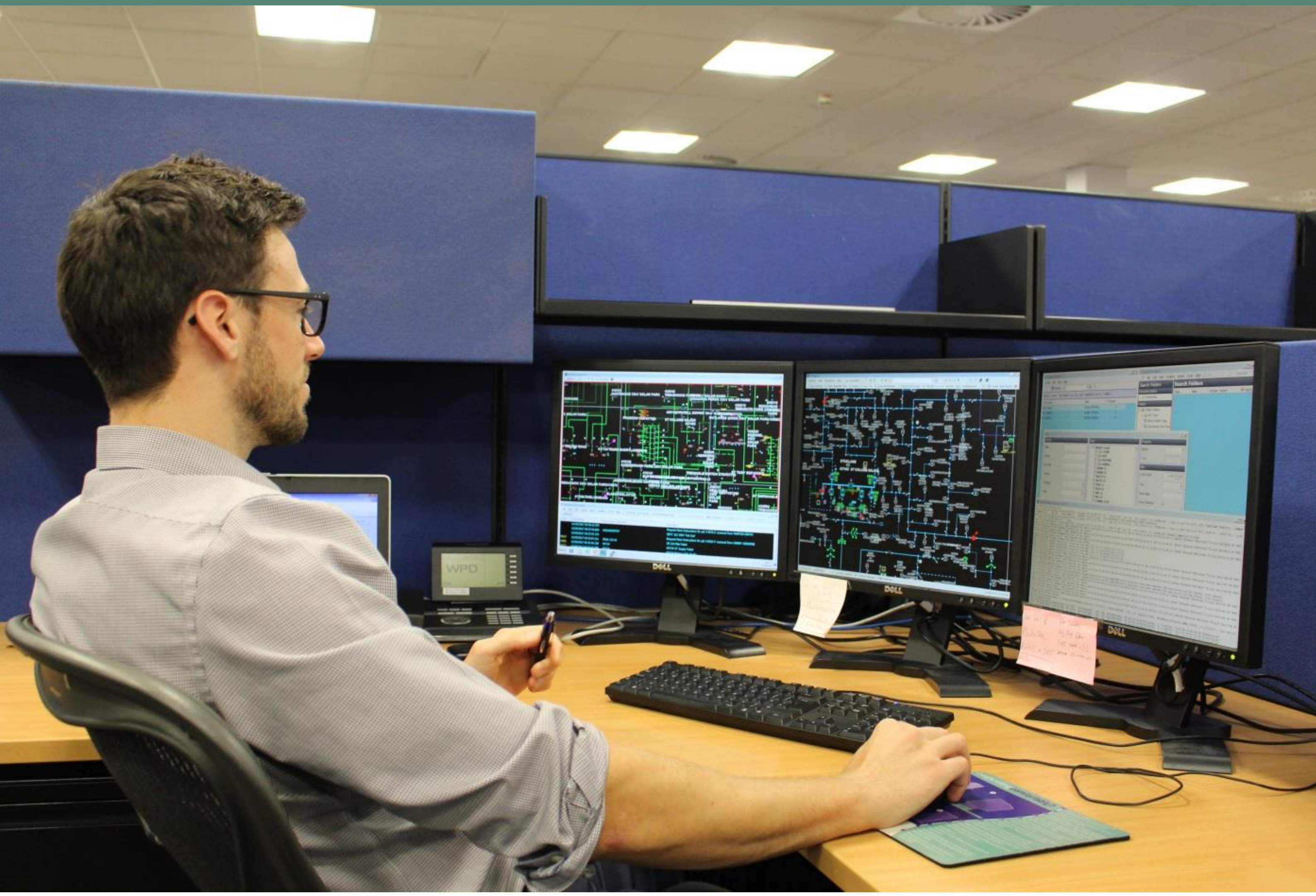
Network Modelling and Analysis



Summary

This article focuses on the requirement for more advanced modelling and analysis in network design, operational planning, and real-time operation.

DSOF June 2018

Note: a glossary and diagram key can be found in the DSOF introduction document on our website

Background

Network analysis is a fundamental part of running a modern distribution network. Network analysis informs the following activities:

- **Network design** – the assessment of new connections and long-term projections of demand and generation growth. At this stage WPD determines what assets and services will be necessary to provide sufficient network capacity to make the network compliant and operable.
- **Operational planning** – the assessment of arranged network configurations against short-term forecasts of demand and generation. WPD has to take regular arranged outages of circuits and equipment for maintenance, reinforcement and asset replacement. At this stage WPD determines how the available assets and services should be used to operate the network.
- **Real-time operation** – the operation of the network in real-time as demand levels and generation output change. At this stage WPD takes arranged outages and reacts to unplanned events such as faults.

Network analysis is used at each stage to determine how the network will respond to the connected demand and generation for different network configurations. This is essential to design and operate an efficient and secure network. Accurate analysis requires up-to-date models of the existing and future network together with software that has sufficient functionality to carry out the studies required.

