STANDARDISATION OF CURTAILMENT ANALYSIS AND THE IMPLICATIONS FOR DISTRIBUTION NETWORK OPERATORS AND GENERATORS

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ABSTRACT

The introduction of Active Network Management (ANM) has enabled managed connections as a business-as-usual option. These provide generation developers with access to network capacity, while avoiding costly network reinforcement. The managed nature of such connections introduces the prospect of energy curtailment during periods of network constraint. It is necessary to perform curtailment analysis in order to estimate the potential curtailment which a generator may expect to experience. The assumptions and limitations of these curtailment assessments must be understood both by those performing the studies and by those who must review outcomes and understand implications for commercial viability of a generation development. The process of agreeing and, consequently, procuring the necessary input data often introduces a source of commercial challenge and possible delay into the curtailment assessment process. There is, therefore, a requirement for standardisation of data inputs for the curtailment assessment process. This will ensure that the analysis provides a representative estimate of curtailment that is based on appropriate network models and data. This paper explores the requirement for standardisation and recommends a standardised approach for the provision of network data and presentation of outcomes.

INTRODUCTION

The United Kingdom is, like many other countries, striving to meet both renewable energy and carbon emission targets [1,2]. The electricity network has undergone significant changes in recent years, with greater volumes of smaller decentralised generation plants connected to the distribution networks. Distribution networks are becoming more active in their nature in the accommodation of bi-directional power flows, responsive demands, energy storage and other novel technologies. Growing volumes of Distributed Energy Resources (DER) is causing saturation of network capacity on distribution networks, and even sections of transmission network, where under worst-case operating conditions networks capacity is fully utilised.

Managed connections, also known as flexible, non-firm, or alternative connections, have been introduced by a number of UK Distribution Network Operators (DNOs). Managed connections provide a means of connecting generation customers in a cost effective and timely manner in network areas where thermal capacity, voltage restrictions, or other limitations would prohibit those customers from connecting on a firm, unmanaged, basis [3]. By autonomously controlling the instantaneous export of generators in real-time, and in response to specific network constraints, capacity on the network is maximised, while deferring, or even entirely avoiding, the requirement to upgrade or reinforce saturated network assets. However these types of connection present a challenge as new forms of network analysis are required to provide generation developers with sufficient information to secure funding or investment.

This paper discusses the data requirements for this type of analysis to ensure reliability, quality, and integrity of the analysis techniques and results. This paper argues that this can be achieved through the standardisation of the data inputs and output, and makes recommendations regarding the form that these standard inputs and outputs should take. The matter of data sharing between parties is also discussed.

MANAGED CONNECTIONS

There are a number of different types of managed connections currently being offered by the various DNOs throughout the United Kingdom. These include:

- Intertrip connections;
- Timed connections; and
- Actively-managed connections.

An intertrip connection generally results in the complete disconnection of a generator site when a specified network constraint emerges. Typically in these cases, the generator will be disconnected for a predetermined period of time, before being either automatically or manually reconnected. A timed connection will restrict the export of a generator to a fixed level during specific times of the day and at specific times of the year; for example, in a heavily congested section of network consisting of significant photovoltaic (PV) plant, a new non-firm generator may be restricted such that its export is heavily restricted in summer, less-heavily restricted in autumn and spring, and

potentially unrestricted in winter to correlate with periods of high export from other generators [4]. An Active Network Management (ANM) connection makes use of real-time monitoring and autonomous, deterministic control to manage the output of a generator against a specific constraint, or multiple constraints. Upon detecting the breach of a predetermined limit at a constraint location, the ANM system issues real power set-points to relevant generators, effecting a reduction in the instantaneous export of those generators. ANM connections have resulted in the successful integration of generation onto congested networks with significant savings for both the DNO and generation developers [5].

CURTAILMENT ASSESSMENTS

The provision of managed connections introduces a requirement for new analysis techniques. For a generation developer, the prospect of uncompensated reduction in yield represents a reduction in revenue. It will be necessary, therefore, to forecast this potential loss as accurately as possible when assessing the economic feasibility of a generation development project, although it will often be off-set by a significant reduction in connection cost. Forecasting curtailment for ANM connections can be a complex matter that is based upon variation in network operation, which is influenced by environmental, technical, and sociological factors including renewable resource availability, network outages and faults, and demand customer behaviour patterns. Furthermore, owing to this large degree of variability, it is risky to guarantee any particular level of curtailment for a generator, therefore generally curtailment estimates will be presented with some measure of confidence or probability.

It is necessary, therefore, for a robust and reliable analysis process to be in place for the feasibility assessment of managed generators, in order that developers and their financiers can have confidence that the methodology is sound, the data representative, and the results as close a representation of typical network operation as can reasonably be modelled. Previous papers on curtailment assessment have investigated the different analysis methodologies that can be applied [6,7].

