Evolution of Electricity Distribution Control Room Data Streams – UK Case Study

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***Abstract*— The move towards 'Net Zero', the balance of greenhouse gas emissions produced and removed from the atmosphere, is increasing the complexity of managing distribution networks, with more deployments of low carbon technologies, new markets for flexibility services, and greater monitoring and visibility of the network itself. This has driven the UK's Distribution Network Operators who manage the network, to evolve towards becoming Distribution System Operators, taking on a role more akin to the traditionally more complex Transmission System Operator. In parallel with this development, the data streams utilised by the distribution network control room have also evolved. This paper sets out this evolution by detailing the existing data streams within a typical distribution control room, and how these data streams will need to evolve, as well what new sources of data a future control room will need to accommodate, and finally by identifying novel ways that that value can be created from this data through the use of new 'smart' tools.**

***Index Terms*-- Power Distribution, Data Acquisition, Data Handling, Intelligent Control**

I. Introduction

In common with countries throughout the world, the UK has plans to achieve 'Net Zero' carbon emissions[1]. As such, the UK's Distribution Network Operators (DNOs) will need to operate in a more complex, rapidly changing environment while interacting with a broader range of network participants. Similarly, managing the increasing number of new technologies such as Active Network Management schemes and ever more advanced network automation and control schemes will require a major change in control room design and operational practice[1].

The mass deployment of new Low Carbon Technologies (LCTs), and higher numbers of flexibility services being utilised across the network, will require DNOs to monitor and manage increasingly complex and variable power flows across the network[2]. This will make it increasingly challenging for network operators to manage and act upon growing volumes of network data. This could have a potentially negative effect on their ability to manage their assets safely and effectively, to maintain network reliability, and to avoid any impact on customer service[3].

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The combination of the amount of newly available data and increasing network visibility has the capacity to provide a very detailed view of the network's operation, far beyond current capabilities. It is important that network operators understand how to utilise this additional data to improve network operation, increase network utilisation and improve reliability while supporting the UK's transition to Net Zero.

To maximise the benefits from these new data sources and provide control room staff with appropriate visibility of an increasingly complex system, the operation of the control centre needs to be re-defined. This requires an innovative approach to control room operation in order to facilitate the transition to Distribution System Operation (DSO).

II. Methodology

To assess the potential evolution of data streams and control room functionalities that are likely to be required in the future electricity distribution control room, extensive engagement with both industry and academia was undertaken. This included a series of workshops and interviews, and an analysis of both externally and internally released design documents and proposals from network operators themselves.

Findings from these engagement exercises are presented in Section 3 with an overview of how the DNO control room functions at present, followed by discussion of how the identified data sources and connections are likely to change in the near future as well as analysis of the new sources of data that the DSO control room will be required to process. Section 4 details a proposal for the use of a 'smart' tool for making the most effective use of the new data sources, while maintaining the control room's ability to perform key functions, with the on-going development of this tool discussed in Section 6.

III. Analysis

A. Existing Data Streams

Figure 1 shows a block diagram summary of the data streams for a DNO control room, with arrows indicating data

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flows between functional blocks. The following sub-sections will set out the function of each of these blocks in more detail, including what types of data are recorded and what they are used for.

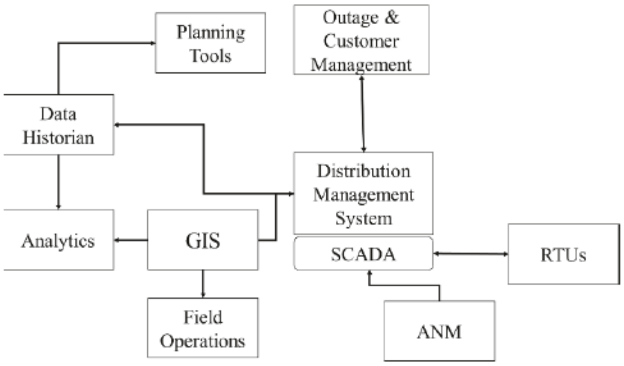

Figure 1. Block Diagram of Control Room Data Streams (based on [2]).

