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Challenges in model and data merging for the implementation of a distribution network contingency analysis tool

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Abstract: The electricity network in the South East of England has become more challenging to manage both for the transmission and distribution network operators due to increased distributed generation connection and increased power flows on transmission interconnectors to and from continental Europe. UK Power Networks (UKPN), the distribution network operator (DNO), has trialled for the first time online contingency analysis on a distribution network in Great Britain. The Kent Active System Management project aims to demonstrate the benefits of using a contingency analysis system for both operational and planning time frames. This study describes challenges and the recommended approach to overcome data exchange and data-quality challenges when developing a real-time power flow model from existing datasets. It provides a real-world example of dealing with data exchange and also highlights the need for transmission system operator/DNO coordination.

1 Introduction

Since 2013, the south-east region of England has experienced increasing volumes of renewables, with wind and solar photovoltaic (PV) generation connecting to transmission and distribution networks. In addition, the area is home to two high-voltage direct current (HVDC) interconnectors to mainland Europe, with two more planned in the near future. Distribution and transmission networks are highly meshed in the region, which has resulted in significant interdependence between transmission and distribution networks in the area. Furthermore, the new ‘active’ nature of the distribution network with the uptake of distributed generation connected at medium-voltage levels brings significant operational and planning challenges. UK Power Networks (UKPN), the distribution network operator (DNO) in the East Kent region increasingly experiences congested networks, power flow volatility and voltage management issues. Consequently, it was established that there was a need for greater observability of distribution networks and closer coordination between transmission and distribution companies was essential to maintain a safe overall system and maximise utilisation of existing assets. Data exchange, operational coordination between DNO and transmission system operator (TSO) and active management of distributed energy resources are referred as key requirements to improve observability of the network and maintain system security [1]. Many aspects of TSO–DNO interaction are addressed by the Network Codes [2].

Historically, DNOs built infrastructure in response to growth in maximum or peak demand as DNOs did not have the ability to influence demand and generation. Today, DNOs are starting to gain access to a portfolio of responsive demand, storage and controllable generation assets that can be used to actively contribute to both the distribution network and wider system operation. DNOs are building and operating a flexible network with the ability to control power flows on its network and coordinate with the TSO to manage and optimise an increasingly volatile system [3]. Since intermittent generation capacity continues to increase in the East Kent area, additional corrective control actions are required in near-real time. Power flow studies need to be run more often than in the past. Currently, power flow studies are performed manually, so outage planners have time to only run a few scenarios per outage. With limited real-time information available, they currently use maximum demand and worst case generation scenarios when modelling the network. As a result, there are periods where solar and wind generation are arguably over-constrained. The Kent Active System Management (KASM) project was initiated in response to the increasing challenge faced by UKPN in operating an active low carbon network.

This paper provides a real-world example of the implementation of an innovative network management solution that requires coordination and data exchange between TSO and DNO. The KASM CAS is introduced, along with its model and data requirements. The paper describes the data interoperability issues that were encountered when creating a base-case model from the disparate data sources. It highlights the needs for merging operational and planning network data models to obtain a single model to be used for near real-time power flow studies. The paper also describes how previously unknown data-quality issues have become apparent, thus helping to target future maintenance activities.

2 KASM project

The Kent Active System Management (KASM) is a low-carbon networks fund (LCNF) tier 2 project. The LCNF is administered by the UK regulator, Ofgem. The project aims to carry out a range of technical innovation trials to demonstrate more advanced operations and planning techniques for the 132 and 33 kV network in East Kent. The project integrates a new inter-control centre communication protocol (ICCP) link which enables real-time data exchange between national grid company (NGC), TSO and UKPN. A new contingency analysis (CA) engine is integrated alongside the distribution management system (DMS) in the UKPN control room. The CA computes online power flows on the 400, 275, 132, 33, and 11 kV networks in East Kent area and prepares contingency analysis studies within near real-time operational timeframes. The KASM solution incorporates new forecasting modules that provide short-term load forecasts and short-term wind and solar generation forecasts.

2.1 Contingency analysis system architecture

The contingency analysis system (CAS), developed by Bigwood Systems Inc. as part of the KASM project, uses advanced power flow and smart Homotopy-based power flow solvers to study the network for thermal, voltage and steady-state violations for a large set of contingencies [4]. Its high-level architecture is shown in Fig. 1. The CAS uses input data from a collection of data sources. Input data is processed by the Data Bridge, State Estimator and Power Flow Solver module. The Forecasting Engine is a standalone application that utilises data from multiple data sources to generate up to 5 days-ahead load, solar generation and wind generation forecasts. The CAS Viewer is the user interface module that displays received results to users [5]. The Real-Time Mode, the Look-Ahead Mode, and the Study Mode are the three main modules available within the CAS which will be described below.