The changing network and in particular the growth in distributed generation connecting to WPD's network, is having a significant impact on the types of modelling and analysis required. The transition towards a Distribution System Operator (DSO) is also giving rise to number of technical challenges.

At the same time, a greater onus is being placed on improving utilisation of existing assets through innovative solutions such as Active Network Management (ANM) and Demand Side Response (DSR), as an alternative to conventional reinforcement. This means that the modelling needed to assess network compliance and network operation is becoming more complex. In addition, there is an increased volume of data necessary to undertake this level of modelling. These challenges must be proactively dealt with to ensure that they do not impede the rollout of smart grid network solutions and alternative connections.

Existing Modelling and Analysis

WPD currently uses a range of separate software tools to build and analyse network models at the network design and operational planning stages. Each tool has a specific application such as determining protection settings or calculating power flows. This approach does not lend itself to tasks which overlap applications, such as assessing how protection settings limit allowable power flows. As network complexity increases, it is expected that more interaction between applications will be necessary. A balance must be found between the specialist features of application-specific tools and the closer integration offered by a single general-purpose package. The possible adoption of Common Information Model (CIM) could prove instrumental in harmonising modelling approaches within WPD and across the industry.

There is limited real-time analysis undertaken at present, but there are a number of innovation projects looking at incorporating this type of analysis into the Distribution Network Management System (DNMS).

Until recently network analysis has focused on passive 'edge case' studies of peak demand and peak generation. At present, most modelling and analysis takes place at the network design stage, where conservative assumptions are used, which limit the need for further analysis at the operational planning and real-time stages. The network must conform to a number of standards and criteria, some of which are licence requirements, including:

- ENA Engineering Recommendation (ER) P2/6 [1] – This gives requirements for security of supply towards demand customers, which forms a condition of WPD's licence. There is currently no standard for providing security of supply to distributed generation;
- ENA ER G74 [2] – Calculation of short-circuit currents in three-phase Alternating Current (AC) power systems; and
- ENA ER G5/4-1 [3] – Planning levels for harmonic voltage distortions and the connection of non-linear equipment to transmission and distribution networks.

Types of Analysis

The most common form of analysis currently undertaken is load-flow studies. These are used to calculate the steady-state voltages and circuit loadings across a network for given demand, generation and running arrangements. The results of load-flow studies are assessed to confirm that circuits are not overloaded and voltages are within acceptable limits. To ensure that the network can cope with credible running arrangements, it is assessed for the following conditions, which are shown in Figure 1:

- **Intact** – the normal running network;
- **First Circuit Outage (FCO)** – a fault or arranged outage; and
- **Second Circuit Outage (SCO)** – an arranged outage followed by a fault.