There are a number of parties that can conduct curtailment assessment, each with its own associated benefits and limitations.

1. The DNO may conduct the analysis in-house;
2. The generation developer may conduct the analysis; or
3. The DNO or generation developer may employ a third party to conduct the analysis.

In all cases of ANM deployment in the UK, some form of curtailment assessment has been performed by the DNO and the outcomes presented with the managed connection offer. Chief among the benefits of this approach is that most of the required network data profiles will be available for unrestricted use, as they will be the property of the party conducting the analysis. The analysis will be conducted by network planners who are familiar with the specific characteristics of the network and have an understanding of all parties that will participate in the ANM scheme and influence curtailment. This removes any issues of commercial sensitivity which may otherwise exist around the sharing of data and network models with customers and third parties.

While these are favourable advantages, limitations exist when considering DNO-conducted analysis. The needs both to manage costs, which are ultimately borne by the customer, and also to treat generator customers consistently, will limit the flexibility of a DNO to meet the specific needs of any particular generator customer. Therefore, the DNO retains complete control over the analysis methodology and the level of detail to which results are presented. It is unlikely that the customer will have the opportunity to specify varying study scenarios, for example to consider the growth of microgeneration, changes in demand profile, or variation in site yield.

For cases where the generation developer conducts curtailment assessment in-house, the primary advantage is that, contrary to option 1, they retain complete control of the data used, the analysis methodology, all assumptions made, and the presentation of outcomes. This allows the modelling of parameters, such as the generator export, using site-specific data. The main limitation to this approach is that it will also rely on the provision of historical data profiles, ANM scheme information, or a network model from the DNO to allow the representative modelling of network power flows or voltages. The commercial sensitivity associated with some of this necessary information can limit the public issue to a generation developer, and must be addressed by the 'masking' of sensitive data. The network data and scheme information that is necessary for study is summarised in high-level later in the paper.

The third option proposed above, where a third party is contracted by the developer or DNO to perform analysis, provides greatest flexibility for secure sharing of data and network models. Establishment of appropriate non-disclosure agreements between all parties will allow both the DNO and developer to share information with the third party consultant. The consultant is then in a position to be able to use the data and model to conduct the analysis without any cause to release it to the developer, thus ensuring that data confidentiality is maintained.
It will often be the case that a developer must perform due

diligence. A requirement will therefore still exist for the DNO to issue network data and scheme information. We believe, therefore, that it is of critical importance that the generation customer be able to access sufficient information to perform the detailed due diligence that meets their own, or their financiers, requirements.

STANDARDISATION

The need for DNOs to treat all customers in a consistent manner will necessitate a standard approach to both the delivery of curtailment assessments and the provision of data to allow 3rd parties to perform studies. Similarly, working towards standardisation in the presentation of curtailment assessments outcomes will aid understanding and interpretation through promotion of clear, concise dissemination which assists commercial decision-making. The following sub-sections provide a high-level summary of preferred data and information required for a developer to: firstly, perform curtailment assessment and secondly, to evaluate the outcomes of a curtailment assessment when performed by the DNO.

Standardisation of Input Data

Curtailment assessment requires the modelling of power flows or voltages at constraint locations [7], to achieve this, at least one of the following must be available:

- A load-flow model of the network area in question;
- Circuit impedance and topological information to allow a load-flow model of the network area to be developed; or
- Details of the sensitivity relationships between each generator or load and each constraint location. With the provision of historical network power flow or voltage profiles, this information allows high-level approximation of ANM generation impact.

The time-varying nature of ANM generator curtailment requires the study of time-series data profiles to model the variation of network parameters across a study period. This is typically achieved by application of half-hourly historical measurements of network parameters, extracted from a DNO logging historian. The typical time-series data required to derive curtailment estimates can be described as:

- Concurrent time-series profile of all loads in the area, coupled with profiles of generator export. In cases of commercial sensitivity, profiles of generator export may be derived from generic anonymous profiles; or
- Historical time-series profiles of power flows or voltage level at each constraint location. Note this requires information regarding the sensitivity relationships between each generator and constraint location.

Other information that can support configuration of curtailment assessment includes:

- Specification of the Principles of Access, i.e. the order in which ANM generators are controlled;
- The network assets that will be monitored as a constraint location, and the ANM curtailment trigger threshold;
- The impact of outages, including loss of communications links in the ANM control system;
- The number and capacity of generation sites with a higher or equal priority position for accessing network capacity, broken down by type of generation, i.e. wind/PV/CHP.

It is advisable that historical data profiles are fully verified prior to analysis, as logged network data is often subject to erroneous values due to measurement error.