1) SCADA: Supervisory Control and Data Acquisition systems, were originally implemented for control and monitoring at high-voltage and primary substations, with expansion to include monitoring placed strategically at specific secondary substations. This monitoring provides control engineers with up-to-date information regarding the status of the network. To achieve this, data acquisition is often carried out through non-continuous polling of remote telemetry units (RTUs). Issues with existing SCADA systems include communication inadequacies due to legacy low speed modems and interoperability problems due to common use of proprietary protocols[3].

2) ANM: Active network management is increasingly deployed to facilitate integration of distributed generation. An ANM system sends control signals to generators and loads with the aim of keeping the system parameters, for example system frequency and voltage delivered to customers, within specified limits. Control of this type can allow increased connections of distributed generation, without the requirement for extensive network reinforcement[4].

3) Planning and Analysis Tools: Data from the SCADA and other systems and devices are recorded and stored in a central database or data historian. From here this data can be accessed for planning purposes and for performing analytics[2]. Existing planning tools use demand load profiles to perform modelling studies and assess where and when network upgrades are required. Profiles may be extracted from SCADA data recorded at primary substations and applied directly to network models to understand power flows and loading on interconnecting lines and cables. In areas of the network where SCADA data is not available (e.g. unmonitored secondary substations), the consumption profiles are estimated using modelling techniques[5].

4) Distribution Management System: The IEEE Power and Energy Society (PES) Task Force on DMS has adopted the following definition : "A DMS is a decision support system that is intended to assist the distribution system operators, engineers, technicians, managers, and other personnel in monitoring, controlling, and optimizing the performance of the electric distribution system without jeopardizing the safety of the field workforce and the general public and without jeopardizing the protection of electric distribution assets."[6]

A DMS therefore, is a computer control system that contains traditional SCADA functions alongside other functions that analyse present and future conditions across the network to support distribution operations. This includes applications to visualise, control and automate the network.

One of the core functions of DMS is to process the monitored SCADA data and present it to control operators. The DMS interprets available information for operators and assists in the analysis of future network scenarios. Furthermore, it can integrate with other databases and applications, including GIS and power system simulation software.

Data flows within and between the multiple functions that are often included within a DMS scheme include[7]:

- SCADA layer – polled data from substation and feeders across the network relating to switching device/auto recloser status, load tap changers, voltage regulator positions, bus phase voltages, active and reactive power flows, feeder currents and relay settings are communicated to the DMS. Supervisory control is provided either autonomously or via operators to substation located protection/switching devices and feeder reclosers.
- Network analysis – the key analytical tool within DMS is power flow modelling, which provides the basis for all studies on existing and future network conditions. Modelling functionality enables operators to understand network switching sequences, substation loadings, feeder loads, voltage profiles and network losses. Power flow models link with dynamic SCADA data, where it is available, to undertake analysis. Network models can also link with short-term forecast substation/feeder demand data to support future studies.
- Geographical information system (GIS) data – spatial information describing the layout and status of the distribution network used for visualising the network for directing maintenance field crews and evaluating the impact of outages. Additionally, GIS data links with network models to enable both detailed model development and for updating models on network configuration changes.
- Customer and Outage Management – the system a DNO has for managing faults on their network, including dispatching of resources and subsequent recording the restoration of the fault, and recording this information for fault reporting. This includes facilitating the flow of information to and from customers and using this information to define network reconfiguration options. Where monitoring exists at this level, information on the operation of protection systems comes through this system. Finally, links with GIS are required to update network models and allow operators to have real-time visibility of existing network problems.