- Real-Time mode via State Estimator: The CA-RT module (real-time mode) provides control engineers an environment that computes automatic near real-time contingency analysis studies using the most recent dynamic network data. A real-time mode data bridge automatically checks for new dynamic data availability and sends the raw data to a distribution system state estimator which outputs a real-time base-case for contingency analysis. Real-time contingency analysis studies are run periodically every 15 min based on new dynamic data availability.
- Look-Ahead mode: The CA-LA module (Look-Ahead mode) provides control engineers and planning engineers an environment that computes automatic short-term contingency analysis studies using the most recent set of load and generation forecasting data. The CA-LA module makes use of real-time current switching status to generate the LA base-case and run contingency analysis studies.
- Study Mode: The Study Mode provides control engineers and planning engineers an off-line environment to study a specific case in greater detail than in the Real-Time Mode. It is suitable for planning and operational planning studies. The user can manipulate many aspects of the studied case such as modify power system loading conditions, control strategy, control availability and power transactions.

The CAS provides online network status, possible voltage and thermal violations and the ability for control room engineers to run the application in Study mode to check the feasibility of suggested network re-configurations. The CA engine runs multiple contingency scenarios in a number of seconds. The three modes are designed to help operators to actively manage the network in a cost-efficient manner by reducing distributed generators curtailment and reinforcement expenditures associated with new generation connections. The tool provides a means of modelling future distributed generation connections and make a realistic assessment of the impacts of new connections on the network, making use of historical operating conditions to simulate future operating conditions (hindcasting). The Contingency Analysis System (CAS) which includes the CA engine, and the forecasting modules, offer a complete package to explore new ways of managing and coordinating network operations in the East Kent region.

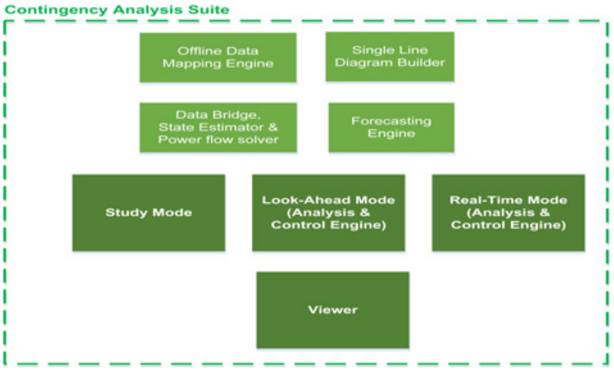

Fig. 1 *CAS high-level architecture*

2.1 Inter-Control Centre Communications protocol (ICCP) link

The KASM project implemented an Inter-Control Centre Communications Protocol (ICCP) link between UKPN and National Grid (NGC; the Great Britain TSO). The ICCP protocol also known as Telecontrol Application Service Element (TASE.2) protocol is specified in the IEC60870-6-503 (part 6) standard. The solution architecture is designed, configured and implemented to provide real-time data exchange over a wide area network (WANs) using a client–server model. It provides an interface that supports data transfer between distribution and transmission control centres. The sharing of near real-time data between control centres such as metering data and status information provides a better visibility of the current conditions of networks. Thus, through the ICCP link, UKPN gain visibility of the 400/275 kV transmission network real-time running arrangement and power flows, conversely, NGC gain similar visibility of the distribution network, connected below the supergrid transformers. Essential information related to large fossil-fuel power plants and HVDC interconnectors operation are also shared.

The solution architecture complies with performance requirements and data security, security aspects associated with data manipulation and unauthorised access being key concerns when implementing an ICCP link [6].

4 CAS design requirements

4.1 Network boundaries

The KASM project is implemented in the South-Eastern Power Networks (SPN) distribution network. The distribution network supplies electricity over an area of ~8200 km^2, incorporating all of Kent, East Sussex, much of West Sussex and Surrey.

Electricity is taken from National Grid's 400 and 275 kV networks at a number of 'supergrid' sites and distributed to customers through a succession of networks operating at various voltages ranging from 132 kV down to 400/230 V. The boundary of the topographical area being used within the KASM project is defined on the basis of a number of substations whose power flows are known to be challenging to analyse. This network is becoming increasingly influenced by intermittent generation on the distribution network and activity on the transmission network, such as flows on interconnectors and large plant outages. The network topology includes substations on the transmission network at both 400 and 275 kV voltage levels, down to the 33 and 11 kV substations of the distribution network where the network trace ends at the SCADA measurements on the 11 kV feeders. Only the primary side of earthing transformers and auxiliary transformers are included in the network model whereas the secondary side are modelled as an impedance to earth.

