ANALYSIS OF THE POTENTIAL UNCERTAINTY IN ACCOMMODATION OF NETSO DISPATCHED SERVICES IN DSO CONTROLLED NETWORKS

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ABSTRACT

*This paper describes the work undertaken by Western Power Distribution (WPD) to assess potential service conflicts where a National Electricity Transmission System Operator (*NETSO) *dispatched service is located within a Distribution System Operator (DSO) controlled network. A bespoke program was written to integrate with the power system software PSSE to determine generator sensitivities to given constraints for daily and seasonal variation. It also analyses sensitivity variation for intact and all credible circuit fault conditions. The results from this analysis are used to assess multiple Active Network Management (ANM) constraints to determine how the availability of NETSO dispatchable services is dependent on the ANM logic, generator location and network topology. A number of information transfer architectures between the NETSO and DSO are proposed and the risks of service conflicts are considered.*

INTRODUCTION

The NETSO has contracted with distribution network connected generators for many years. These generators are dispatched for System Operator services such as frequency response and Short Term Operating Reserve (STOR). Traditionally, the distribution network has been operated as a passive network, where any generation connected was able to operate up to their agreed connection capacity without any Distributed Energy Resource Management Systems (DERMS) dynamically altering their output. In 2014, WPD started offering some generator customers the option of time constrained, soft-intertrip and export limited connections to help customers avoid long connection times and significant reinforcement costs. Generators operating for NETSO services have generally not accepted this type of offer, due to the requirement that they have a high flexibility and availability as to when they operate.

These simple types of alternative connection do not pose the same type of technical challenge as DERMS that dynamically alter generator outputs based on current network conditions. This report focuses on ANM as it is the most mature DERMS and is currently in the process of being adopted as business as usual by 2021 across all WPD areas where necessary. The current ANM systems have the ability to manage multiple complex constraints, by pre-event curtailing generators to reduce potential voltage or thermal exceedances within operational limits.

This work was undertaken to further WPD's understanding on how ANM systems will interact with the NETSO dispatchable generation located on the distribution network; specifically looking at the potential for service conflicts. The output from the work also helped informed the Energy Networks Associations (ENA) Open Networks project, which is a major energy initiative in the United Kingdom that is underpinning the delivery of smart grids. Work stream (WS) 1, the first of 5 work streams in Open Networks, focuses on Transmission-Distribution (T-D) processes, with Product 13 of WS 1 investigates Operational Data and Control Architecture.

ANM SYSTEM LOGIC

To determine possible service conflicts it is important to understand how the existing ANM systems operate. WPD has defined three possible ANM curtailment strategies [1]:

- **Full pre-event curtailment** – Generators are curtailed sufficiently to ensure that the network is steady-state compliant prior to the next event, and will be steady-state compliant immediately following any next event;
- **Partial pre-event curtailment** – Generators are curtailed sufficiently to ensure that the network is steady-state compliant prior to the next event, and will be short-term compliant for a specified recovery timeframe immediately following any next event. Following an event it is necessary to further curtail generators to restore steady-state compliance; and
- **Post-event curtailment** – Following an event the generators are curtailed immediately to return the network to steady state compliance.

WPD currently has two active ANM systems which are implemented using different logic. Both systems are principally full pre-event curtailment, but where short-term ratings are available then the system has the ability to partial pre-event curtail. They are complemented by 'hard-wired' intertripping schemes, which implement a form of post-event curtailment. Progressing to a partial pre-event curtailment strategy for WPD assets may reduce energy curtailment but will require the determination of short-term ratings for a wide variety of circuit assets, which are not yet available. ANM systems could use any of the following approaches when determining generation curtailment order:

- **Last-In-First-Out (LIFO)** – The most recent generator to join the ANM stack is curtailed first.
- **Technical Best** - The ANM system calculates which generators to curtail to minimise the MW curtailment requirement.
- **Economic Best** – Where the cost of curtailment is factored in, to minimise the total cost to customers.

At present, both active ANM systems are operating a LIFO stack, as it is the easiest to contractually implement.

BESPOKE PROGRAM

The power system software chosen for this work was Siemen's PSSE, as it is used extensively within WPD and is highly customisable through an Application Program Interface (API) using the programming language Python.