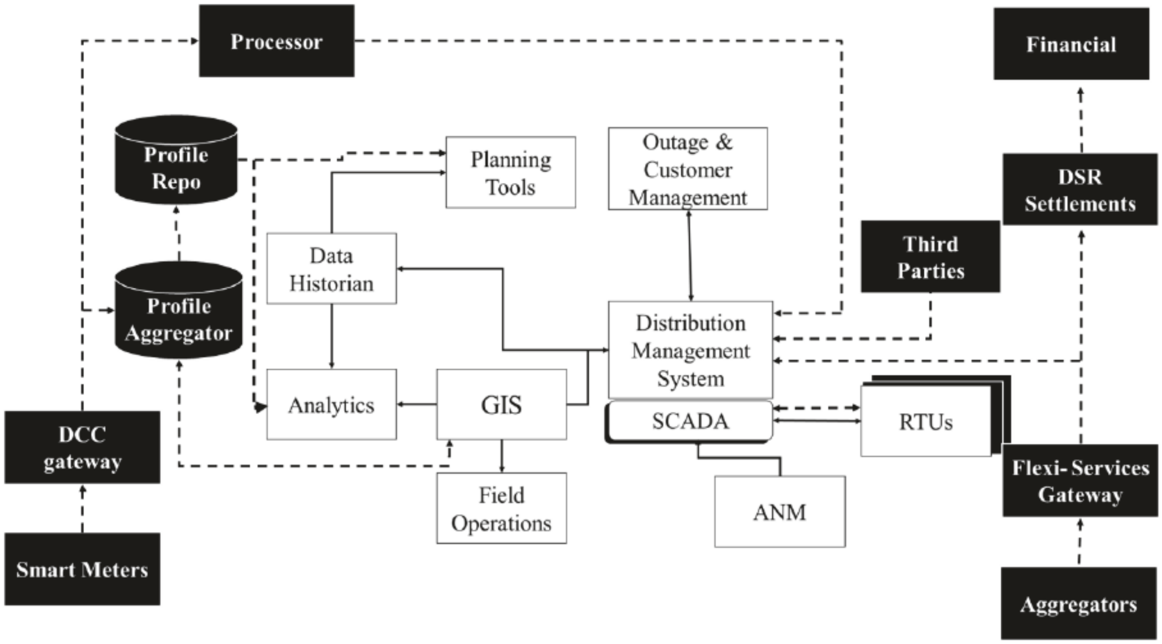

Figure 2. Block Diagram of Future DSO Control Room Data Stream Scenario

B. *Evolution of existing data streams*

While the transition to DSO will include the incorporation of new data streams into the functioning of the control room (shown in Figure 2, and discussed in the next section) there will also be changes to the operation and functionality of some of the existing data streams highlighted in the previous section

1) SCADA: As the functions of the DNO control room increase, there will be a requirement for additional monitoring and automation beyond the primary substation level to manage demand uncertainty and growth brought about by low carbon technology at feeder and secondary substation levels. The existing SCADA network will need to be supplemented to support this additional monitoring[2].

The majority of the increase monitoring by RTUs on LV networks will likely bypass the DMS itself, and be used by the planning and maintenance functions, with filtering of collected data points applied to relay those determined to be relevant to the DMS in real-time. This would ensure that control room engineers only receive data that is required for control room management.

2) DMS: Major changes to DMS systems will likely include additional real-time modelling functionality. This will involve access to online SCADA data streams as well as real-time data from SMs and RTUs. This will allow analysis of real-time power flows and evaluation of control actions and decisions[2].

C. *New data streams*

1) Flexibility Markets: The facilitation of flexibility markets is a significant requirement for future DSOs[8]. This involves allowing existing assets connected to a DSO's network to be coordinated and traded to address network constraints. Flexibility services can be offered at a small scale through peer-to-peer energy trading, or on a larger scale as direct services to the grid. As well as engaging on a peer-to-peer basis, smaller flexibility providers can also interact with the grid directly through flexibility aggregators.

