis (CA) and Stability Analysis (SA). However, there are additional business requirements for modelling relating to operational responsibilities, liaison with Distribution Network Operators (DNOs) and generators, and forecasting of embedded generation.

Data modelling consistency

At present DNOs submit their network data based primarily on Winter Peak conditions in accordance with the GB Grid Code. A mapping table is then created for the distribution of LV load at supply points on the distribution network, based on this submission and later used during summer as well. As the seasons change, demand levels change along with them and the associated forecast values are then adjusted to reflect the underlying demand using the mapping table. During summer, the same model is used with reduced demand, but keeping the LV load distribution constant. This assumption of keeping the proportion of the LV load constant may not always be true, which can lead to an inaccurate model representation. By reducing the DNO network representation and using dynamic load equivalents, it will be possible to update the LV network more frequently, and so the overall process can be improved. Additionally, the network reduction can also avoid the necessity of having apportionment to the LV load.

Accuracy of the results

Post event comparison of off-line and on-line models can be a good indication of how accurate the offline model is. NG is currently refreshing its Energy Management System (EMS), and this project will deliver a separate Power Network Analysis (PNA) test environment enabling the capture of profiles at different times of the day. After some modifications it will be possible to run with an updated LV model and the actual telemetered data to investigate the accuracy of the model. Higher accuracy results may also be achieved through the use of Phasor Measurement Unit (PMU) data.

Mutual interrelation between different platforms

Realizing the interdependency of different platforms, the online (EMS) version of the NG's transmission model uses the element parameters from the OLTA model, but not the topology. The topologies are very close between EMS and OLTA at the transmission level, but OLTA contains more detail for the LV network using various data sources and assumptions. In contrast, the EMS model is constrained to available telemetry sources, and uses a more simplified LV model. The LV model in these two platforms is used for different purposes and analysed with different algorithms. Moreover, online FLA is performed only at the transmission level which relaxes the online model from following the Engineering Requirement (ER) G.74 standard at the transmission and DNO interface. In OLTA, the FLA is performed at the Grid Supply Point (GSP) which requires the offline model to be represented all the network connected at the same voltage level and step down transformers to the voltage level below (NG's interpretation of ER G.74). Nonetheless, ER G.74 does not prevent the use of distribution system equivalents.

Embedded generators and GSP interconnections

Modelling the embedded generators depends on how they react following a change in the HV network, such as tripping of an embedded generator due to a trip on the HV system causing a voltage dip. It requires performing some sensitivity analyses before putting them in to the model. If the overall impact of the embedded generator is to net off the demand, it will be picked up by the flow and voltage of the load and boundary, so in this case discrete modelling will not be required. The impact includes voltage dip, different power electronic device models and so on. Furthermore it has been derived from the survey that the results provided by OLTA will be distorted by not modelling the 132kV GSP interconnections. This is because of the following:

• The impact of parallel flows on HV and LV systems will not be included.
• The voltage support provided by any interconnection and effect on fault levels and stability will not be reflected.

SCOPE OF THE DYNAMIC EQUIVALENTS

Despite the availability of dynamic equivalent (DE) models in the literature, very few utilities have adopted them into their network models. This could be due to three main reasons; firstly, uncertainty as to which type of dynamic equivalent model should be used, secondly, what minimum dynamic model components are needed for sufficient accuracy and lastly, the lack of clear business justification for implementing equivalents.

The first two points have already been discussed in [1-3]. Concerning the third reason, in order establish a business justification, we have categorized all the benefits of DE in two broad terms; tangible and intangible benefits (see table 1). The tangible benefits are termed as those benefits which can be quantified financially or technically up to an extent. On the other hand, the intangible benefits cannot be quantified; however, they assist the business case.

Focusing on the network modelling challenges mentioned in the previous section; we have applied the Quality Function Deployment method (QFD) [4] in order to provide a logical relationship between all the stakeholders' requirements for NG's network modelling issues (rows of figure.2) and the technical capabilities/benefits of dynamic distribution system equivalents (columns of figure. 2) and subsequently built the relationship matrix. There are several QFD tools available, but in this paper a

Tangible Benefits	Intangible Benefits
i. Reduction in model size and data volume. ii. Less manual intervention by automating the network modelling processes. iii. Simpler to utilize the real time metering data as they are readily available at the GSP level. iv. Equivalences small embedded generators and radial networks. v. Lessens the work load in network validation process. vi. Supports better TSO-DSO interaction. vii. Faster simulation. viii. Enabling more users to be supported by the same hardware.	i. Reduces non-convergence scenarios in system analysis caused by improper LV network configuration. ii. Improves and standardizes dynamic load models (in accordance with ER G.74). iii. Improves platform interoperability iv. Eases the data exchange process with DNOs. v. Improves accountabilities in the modelling process, by limiting full detail to areas for which NG is operationally responsible.