Time Series Contingency Analysis

PSSE does not currently offer functionality to run time series contingency analysis so a bespoke analysis program has been developed as part of WPD's Shaping Subtransmission series of reports [2]. This custom analysis program can assess half hourly and seasonal variation in generator sensitivity for intact, arranged and fault conditions. PSSE's Remedial Action Scheme (RAS) add-on is used to model advanced intertrips, load-transfers and most operational actions. The current inputs enable the following representative days to be studies for all 48 half hours:

- **Winter Peak Demand, Summer Peak Demand and Autumn Peak Demand**, with minimum coincident generation
- **Summer Peak Generation**, with minimum coincident demand

Generator Sensitivity Analysis

The complexity of the network being managed will determine what ANM curtailment strategies are appropriate. For a simple two feeder network where the circuits are impedance matched and share load equally, it may be possible to determine the worst post-fault flow based on intact flows.

In reality, the majority of distribution networks are not this simple and are often run highly interconnected. On more complex networks, intact flows give little indication of post fault flows. For this reason, complex networks require an ANM system with load-flow and a form of contingency analysis in the loop.

On a complex network, the worst fault can change depending on prevailing demand and generation conditions and current running arrangements. For a single constraint there can be multiple faults that will cause an overload; the ANM system algorithm needs to be able to manage all of these to ensure no thermal or voltage exceedances will occur following any credible fault. There are situations where resolving one fault overload on a given constraint exacerbates other faults. This gets more complex when considering a network with multiple constraints as curtailing one generator for a given constraint can exacerbate other constraints. The ANM system must determine the generation curtailment that resolves all post-fault overloads for all credible fault conditions. Understanding how generators are curtailed in anticipation of a given fault is crucial to being able to understand potential service conflicts with NETSO dispatched generation. Figure 1 shows a flow diagram with the program logic used to determine generator sensitivity to network constraints.

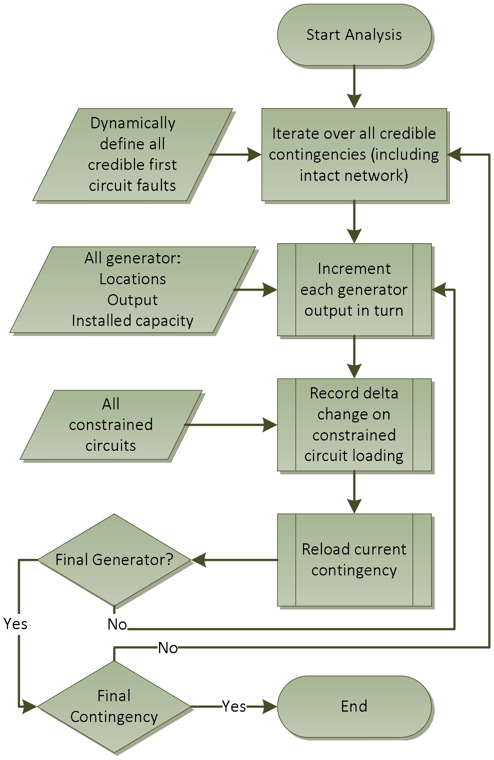

Figure 1: Sensitivity analysis logic

Within these studies a positive sensitivity factor is where curtailing the generator (MW output reduced) reduces the loading on the circuit. Conversely, a negative sensitivity factor means curtailing the generator increases the flow on the circuit.

CASE STUDY NETWORK

The Alverdiscott and Indian Queens Grid Supply Point (GSP) group is in WPD's South West licence area and was chosen for the case study. These GSPs are supplied via the National Grid 400 kV network and are run normally in parallel at 132 kV. Alverdiscott has two Super Grid Transformers (SGT) and Indian Queens has four SGTs (not shown in diagram). This GSP group was chosen to demonstrate the difficulty of assessing and describing service conflict on complex constrained network. The Indian Queens and Alverdiscott has approximately 880 MW of embedded generation connected to the network, with 176 MW connected to 132 kV network. Figure 2 shows a simplified single line diagram of part of the Alverdiscott/Indian Queens 132 kV network. All generators connected below 33 kV are assumed lumped on the 33 kV bars of the Bulk Supply Point (BSP).