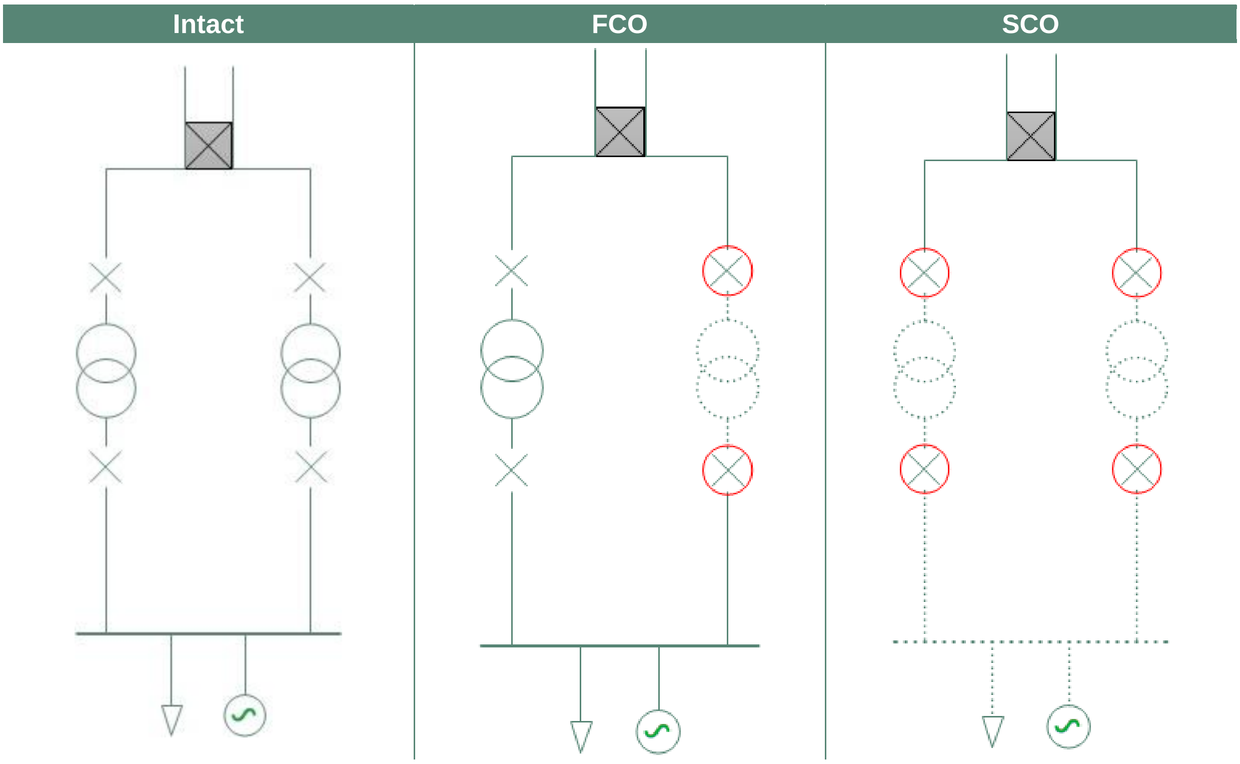


Figure 1: Simplified power system diagram showing intact, FCO and SCO conditions at a substation

Since a network can have dozens or even hundreds of credible faults and arranged outages, analysing all of the combinations that form second circuit outages can be computationally intensive. ER P2/6 sets minimum requirements for how much demand can be supplied in a group (area of network) following each type of outage. The network may be designed to a higher standard than that required by P2/6, with considerations given to Customer Minutes Lost (CML) and Customer Interruptions (CI) incentives.

Other types of analysis are also undertaken regularly including protection studies, power quality studies, and earthing studies.

Network Impact

Having appropriate modelling and analysis tools with high quality, integrated data will help us to ensure that:

- Networks are operated within thermal, voltage, fault level and other constraints;
- Schemes such as ANM and flexibility services procured by different parties are coordinated;
- The network impact of new technologies such as electric vehicles and battery storage is understood;
- Generator curtailment is minimised;
- Asset utilisation is improved;
- Capacity is made available for new connections;
- Reinforcement projects are triggered in a timely and efficient manner; and
- The impact of control actions can be predicted.

The rollout of innovative technological and commercial solutions to increase network flexibility, will mean significant changes to when and how we model and analyse our network and its interface with National Grid, customers and other third parties.

Detailed Assessment

This section details some of the modelling and analysis challenges that are likely to affect the operability of the network directly, or as a consequence of insufficient support systems.

Network Design Analysis

Passive distribution networks are designed against the most onerous edge cases, with a presumption that the network will be compliant in-between the edge cases. Becoming a DSO, where the distribution network is no longer passive, will require analysis which extends beyond the traditional edge case studies. Network Design studies can be divided into two categories:

- **Network Capability Assessment** – determining what assets and services will be necessary to make the network compliant and operable. As demand and generation behaviours change and become more active, fixed edge cases will no longer necessarily the most onerous conditions.
- **Energy Curtailment Estimation** – estimating generation and demand curtailment through mechanisms such as ANM and DSR to inform investment decisions. A significant portion of energy curtailment is not expected to occur at times of peak generation or demand, but during the periods between these peaks.

Time-Step Analysis

Time-step analysis is a technique where a series of load flows are run on the same network to represent successive time-steps in steady-state. This allows the interaction between dissimilar demand and generation profiles to be analysed, which is necessary for both network capability assessment and energy curtailment assessment. Time-step analysis requires defined profile behaviour of all demand and generation for each time period studied.

Time-step analysis is distinct from dynamic analysis. Dynamic analysis considers network behaviour *during* changes in network topology, generation output and demand levels; time-step analysis considers network behaviour *between* changes in network topology, generation output and demand levels.

Existing Time-Step Analysis

One of the main implementations of time-step analysis currently used by WPD is the Distribution Constraint Analysis Tool (DCAT). DCAT is a bespoke energy curtailment estimation tool, used to provide curtailment estimates to customers who have applied for ANM generator connections. DCAT runs a load-flow for every half-hour of a year, and calculates the power curtailment of each generator for each half-hour. It then aggregates the power curtailment from all half-hours to estimate annual energy curtailment.

Wind and Photovoltaic (PV) site outputs are based on sampled outputs for the given half hour and all other generation is assumed at 100% output. Demand is derived from the half hourly measured values at each primary substation.

Figure 2 shows the output from the DCAT, giving the curtailment for a 0.5MW windfarm over a year. It shows that the site will see a total of 31MWhs of curtailment across a typical year. Whilst this is not exact, it gives the customer an indicative curtailment figure in MWhs, which they can use to help determine if it is a viable investment.