Table.1. Benefits of the Dynamic Equivalent

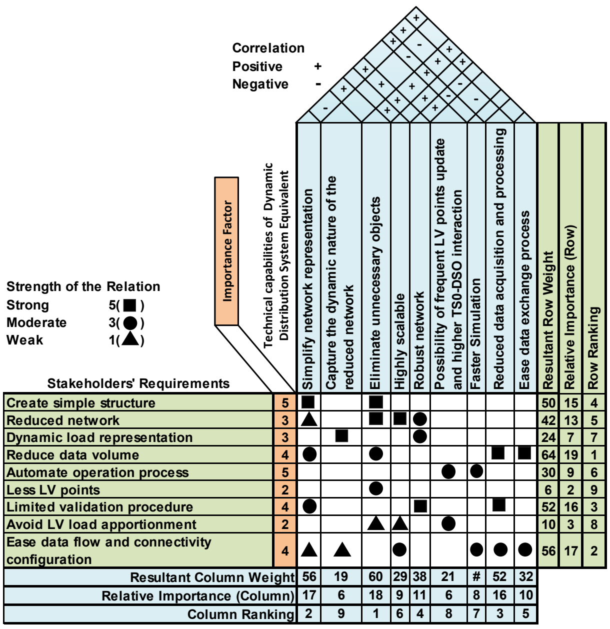

Figure.2. HOQ considering the NG's business requirement

simple representation of House of Quality (HOQ) has been adopted as it was easy to construct and comprehend. Each row of HOQ in figure.2 was assigned with an importance factor. The values were set by the stakeholders after they had been asked to rank the solutions (a higher value means more important). The weight of rows resulted by adding all the strength of the relation of any specific row and then multiplying it with the corresponding importance factor, such as for the first row, $(5+5)\times 5 = 50$. On the other hand, each column weight has been derived by first multiplying the strength of the relation with the corresponding importance factor of the specific row and then summing up all the terms. For instance, the first column of figure 2 has been calculated as $(5\times 5)+(1\times 3)+(3\times 4)+(3\times 4)+(1\times 4)=56$. The roof of the matrix in figure 2 signifies the co-relationship matrix and shows how the different technical capabilities of dynamic distribution equivalents interrelate with each other. The positive and negative symbol in the co-relationship matrix implies the positive and negative correlation respectively. The outcome of this HOQ was an overall indication of which requirements should be given higher priority (row ranking) than others and which technical capability of the dynamic network reduction has the higher prospect (column ranking) than the others. However, this is worthwhile to mention that, any individual solution is not capable to solve all the problems rather than it is the combination of all of them which will confront network modelling challenges.

PROPOSED MODELLING STRATEGY

From the business perspective, in order to embrace any load model, the load modelling approach is a vital concern. According to CIGRE WG C4.605 [5], the load modelling approach can be sectioned into two parts (see figure. 3). Based on figure 3, NG currently represents the DNO network by following the B→E route starting from the initial design up to the operational stage. The DNO loads are modelled with a single, static load model structure; fixed P and Q are assuming after transformer tapping timescales, and a three-part polynomial model is used for the period before tapping [6]. Thus these parameters are required to be updated considering the present scenarios of ADNs. During the operational planning stage, the operational data (e.g. P and Q) of the load are updated in reference to the forecasted data.

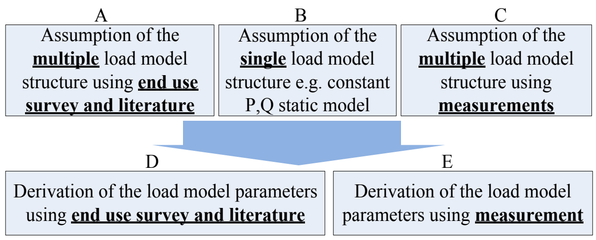

Figure.3. Classification of load modelling approach [5]

We have established an enhanced extended ward equivalent (EEWE) by complying with ER G.74 (see figure 4), which is able to capture both the static and dynamic nature of the equivalenced area [1-3]. Therefore, in this paper we have proposed to change the load modelling approach from B→E to A→E. By doing so, NG will be able to adopt a dynamic load model consisting of multiple components.

Each component of the EEWE model has different functionality. The motor component (marked with a red dotted line) captures the dynamic nature of the equivalenced area whereas the generator component with Z_{ext}, provides reactive power for VAr correction at the connecting boundary node. The rest of the components represent the static objects where frequency dependent parameters are also available. In order to get a realistic fault level analysis result, multiple *X/R* ratios have also been included in accordance with IEC-60909 method C. The apportionments of the real and reactive power have been achieved through the combination of a "constrained ZIP model" with the 3rd order induction motor model [5] (marked with blue dotted line). It has been demonstrated in [1-3] that the equivalent model showed resilient results (all the errors are within the tolerance limit of 5%) over a variety of system states. However, some deviations have been observed in the swing curve while performing SA with the presence of EEWE [3], thus it has been suggested only in the case of SA to either adopt EEWE with wavelet decomposition technique [3] or to use equivalent model without any generator component. The final recommendation was to model in full non-linear detail only at the transmission level and equivalence the remainder provided that the GSP interconnections (132kV interconnection) were retained intact. However, it should be taken into account while comparing any real time/field data with the derived result from this model is that the way tap-changing transformers are represented in typical load flow models (continuous tap ratio, as in figure.5.b) differs from real life operation with discrete taps (figure.5.a).