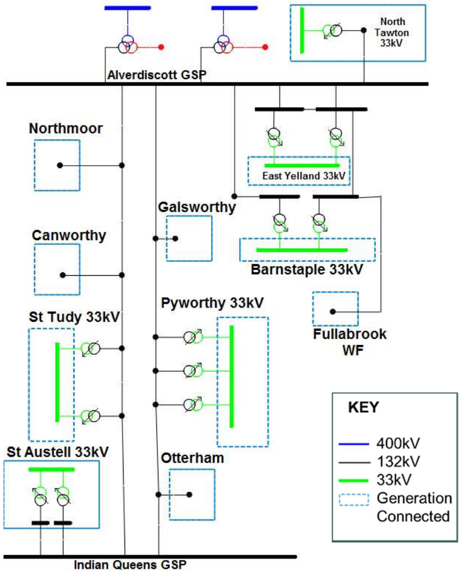

Figure 2: Case Study Network

Case Study Sensitivities to Constraints

GSP Constraint

The first constraint assessed is a thermal constraint on the 400/132 kV SGT2 at Alverdiscott GSP.

Daily Intact Sensitivity Variations

The results showed sensitivity variation of below 2% for all generators to the SGT constraint for each representative day analysed.

Seasonal Intact Sensitivity Variation

The variance in seasonal generator sensitivities can be seen in Figure 3. The change in sign is due to the SGT having reverse power-flow during the high generation representative day, meaning that curtailing a generator reduces the loading on the SGT, hence a positive sensitivity. Reducing generator outputs for the demand representative days increases loading on the SGT, hence a negative sensitivity factor.

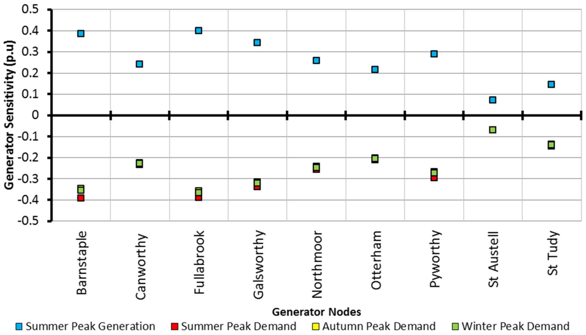

Figure 3: Intact Seasonal Variation of Alverdiscott SGT2 for intact network conditions – half hour 28

Intact vs Fault Sensitivities

Figure 4 shows the variation of generator sensitivities to Alverdiscott SGT2 for intact and all credible faults.

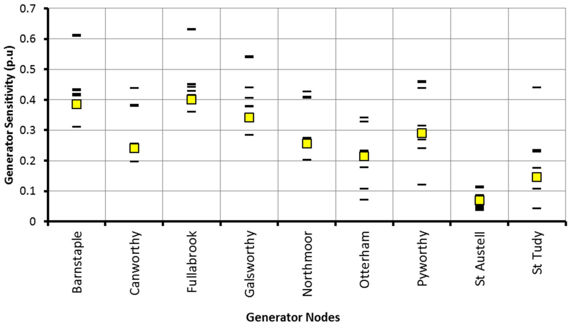

Figure 4: Intact vs Fault Sensitivities of Alverdiscott SGT2 for a peak generation representative day - half hour 28

The yellow box shows the intact sensitivity and each black line shows the sensitivity factor for each credible fault. These results show that there are significant variations in how sensitive a generator is to this SGT constraint, depending on the fault that occurs.

132 kV Circuit Constraint

The second constraint assessed is a thermal constraint on the 132 kV circuit between Northmoor and Alverdiscott GSP, as shown in Figure 2.

Daily Intact Sensitivity Variation

The daily variation of generator sensitivity to this 132 kV circuit has a larger variance than the SGT constraint, due to St Tudy BSP changing from a net importer to a net exporter during the summer maximum generation representative day. The sensitivity variation is as high as 6% for the maximum generation day.