4.2 Data requirement

4.2.1 Data sources: The CAS requires data that is assembled from various data sources, internal and external, as illustrated in Fig. 2. In the context of this paper, our focus will be on the UKPN internal data sources that are used to create the CA base-case models. The CA engine makes use of UKPN's existing

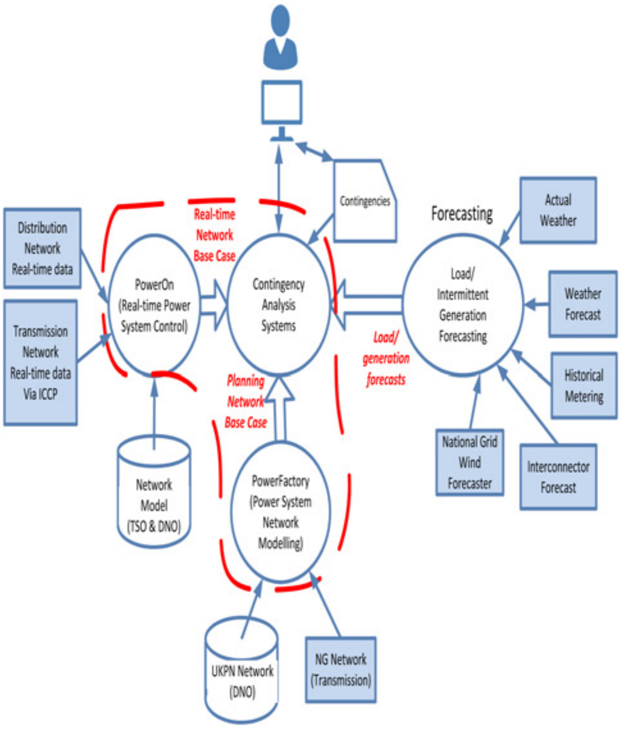

Fig. 2 *CAS data flows*

static and dynamic data to create a model of the network usable by the three modules of the CAS. This data is extracted and combined from two sources:

- *Operational DMS* (PowerOn Fusion): This tool makes use of a full network model, distribution network SCADA data and transmission network data (relayed via the ICCP). Data can be exported in a proprietary XML format.
- *Network planning tool* (DigSilent PowerFactory): The network model can be exported in CIM (common information model) format.

PowerOn Fusion contains both the network model topology and real-time data. At the time of writing this paper, the DMS model does not contain sufficient data regarding asset parameters which are key requirements for power flow studies. The PowerFactory model had been used for detailed planning studies and contains sufficient data regarding asset parameters; however, the application cannot run online power flows studies as real-time network data cannot be imported in the tool. Therefore, the decision was made to merge PowerFactory and PowerOn Fusion models, PowerFactory, providing accurate network asset parameters and PowerOn Fusion supplying the network model topology and real-time data.

4.2.2 Dynamic data: The dynamic data reflects the current operating state of the network, consisting of analogue measurements and switches statuses, updated in real time. Distribution and transmission network dynamic data are available within the DMS. The CAS collects real-time data through the PowerOn XML file. The XML file contains a full-network model (transmission and distribution). The real-time network configuration and analogue measurements are exported from PowerOn using the distribution power flow trace function available. The real-time analogue measurements are reported as follows:

- Voltages (reported against busbars)
- Current (reported against individual switches or circuit breakers)
- Switch states
- Power flow metered values (reported against individual switches or circuit breakers)
- Tap changing positions (reported against individual transformers)

An updated PowerOn XML file can be requested manually or automatically generated every 15 min.

4.2.3 Static data: Static data captures the static aspect of the network infrastructure. It needs to be updated only when new equipment is added to the power system or existing equipment has changed. PowerFactory is used to export the network parameters to build the data model. In addition to the data model, static data is required to produce a single line diagram (SLD). To create the SLD, three additional files are exported from PowerOn. These include a hot-spot file, a connections file and a world list file. Network diagrams in PowerOn are organised by voltage levels, named 'worlds' (400, 33 kV etc.). The hot-spot file contains all components on the network. Component positions, internal coordinates and 'world' information are included in this file. The connections file describes the connection components (busbars and lines), coordinates and world information. Worlds are described in the list of worlds. The resulting single-line diagram is stored in a text file format.

5 Model merging

The CAS single-line diagram is built off-line by the Single Line Diagram Builder module (Fig. 1), based on the connectivity and line definitions from the PowerOn extract. The parameters of the network components were extracted from a PowerFactory CIM file and matched to the corresponding components in the PowerOn XML file. The component matching task is executed by the Off-Line Data Mapping Engine (Fig. 1), which runs as a stand-alone application. A mapping engine is required because there is no consistent ID for assets in PowerFactory and PowerOn. The application performs the matching and stores the matched parameter data in the parameter-matching table in a text file format. Correctly associating components between the different network models required addressing the challenges described below.