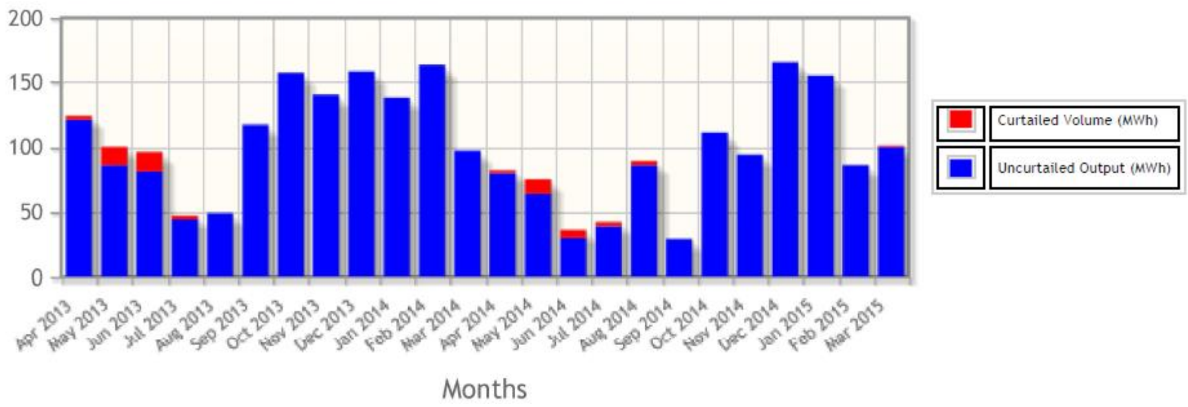


Figure 2: Example DCAT output showing energy curtailment estimates for a generation site

Time-step analysis is also used by WPD's Network Strategy team to carry out the studies underlying the *Shaping Subtransmission to 2030* series of reports. In these studies, time-step analysis is combined with comprehensive contingency analysis to provide a detailed insight into network behaviour. The studies focus primarily on network capability assessment, but are also starting to consider energy curtailment estimation.

Further Time-Step Analysis

Extending the use of time-step analysis at the network design stage will enable:

- Assessment of the interaction between flexibility services;
- Daily network variance to be assessed in more detail, which will enable the network to be designed based on a full representative study;
- ANM to be fully rolled out where required by 2021;
- Cyclic ratings of equipment to be assessed in greater detail, which will allow for better utilisation of existing assets;

- Assessment of where asset replacement or reinforcement of equipment can be justified based on losses or excess asset ageing; and
- Assessment of how commercial drivers for generators, storage and demand could impact the network.

Case Study – Time-Step Analysis

This case study demonstrates how time-step analysis can provide new insights that assist network design. Three 132kV circuits from a Grid Supply Point (GSP) to a Bulk Supply Point (BSP) are shown in Figure 3. The group demand exceeds 300MW, putting the BSP into ER P2/6's class E. This requires that:

- After a first circuit outage, group demand is met; and
- After a second circuit outage, all customers are supplied at ⅔ group demand (it is assumed that maintenance can be undertaken when demand is below ⅔ of peak).

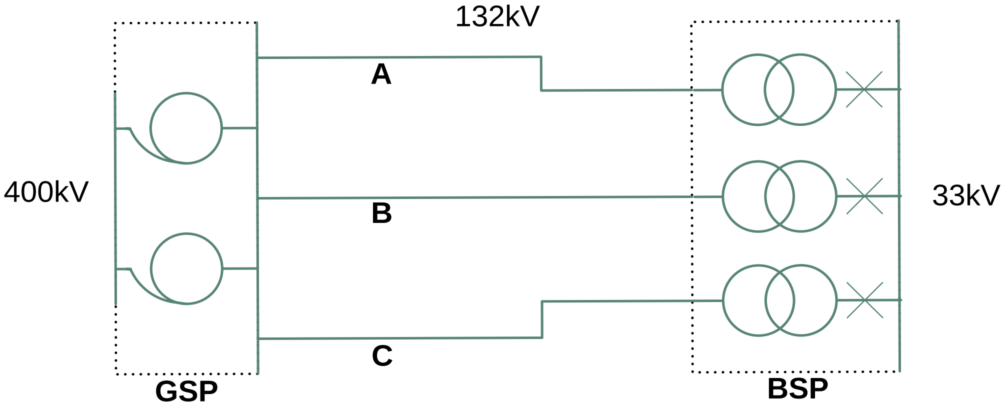


Figure 3: Three circuit 132kV supply group

Figure 4 shows flows in circuit C over the course of the day of winter peak demand. It can be seen that circuit C is overloaded for most of the day under the worst second circuit outage – an arranged outage on circuit A followed by a fault on circuit B.