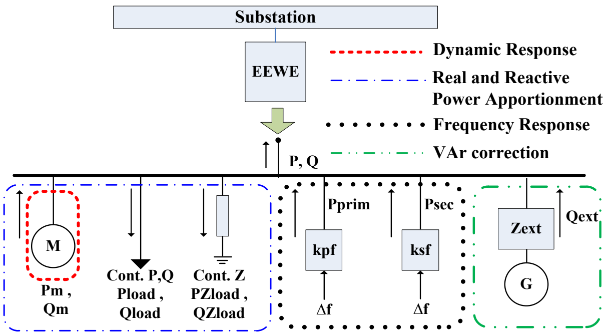

Figure.4. Components of ER G.74 Compliant EEWE

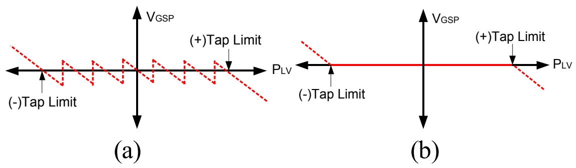

Figure.5.(a) Behaviour of tap-changing in real life(b) Typical representation of tap-changing transformer.

Due to the complexity in the network there may be cases where generic rules cannot be applied. For example, a large LV-connected generator may require explicit modelling for calculating the system reserve. Nonetheless, the connecting components between the embedded generator and GSP point can be equivalenced whilst maintaining sufficient accuracy of results. Generators which are participating in the balancing mechanism (BM) also need to be modelled.

CHALLENGES

In the proposed new approach, the DSO would derive dynamic equivalent models for its network and supply these to the TSO. A number of challenges would need to be overcome to reach this goal:

i. Proper data availability (e.g. updated load model parameters) to support the proposed load modelling approach.

ii. Model Derivation: Deriving dynamic equivalent models would be an additional task for the DSO compared to the current practice of supplying unreduced data. However, this change should be part of a wider development of data exchange between DSO and TSO (including real-time as well as planning data) which will bring benefits to both parties.

Even if this change cannot be implemented immediately, there should still be a benefit to the TSO from carrying out the model derivation in-house, because a number of objectives identified by stakeholders will still be achieved.

iii. Updating Codes and Standards: Data exchange practices between a TSO and DSOs are typically enshrined in industry codes (the Grid Code in GB). A permanent modification to data exchange practices should be reflected in a change to these codes, which would require the agreement of all parties involved.

CONCLUSION

Future trends and technological advancements will challenge today's modelling approach. The opportunity is that it can be well-organized by developing practices and governance requirements in the utilities. Implementation of the proposed dynamic equivalent model strategy will establish mutually beneficial situations for all the stakeholders. Network reduction with dynamic equivalents should eventually support a higher level of TSO-DSO interaction. There may be some challenges to reach this goal, but there are significant benefits in prospect.

REFERENCES

[1] A Z M S. Muttalib, G. A. Taylor and M. E. Bradley, "Modelling Enhancement of LV Network Equivalents for Accurate Operational Planning of the GB Power System", in *IET ACDC 2015*, pp.1-8,10-12 Feb. 2015.

[2] A Z M S. Muttalib, G. A. Taylor, and M. E. Bradley, "Contingency Analysis of Operational Planning Models with Distribution Network Reconfiguration", in *PESGM 2015*, pp.1-5, 26-30 July 2015.

[3] A Z M S. Muttalib, G. A. Taylor and M. E. Bradley, "Improvement of Stability Analysis and Assessment through Wavelet Decomposition", in *RTDN 2015*, pp.1-8, 22-24 September 2015.

[4] D. Gutschow and M. O. Kachieng'a, "Making business sense of distribution automation systems: the case of Eskom, South Africa", in *IEEE Transactions on Power Systems*, vol. 20, no. 1, pp. 272-278, Feb. 2005.

[5] Z. Y. Dong, A. Borghetti, K. Yamashita, A. Gaikwad, P. Pourbeik and J. V. Milanovic, "CIGRE WG C4.065 Recommendations on Measurement Based and Component Based Load Modelling Practice", 2012.

[6] Central Electricity Generating Board (CEGB), "Voltage Criteria for the Design of the 400kV and 275kV Supergrid System, Planning Memorandum PLM-ST-9 Issue-1", Technology Planning and Research Division, System Technical Branch, December, 1985.