Seasonal Sensitivity variation

The seasonal generator sensitivity variation to the 132 kV circuit shows a small variation for all the demand representative days, with the generation study showing a change in sign as the direction of power-flow changes.

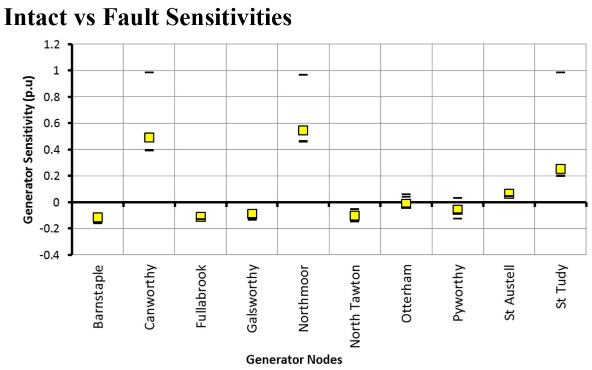

Figure 5: Intact vs Fault Sensitivities of Northmoor to Alverdiscott 132kV circuit for a peak generation representative day - half hour 28

Unlike the SGT constraint, the 132 kV Northmoor to Alverdiscott GSP constraint has intact positive and negative generator sensitivities. This means curtailing some generators will help reduce the constraint loadings and curtailing others will actually exacerbate the overload. The sensitivities are generally quite low, with most generators having below 0.2 p.u. sensitivity to the constrained circuit. This also shows that there are some faults which can cause a large variation in generator sensitivity. When NETSO dispatch services within an ANM zone, understanding this level of detail will be crucial in avoiding conflicts.

Table 1: Generator change in sensitivity factor for the fault between Indian Queens and St Tudy

Generator Location	Intact network Sensitivity to constraint (p.u.)	Post St Tudy to IQ fault sensitivity to constraint (p.u.)
Barnstaple BSP	-0.1156	0.0002
East Yelland BSP	-0.1166	0.0001
Fullabrook WF	-0.1102	0.0006
Pyworthy BSP	-0.0578	0.0003
Northmoor	0.5443	0.9681
Canworthy	0.4896	0.9853
Otterham	-0.0140	0.0003
St Tudy BSP	0.2539	0.9851

Service Conflict Case Study

The 132 kV constrained circuit described above has a number of faults which will impact how the ANM system will manage generator curtailment to ensure no overload is seen for any credible next fault. The worst overload is normally seen for the fault between Indian Queens GSP and St Tudy BSP. This leaves St Tudy, Northmoor and Canworthy all exporting via the ANM constrained circuit. Table 1 shows how the generator sensitivities significantly change prior to this fault and post fault. Only St Tudy, Northmoor and Canworthy have any notable impact for this constraint/fault combination.

The ANM system will be curtailing in anticipation of this fault and all other faults that will cause exceedances. The exact approach to ensuring compliance will depend on the specific ANM system.

DATA ARCHITECTURES

As part of the ENA working group, WPD used the analysis described above on generator sensitivities and detailed knowledge of ANM implementation to help assess where service conflicts may arise. A number of Information System architectures and communication approaches were evaluated to determine which ensure service conflicts will not occur, or will be within jointly agreed limits.

When the NETSO dispatch services it is important to consider how they are prioritising which services to dispatch. It may be prioritising the technical best, economic best or a combination of both. This will have an impact on the data architecture that will be required.

Another consideration is how important it is to maximise the availability of NETSO services within a GSP. At present, the NETSO knowing a conflict may occur may be sufficient, as they can look elsewhere for services whilst DERMS systems are not utilised extensively on most GSPs. This approach will likely only work in the short-term, until DERMS become commonplace. The overview of the different architectures is primarily looking longer term, where NETSO will likely want to maximise the level of services they can dispatch within a GSP without unwanted service conflicts.

NETSO Managed

A fully NETSO managed approach would mean determination of possible service conflicts and dispatch priority would be calculated by NETSO. This would mean they would need to replicate the behaviour of a complex full pre-event curtailment ANM system to a sufficient accuracy, so as to avoid service conflicts. This would require real-time transfer of large quantities of data. It is generally accepted that trying to replicate a complex control system twice would not be a good use of resource and would inevitably lead to unexpected behaviour.