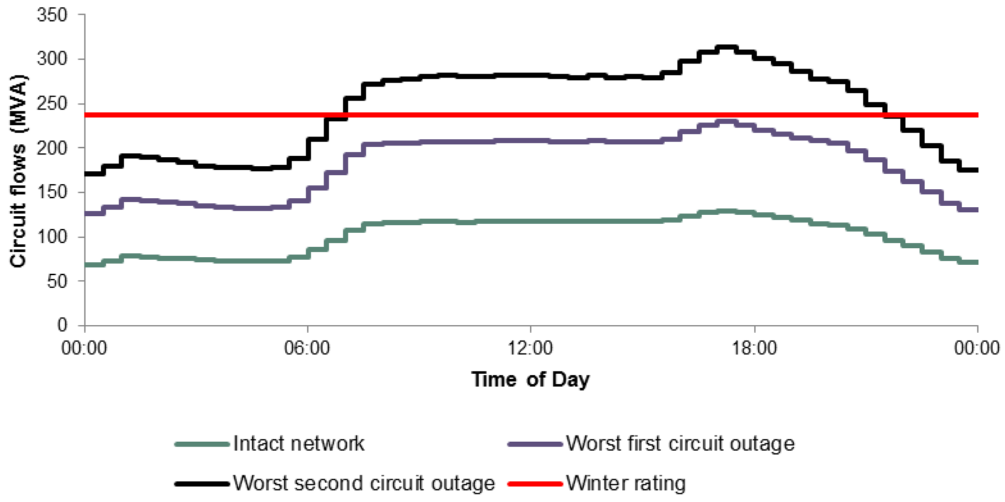


Figure 4: Winter flows on circuit C calculated using time-step analysis

The overload shown in Figure 4 can be avoided by scheduling arranged outages away from winter peak demand. This is a common practice; the period of spring, summer and autumn in which arranged outages are normally taken is known as the access window. Figure 5 shows flows in circuit C over the course of the day of spring peak demand. The demand at the BSP is lower in spring, but the rating of circuit C is also reduced due to increased ambient temperature. This means that circuit C is still overloaded at the spring peak.

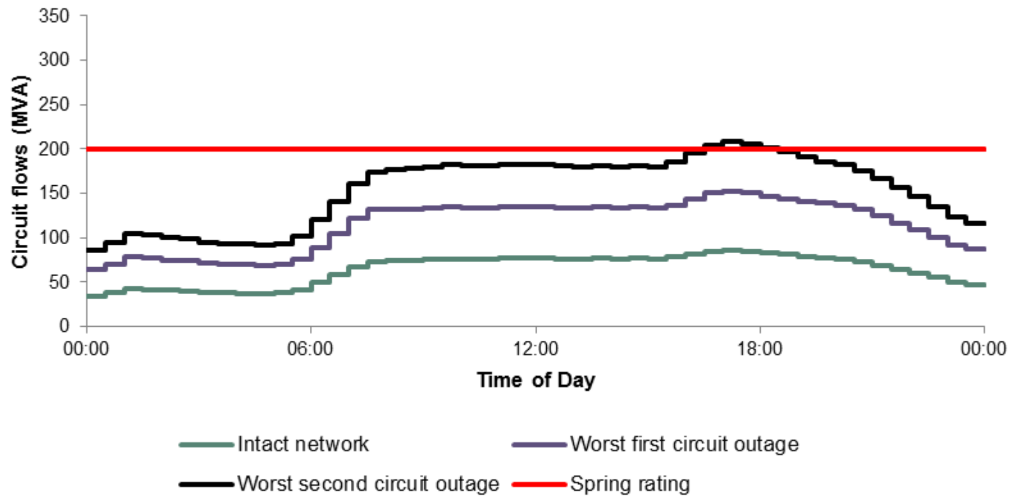


Figure 5: Spring flows on circuit C calculated using time-step analysis

If only the peak half hour were considered, it would appear that reinforcement was necessary. By assessing the whole day using time-step analysis, it can be seen that the overload only persists for less than two hours. This raises the possibility of alternatives to conventional reinforcement including:

- Applying cyclic or real-time ratings to circuit C;
- Using DSR or other flexibility services to time-shift or reduce demand; or
- Scheduling the arranged outage for a different part of the access window when circuit C would not be overloaded.

Impact on Operability

Up until recently, the network has been designed without the need for extensive time-step analysis. Without this type of analysis the ability to estimate energy curtailment for ANM is limited. It can be estimated using persistence curves of different demand and generation technologies, but would not provide such an accurate estimate of curtailment for potential customers, due to the complexities of power-flow on an interconnected network.

In the *Shaping Subtransmission to 2030* series of reports, combined time-step and contingency analysis has proven particularly effective at identifying network issues prior to them being seen on the network. Integrating this technique into business-as-usual will help to identify more issues that can be proactively dealt with, reducing the risk of network constraints limiting network operation.

Some of the benefits that time-step analysis will provide are:

- Estimating energy curtailment of generators;
- Accurate assessment of cyclic loadings on circuits and transformers; and
- Better determination of the worst contingency permutation, which will enable the most appropriate conventional or innovative solutions to be chosen.

Operational Planning Analysis

It is necessary to take regular arranged outages of circuits and other parts of the network for maintenance, reinforcement and asset replacement. Operational planning focuses on scheduling arranged outages and securing the network against faults that could occur during arranged outages.

WPD currently uses the same network models and analysis tools for network design analysis and operational planning analysis. This can make operational planning analysis manually intensive, since model parameters need to be tweaked to the prevailing demand, generation and network configuration before analysis can take place.

Building operational planning analysis tools that integrate more closely with the DNMS would allow demand, generation and network configuration to be automatically inputted from live or historical data. The Advanced Planning Tool (APT), part of WPD's Low Carbon Network Fund (LCNF) Network Equilibrium Innovation project, trialled techniques including the use of weather forecasts to generate demand and generation forecasts.