To facilitate, and benefit from these markets the following capabilities must be realised:

- Coordination of flexibility assets (including communication of requirements to the market)
- Signals to dispatch assets (including notification and verification that an asset has been dispatched)
- The financial settlement for transactions (including initial verification steps such as credit checking)
- Network analytics (such as response times, effectiveness of action, and detection of any market faults)

2) Smart Meters: Unlike conventional electricity meters, Smart Meters (SM) measure energy use at much greater resolution and provide an improved understanding of electricity consumption. SM data can, in theory, be communicated in near real-time to industry participants (e.g. electricity suppliers) as required, although privacy and technical concerns do limit this in practice[1]. SMs store data regarding customers' energy usage at half-hourly intervals, as well as network related data such as voltage level at the meter. Alarms can also be communicated from the SMs to the DNO during abnormal conditions.

In the UK data communication from the SMs to the DNOs will be via the Data Communications Company (DCC) intermediary (other countries have similar methods to ensure customer privacy). Before SM data can be accessed by a DNO, readings from multiple premises will be aggregated by the DCC. The interface between the future control room and DCC will be a Network DCC Access Gateway (NDAG). The NDAG will deal with security aspects of transmitting and receiving SM data and will include facilities for mapping meter readings to other reference data. The NDAG will have to be integrated with existing (upgraded) systems within the future control room for processing and storing metering data.

This may form an architecture whereby DCC readings are extracted and processed primarily into a secure aggregator database and then into a profile repository database. An aggregator could link with existing GIS to align aggregated SM readings with asset locations (while maintaining customer privacy)

It is likely that the infrastructure overheads would limit the practicality of storing both SCADA and SM data within a single historian. The profile repository database may therefore only store SM related time series data. Furthermore, the completion of a national roll-out of SMs would mean it is unfeasible to store complete historical consumption and voltage time-series data for individual SMs, even if these were available in non-aggregated form due to the significant volume of data generated. It is probable that DNOs in the future will only collect and temporarily store SM data when needed. This could include during periods of high demand or when areas of the network experience operational challenges. Stored SM data stored in may also support future demand forecasting and Planning strategies and, in particular, will inform LV planning and assessment of new connections.

Another source of data from smart meters is alarms, which in future could form part of the Outage Management Systems (OMS). Each SM could report power outages (via the NDAG) to the DNO if power remains off after a pre-specified period of time. Polling of SMs can also be used to undertake energisation state checks. During periods where high volumes of alarms are communicated from SMs (e.g. during storm conditions), a buffering process would be required to optimise the information sent to the OMS.

3) Third Party Access: In the future there is potential for enhancing the functionality of the DSO by enabling greater coordination with third parties. Some of these new coordination links could include[9]:

- Gas Distribution Network – Taking a whole systems approach to energy supply is increasingly becoming a requirement as the move towards more renewable sources of energy create greater interdependencies between the gas and electricity networks. These interdependencies extend beyond the behaviour of consumers, and can include distribution level gas-fired generators, as well as the use of flexible electricity-driven gas compressors.
- System Operator – Coordination between the System Operator and DNOs is already a critical part of the function of a DNO control room, however as the DNO takes on more system operator roles, greater coordination will be required.
- IDNOs – Independent Distribution Network Operators are responsible for the operation of local distribution networks, as such coordination between IDNOs and DSO is required to meet the additional requirements of a DSO.
- Other DSOs – A key change from the DNO to DSO control room will be the need for wide-area situational awareness. This will help DSOs gain a better understanding of the functioning of the grid outside of their own network, which will help with optimising the function of their own network, as well as helping to anticipate problems before they are directly affected.

It is clear that the data streams for a DSO control room are significantly more complex than those of a DNO control room. Managing and accessing this data will be a much more challenging task than current arrangements, but with these additional complexities there are opportunities to leverage this wider array of data sources to make more informed control and planning decisions.

IV. Intelligent Control System Data Utilisation

One option for a 'smart' solution to managing and benefit from these additional data flows and sources would be an intelligent control system (ICS). This is foreseen as being a tool within a future control room which would provide greater automation, decision support, and information processing while dealing with increased amounts of control room data.