NETSO Dispatch, DSO Constraint Management

This section describes some of the data architectures assessed, where the DSO provide different headroom/footroom signals to the NETSO and with this information the NETSO can then determine which services to dispatch.

Headroom and Footroom per GSP

The initial proposal was for the DSO to provide a MW headroom/footroom signal per GSP. This was shown to not be sufficient for either a single GSP or a more complex interconnected GSP group. This level of data transfer does not give sufficient information on which generators will exacerbate (or help) the constraint(s) and which will have no notable impact. It also does not account for the internal ANM logic. So long as NETSO are able to look elsewhere for services, this may be sufficient if the headroom provided was the minimum headroom of all NETSO contracted generation.

Headroom and Footroom per Constraint

The next data transfer option assessed was a MW headroom/footroom per constraint. Fundamentally this suffers from a number of the same shortfalls as a per GSP headroom/footroom figure. It does not provide NETSO with enough information to determine which generators can be dispatched and how the ANM system will manage the generator stack, with generators having positive and negative sensitivities to different faults. This gets more complex once the ANM is managing multiple constraints.

Headroom and Footroom per Generator

This is where the DSO ANM provides NETSO with a headroom/footroom for each generator. The benefit of this is it will fully account for the pre-event curtailment logic, generator curtailment stack, interaction of multiple constraints and multiple faults. This data transfer would be a +/-MW value per generator. The fundamental limitation with this approach is that each generator is interdependent on all other generators. This means that the DSO could provide a MW for each generator, but the NETSO would not be able to dispatch multiple generators from this information, as depending on which generator was dispatched first, it would alter the available headroom/footroom of all the other generators. Further work is needed to determine if an iterative data transfer between the NETSO and DSO could make this viable. This would need the ANM system to reassess headroom/footroom for all generators of interest every time one is dispatched. This may work to avoid service conflicts, but it is unlikely that the NETSO would be able to determine the technical or economic best due to the interdependencies of the generators.

DSO Led

The final architecture is where the DSO ANM system determines of headroom/footroom per GSP and also priorities the generators based on technical or economic best. The main benefit of this approach is all the calculations are undertaken within the ANM system, so when implemented correctly there would be reduced risk of service conflicts. It also means that the optimisation of the technical/economic best services will be within the system, so all permutations can be assessed, unlike with the headroom/footroom per generator. This DSO led approach has a number of benefits, but it does have the following challenges:

1. It would require potentially confidential information from the NETSO regarding real-time pricing/availability of generators
2. Where services can be accurately measured at a GSP boundary (e.g. MW support) this approach would work. Where the generator dispatch is providing a service that the DSO cannot easily assess, determining the technical/economic best would require additional information from NETSO.

Conclusions

This project has helped further the understanding of the intricacies of ANM systems running full pre-event curtailment. Specifically, how intact loading has little relevance to post fault flows on complex interconnected networks. The case study also showed how generators can have positive and negative intact sensitivities to a given constraint and faults can significantly change the sensitivity of the generator to the constraint. This was show to be particularly important when assessing service conflicts on the current generation of ANM systems running full pre-event curtailment.

The different data architectures between the DSO and NETSO identified that a simple headroom/footroom per GSP or constraint may be sufficient whilst the NETSO have the ability to look elsewhere for services, but as DERMS become more widespread, the data architecture will need improving and a decision as what approach is ultimately used will need determining. At present, there is insufficient information available to say which approach will ultimately be adopted, as further work is needed.

Further Works

Trials are planned for 2019 with NETSO, WPD and UKPN for approaches where the potential service conflicts are assessed and managed by NETSO or by the DSO. Other desktop studies that may help further understanding include:

1. Assessment of multiple constraints within an ANM system
2. Assessment of voltage constraint management

Acknowledgements

WPD have worked with UKPN and National Grid as part of the Open Networks project to further the industries understanding of service conflicts.

REFERENCES

[1] WPD, Shaping Subtransmission, 2018, www.westernpower.co.uk/netstrat

[2] WPD, Distribution System Operability Framework (DSOF), www.westernpower.co.uk/dsof