Real-time Analysis

Real-time analysis is the assessment of the network in near real-time, typically using instantaneous monitoring as an input. The output from this analysis is used to automatically adjust network arrangements or provide predictive forecasts to network operators. The GBSO uses real-time modelling extensively, as they require a detailed understanding of what is happening on the network to balance demand and generation and dynamically deal with network incidents.

It is worth noting that this is different to local control systems such Automatic Voltage Control (AVC) and automatically switched reactive compensation, which have been used for many years. Those make decisions in isolation based upon locally measured network conditions and do not link to a centralised DNMS to inform the control process. Interaction with these systems must be considered when designing real-time systems.

Existing Real-time Analysis Systems

For a passive distribution network, this type of modelling has not generally been necessary, because the network has been designed so it can safely operate within predefined limits. The smart solutions we are in the process of implementing are changing this.

The most mature smart solution using real-time analysis is ANM. There are currently several ANM systems open to application across WPD licence areas. The other real-time analysis tools are being trialled are part of WPD's LCNF Network Equilibrium Innovation project.

System Voltage Optimisation (SVO)

This system will use a real-time monitoring and analysis tool to evaluate the real-time network situation on the 11kV and 33kV network to optimise the voltage at primary and BSP substations, through the use of enhanced AVC relays at each site. The online tool will be directly connected to WPD's existing DNMS via an internal Inter-Control Centre Communication Protocol (ICCP) link. The aim of the SVO is to minimise or maximise the voltage, within existing statutory limits, at a given substation to enable either additional generation or demand respectively to connect to the system. This is currently in the testing phase.

Flexible Power Link (FPL) Control System

A 20MVA AC-DC-AC converter is currently being installed between two 33kV networks that are not currently able to operate in parallel due to their specific operational arrangements. The FPL enables significantly increased flexibility of the two existing networks by allowing controlled real power transfer through the device and independent reactive power control at each side. The FPL will be actively and dynamically controlled via a real-time control module linked to the existing DNMS and will determine the required real and reactive power characteristics to optimise the complete network for maximum generation and load capacity. The system has gone live and is now undergoing real world testing.

Impact on Operability

System Coordination

Two options for running real-time analysis are to have the DNMS software with native ability to run the analysis, or bespoke software linking directly to the DNMS. These systems will be making assessments in real-time and automatically changing the network based on these results. It is of operational importance that there is high confidence in the decisions these automated systems are making and appropriate failsafes are built in.

If multiple systems are utilised then the interaction between control systems will need detailed assessment to ensure they are coordinated in their approach to network management. This will include their interaction with existing local control systems and protection such as G59 [4] protection, Directional Over Current (DOC) and voltage control schemes.

Without detailed design and coordination, there is a risk that multiple control systems will not coordinate and cause the network to operate in a detrimental way.

Time Delay

These systems will have an inherent delay between the trigger (network event or threshold limit) and network resolution. Figure 6 shows an example of the delays that will be seen for a typical real-time control system.

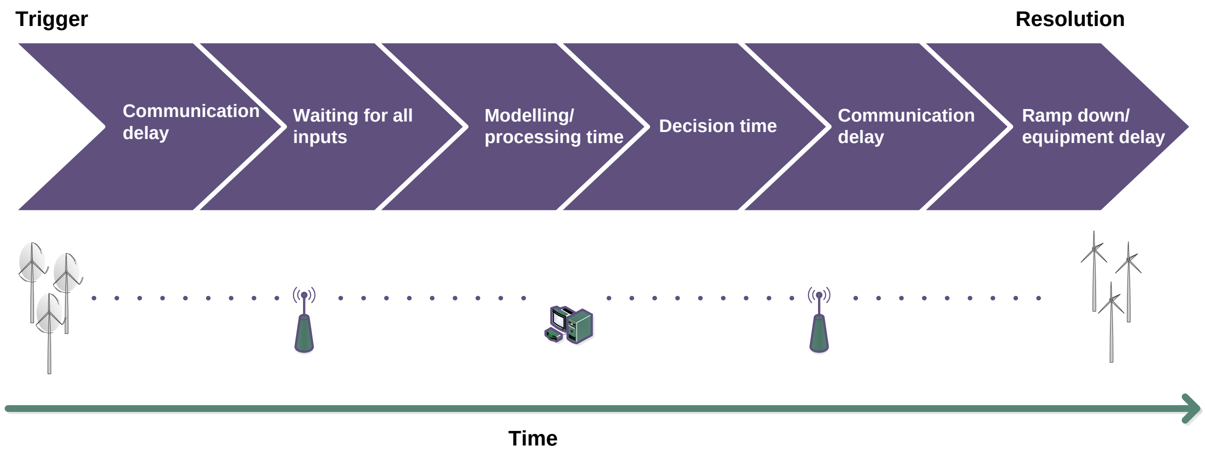


Figure 6: Example of the delays seen when carrying out switching or generator curtailment with real-time analysis in the loop

The operability challenge will be making sure the time delay is acceptable and does not negatively impact the network. If a load-flow or iterative analysis is required in the loop, then this will need to meet acceptable convergence limits before any action can be taken. Systems like the FPL will be dealing in second timeframes whereas ANM will be operating within minute(s). It will be crucial to ensure the control systems are coordinated and do not have excessive time delays as this could cause hunting, instability and model non-convergence (e.g. ANM models).