Standardisation of Outputs

Curtailment assessments are performed to satiate the need of financiers and investors to gain visibility of an anticipated level of curtailment. Given this requirement, there is a minimum level of detail which is generally acceptable for the reporting of the analysis results. Again, through experience, a set of basic requirements can be defined which in most cases, if met, will ensure that the developer and financiers are suitably well informed and enabled to make prudent investment decisions.

Naturally, the estimated level of curtailment must be stated, ideally in both MWh energy and percentage capacity factor terms. This is of greatest use when compared to the *uncurtailed* equivalent, which reflects the estimated yield in the study if ANM curtailment actions not been simulated. Table 1 illustrates an example of the study results for an anonymous 9 MW wind farm with an uncurtailed capacity factor of 33%, connecting behind a thermal power-flow constraint.

Table 1 - Example numerical results for curtailment

Estimated uncurtailed MWh generated	26,020
Estimated curtailed MWh generated	19,830
Estimated MWh of curtailment	6,190
Estimated uncurtailed Capacity Factor	33.0%
Estimated curtailed Capacity Factor	25.2%
Reduction in output due to curtailment	23.8%

The nature of the curtailment assessment process is such that accuracy cannot be guaranteed. Historical data is assumed to be representative of any given time period of similar span in order to estimate future energy yield; consequently, the results are subject to variation due to a number of influencing factors. When reporting curtailment assessments, sources of uncertainty must be clearly stated and any assumption of certainty must be explicitly disclaimed. Similarly, details should be provided of any modelling assumptions made during the study, for example during the simplifications of network models or derivation of data profiles. Providing a clear picture of the modelling methodology will allow the generation developer or investor to determine how robust the analysis process was and if further analysis is required.

The clear, graphical representation of results provides quick illustration of variation in curtailment and comparison with an uncurtailed equivalent. A number of formats may be used to present this information, each with their own merits. A time-series graph of the study period illustrates the variation between the uncurtailed and curtailed exports of a generator. A duration curve is a useful graphic to illustrate the percentage of time that the generator will be exporting at a particular output. Figure 1 and Figure 2 illustrate examples of such graphics for a wind farm.

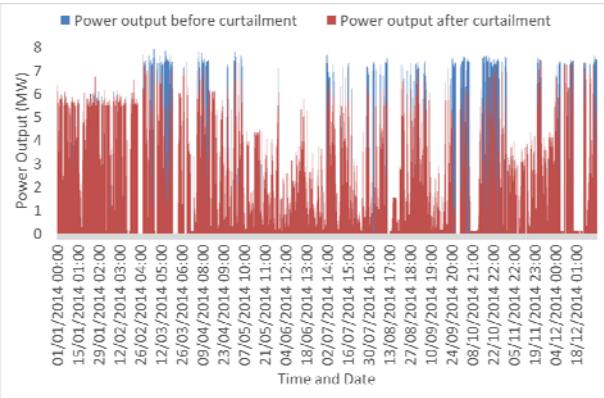

Figure 1 - Example time series graph illustrating curtailment

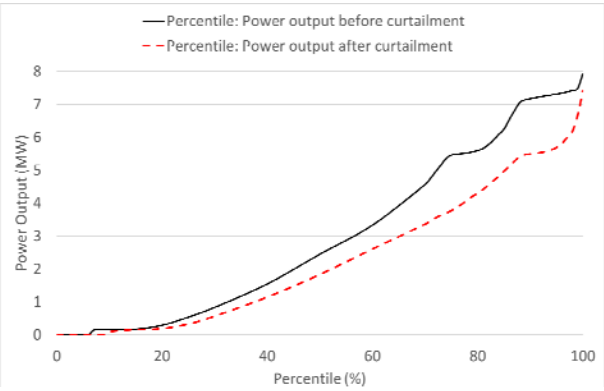

Figure 2 - Example duration curve

CONCLUSION

The provision of representative estimates of curtailment is essential for a generation developer to make a decision to proceed with a managed connection. As the provision of managed network connections is becoming commonplace, DNOs and generation developers are becoming increasingly aware of the information requirements for performing or interpreting results from these studies, and are contributing to the definition of standard methodologies for their delivery.

It will ultimately be stakeholders such as generator developers and financiers who will drive requirements for both information provided through curtailment assessment and the methodology applied to derive the estimates. The most significant challenge for generation developers or other parties performing curtailment assessment studies is the commercial sensitivities associated with DNO provision of suitable data or network models.

The anticipated changes to the role of the DNO, moving towards the Distribution System Operator (DSO) model, is expected to result in changes to managed connections on distribution networks. The integration of new types of device, such as grid-scale energy storage, will require new methodologies for curtailment assessment, as well as a need to present resultant available network capacity in different forms.

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