In a layered architecture, back-end control system layers could query the real-time and historian databases through relevant interfaces within the future control system and pass the data to the relevant analytic environment. Information received back from multiple intelligent analytics would also be processed within the ICS. One of the core functions of the ICS would be to evaluate the data sent back from the analytics prior to updating the DMS and/or issuing decisions to actuation and market functions.

TABLE I. Example ICS Functions

Function	Data Requirements	Outputs
LV Load Forecasting	• Secondary SCADA • Real and Reactive Power • Weather Data	Day-ahead load forecasts
MV/LV State Estimation	• Primary SCADA • Secondary SCADA • Smart Meter	Voltage magnitudes and angles at nodes
Headroom/ Losses Estimation	• Smart Meter • GIS	Headroom and loss estimates
Flexibility Forecasting	• Flexibility Market • Weather Data	Less than day-ahead flexibility forecasts
LV Network Characterisation	• Real Power • GIS	Customer profile classes
Fault Restoration	• Fault Data • Waveform	Fault classification Resource estimates

To establish ICS data requirements the main functionalities of the ICS (in terms of the new or enhanced decision-making objectives that it would provide) had to first be defined. Various analytical functions were proposed and are summarised in Table 1. These include a mix of operational functions, such as Fault Restoration, as well as analytics that will assist future network planning and assessment, such as use of Smart Meters (SMs) to infer existing headroom on unmetered substations. These functionalities provide a snapshot of existing AI algorithms and models which could be integrated into the control room with an ICS[5], [10]–[12].

V. Conclusion

To better cope with the increasing complexity of managing distribution networks arising from the move towards 'Net Zero,' including the increased use of low carbon technologies, flexible services, and increased network monitoring, Distribution Network Operators are transitioning to Distribution System Operators. This paper has set out how data streams within a Distribution Network Operator control room will evolve to align with this industry move towards a Distribution System Operator model.

One major identified change is the planned availability of smart meter data, which would provide information on (aggregated) customer consumption at a much higher resolution, as well as providing additional information that can support fault location and hence improve reliability. It is hoped that this data will be utilised to both optimise network performance, and to allow for more accurate scenario planning.

Another expected new addition to the sector is a more widespread and complicated flexibility market. The DSO will have to provide a platform for this new market, which will support network optimisation with flexibility trading reducing the need for more expensive network reinforcement to facilitate the continued installation of low carbon technologies.

Addition of real-time modelling into the Distribution System Management functions will enhance the ability of DSOs to provide actionable information to control engineers (i.e. suggested control actions and corresponding network impact).

Lastly, the DSO control room will need to be more integrated with third party data sources, including the ESO, other DNOs, IDNOs, as well as other energy vectors such as the gas distribution network, and other types of external data streams (e.g. weather, markets, etc.).

Overall, it is clear that the data streams associated with DSO control systems are significantly more complex than those of a DNO control room. Managing these data flows, and access to these data flows will be a much more challenging task than current arrangements. There is therefore strong potential for additional smart tools and technologies to assist with this transition.

One such tool would be an Intelligent Control System, designed to sit between the control room ADMS and a selection of plug-and-play AI/ML functionalities. The ICS would control the flow of data from the ADMS to the AI/ML functionalities, and then return the resulting data to the ADMS. These data sources either already exist within the ADMS or are projected to be available in the future.

VI. Future Work

Through continued collaboration with network operators, subsequent work will explore the use of additional technologies to assist in the transition to DSO: particularly platforms to facilitate early development and familiarisation with data processing techniques. As network operator data requirements evolve in step with challenging demands to decarbonise energy systems, suitable means of being able to test, refine, and evaluate data processes are necessary to aid more responsive (and even agile) translation of conceptual data processing techniques to augment and gradually support operational control centre decision making. Follow on work is likely to demonstrate this with a set of examples.

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