5.1 Component identifiers

An algorithm was developed to match components in the PowerOn XML file to those in the PowerFactory CIM file. Components were matched based on a device name, derived from the site/substation unique identifier associated to an item number. There was generally a good one-to-one mapping between PowerOn and PowerFactory substations but when a common identification of substations and the equipment within were not consistent in both models, the Off-line Data Mapping engine failed to find a match. Extra manual mapping was required to map data between these assets. This involved the creation of a number of exceptions tables to tackle the issue.

5.2 Model topology

A complicating factor was that the real-time model exhibits a higher granularity than its planning counterpart. Thus, the model use for real-time operations is known as full-topology model in contrast with the consolidated-topology model that is implemented for planning functions. Traditionally, planning models have applied a number of simplifications to reduce the model size and therefore improve computation time [7]. These simplifications consist of omitting electrical components such as circuit breakers and disconnectors, modelling equivalent networks at transmission network connection points and collapsing all equipment of the same voltage level within a substation down to a single node (referred to as a 'bus'). Hence, the key challenge in the component data mapping exercise was in trying to match a consolidated-topology model to the full-topology model. The decision was made to use only switches that were present in both models so that the CAS single-line diagram implemented a consolidated-topology model.

Finally, it was necessary to account for differences in the way lines are implemented in both models. A single line in PowerFactory could be broken into multiple line segments in PowerOn. This is because PowerOn lists individual sections of cable/overhead line whereas PowerFactory simplifies this to a single cable/overhead line between two nodes. Significant development time was spent to handle the one-to-many line-matching issues. Also, missing or mismatched switches would prevent the line-matching process. Data cleansing rules and matching rules were implemented to overcome the connectivity matching problem. Once a line was mapped between the two models, then all the components on the lines were considered to have been matched.

6 Data quality

A state estimator (SE) was developed by Bigwood Systems (BSI) as part of the CAS. The current state of the network is estimated based on the network component parameters information, network topology and measurements, necessitating the detection and rejection of bad measurements. While developing the SE, a number of data-quality issues arose that initially prevented the power flow solvers from converging. A first class of errors was related to the polarity of active power (MW) and reactive power (MVAR) measurements. In some cases, polarity of measurement points was not consistent across the network. These were resolved by investigating the sign convention that was considered the standard and applying this principle across sites which did not follow this standard. An additional challenge when investigating real-time data quality was determining the direction of power flow where only ampere measurements were available. This required significant manual effort to determine the direction of flow at these sites.

After these corrections, measurement errors and poor synchronisation were reported as the major sources of SE residual error. High residual errors that exceed tolerance levels were observed on current and real power measurements. The analogue data acquisition is achieved through current transformer (CT) and potential transformer (PT). The overall accuracy of measurements can be affected at the acquisition stage, at the processing stage, at the transmission stage or at recording stage. Errors can be introduced by instrument transformers, transducers, intelligent electronic device (IED) performance and analogue-to-digital (A/D) conversion. Managing data quality at the point of data creation and consistently applying techniques to find and eliminate the root causes of error remains an expensive task as metering equipment are distributed across wide areas. Communication media failure or sensor failure may also lead to missing data, which is a recurrent and unavoidable phenomenon when dealing with power systems datasets. In combination, noisy and missing data can be a serious impediment to computational power analysis studies. To address this challenge, UKPN has initiated a data-quality program for a number of sites in the trial area.

The KASM project carried out a desktop data analysis to validate the MW analogues from selected circuits in East Kent to validate the data issues by focusing on some of the power analogues in PowerOn which appear inconsistent with the associated amperes and volts measurements. If a potential issue was found, a data survey was undertaken using a non-intrusive method. The non-intrusive methodology involved tapping power flow measurements using power quality monitors (PQMs) without interfering with operational protection and metering equipment. PQMs (data loggers) were used to record analogue measurements for a period of 24 h at 1 min granularity at selected circuits. A whole range of data was recorded in the data loggers including volts, amperes, real power and reactive power flows, power factor etc. The PQM data was used as the reference data and comparative data was obtained from PowerOn Fusion in half-hourly averaged values for a corresponding 24 h period.

7 Conclusion and recommendations

Moving forward in smart-grid paradigm, data consistency, data exchange and data quality are key to delivering benefits from a smart grid.

It is essential for network operators to keep consistent nomenclature and model parameters in both real-time and planning models. Reviewing model parameters on a regular basis will help avoiding discrepancies between models.

The implementation of a common data repository will facilitate internal and external data exchange. It will benefit not only short- and long-term planning but also financial and strategy business activities. Industry standards should be preferred for data export and the data exchange method should be extendable and scalable.

Data-quality programs are key requirements that drive innovation projects to success, thus they have to be well-defined and implemented. The development of applications for advanced analytical studies relies on the integrity of the data input; therefore, it becomes increasingly important to ensure that data-quality issues are monitored and mitigated. Data-quality monitoring should be run at the right start of the creation of the data.

8 Acknowledgments

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