Data Availability

There is currently insufficient remote monitoring on the network to enable determination of network conditions at all strategic locations, especially at the lower voltage levels. State estimate can be used to approximate network conditions, but requires a minimum level of data to achieve a realistic estimation. The challenges associated with insufficient monitoring and data recorded are discussed in the Network Monitoring and Visibility DSOF article.

Where there is insufficient data, or confidence in the data (e.g. from unreliable communications) the systems will need appropriate failsafe mechanisms. Low confidence in data/results or insufficient monitoring will mean these systems will not be able to operate effectively.

ANM Modelling and Design

WPD currently offer four types of alternative connection to customers wishing to connect generation to constrained areas of network:

- Active Network Management;
- Timed;
- Soft-intertrip; and
- Export Limited.

Alternative connections enable faster connection of distributed generation, with some form of curtailment arrangement to avoid expensive reinforcement costs. These alternative connection solutions are regarded as the first stage in preparing for full DSO role.

ANM is the most complex form of alternative connection, but can release the most network capacity. It uses real-time network analysis to determine the allowable output of generators across an area of network. A power-flow management algorithm is used to determine which of the possible constraints are exceeded and allocates export capacity to generators in Last In, First Out (LIFO) order. ANM is due to be rolled out where required across our network by 2021. As a result, the assessment of flexibility services in this section focuses on ANM; however this is expected to include other flexibility services in the future as the market develops.

Existing ANM Modelling

Under WPD's current methodology for designing a generator connection in an ANM zone:

1. The customer's application to connect the generator is assessed for a conventional connection. The connection works and any necessary reinforcement are designed and costed.
2. If reinforcement is necessary and ANM can be used in place of some or all of it to alleviate steady-state thermal and voltage constraints, the generator is allocated a place in the LIFO stack and assessed for an ANM connection. The principal of the LIFO stack is that the last generator to apply for connection is the first to be curtailed when curtailment is necessary.
3. The DCAT tool is used to estimate how much energy curtailment that the generator would be subjected to. This estimate is provided to the customer to inform the comparison between curtailment and the cost of reinforcement.

Any new generation connections are assessed in the same way, with any connected or accepted-not-yet-connected ANM generators in the model at their export capacity. Currently, ANM can manage voltage and thermal constraints within the technical limits of the ANM system. These limits will depend on the ANM logic and the transient limits of the network. If these limits are exceeded then conventional reinforcement or another alternative solution will be needed.

ANM Strategies

WPD have identified three curtailment strategies that could be applied by ANM and other schemes that manage generator output:

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;
2. **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
3. **Post-event curtailment –** Following an event the generators are curtailed immediately to return the network to steady state compliance.

Case Study – Curtailment Strategies

This following case study compares the three curtailment strategies and highlights some of the design and operability challenges associated with them. The network in Figure 7 represents an ANM-managed 132kV network running under intact conditions. The demands, generation and circuit loadings shown are for a period when generation output is high and demand is low. The demand and generation connected downstream of each BSP are represented by lumped demand and generator symbols at each BSP for the purposes of these studies. Every BSP has a high penetration of distributed generation, resulting in reverse power-flow from each BSP onto the 132kV network.

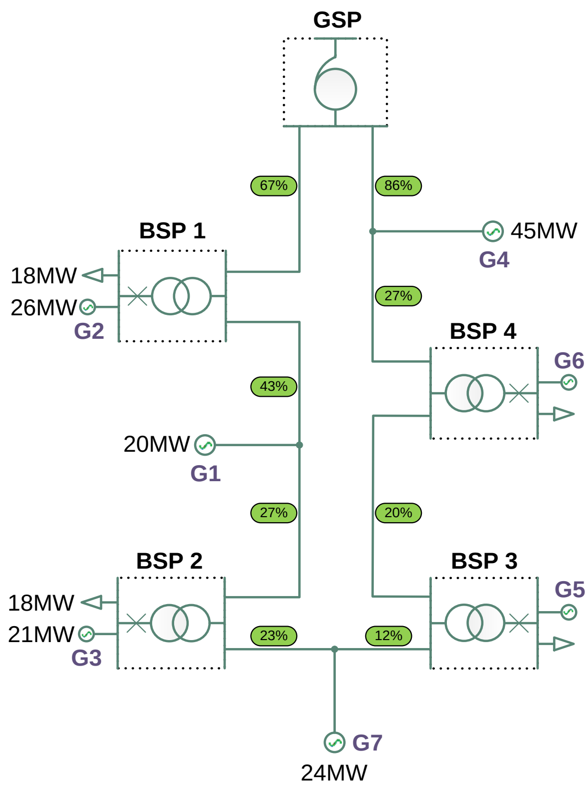


Figure 7: Intact network showing circuit loadings with no generation constrained

This case study focuses on how the ANM system manages a thermal constraint on the circuit between the GSP and generator G4. The most onerous fault that can occur is the loss of the circuit between the GSP and BSP1. Depending on the time of day and the balance of demand and generation, the most onerous event may change. The ANM system constrains the generators in LIFO stack order; this is G7, then G6, then G5 etc.

Full Pre-event Curtailment

Under the full pre-event curtailment strategy, generators are curtailed in anticipation of events such as faults to prevent overloads. The ANM system determines what the loading of each circuit would be after each credible fault and curtails the generation in LIFO stack order to ensure that post-fault circuit loading cannot exceed steady-state ratings. The post-fault loading can be determined using pre-populated lookup tables, or real-time load-flow analysis. This strategy ensures that there are no short-term overloads between the fault occurring and the ANM system re-curtailing generators for the new running arrangement.

Figure 8 shows how this strategy manages the fault outage of the circuit between the GSP and BSP 1, applying curtailment under intact network conditions to ensure that no overload will occur after the fault.

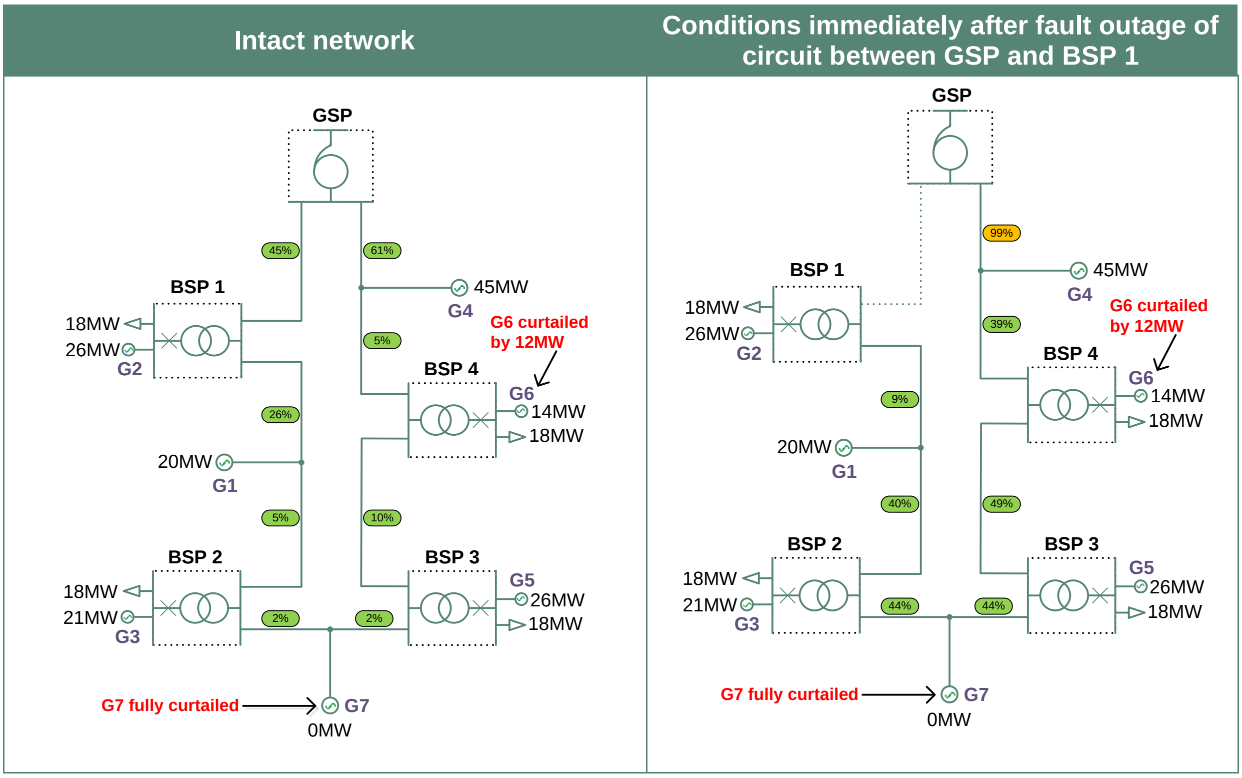


Figure 8: Full pre-event curtailment example

Under intact running the following generators have to be curtailed by a total of 36MW in anticipation of a fault between the GSP and BSP1 overloading the circuit between the GSP and generator G4:

- G7 is curtailed by 24MW (its full output); and
- G6 is curtailed by 12MW (from 26MWs to 14MWs).

No further curtailment is necessary in the immediate aftermath of the fault.

A disadvantage of this strategy is that it is necessary to curtail generators under intact conditions in anticipation of faults. An advantage is that it is more tolerant of delays in calculation, communications and curtailment than the other strategies.

Post-event Curtailment

Under the post-event curtailment strategy, generators are not curtailed until after events such as faults have occurred.

Figure 9 shows how this strategy manages the fault outage of the circuit between the GSP and BSP 1, not applying curtailment until after the fault occurs.

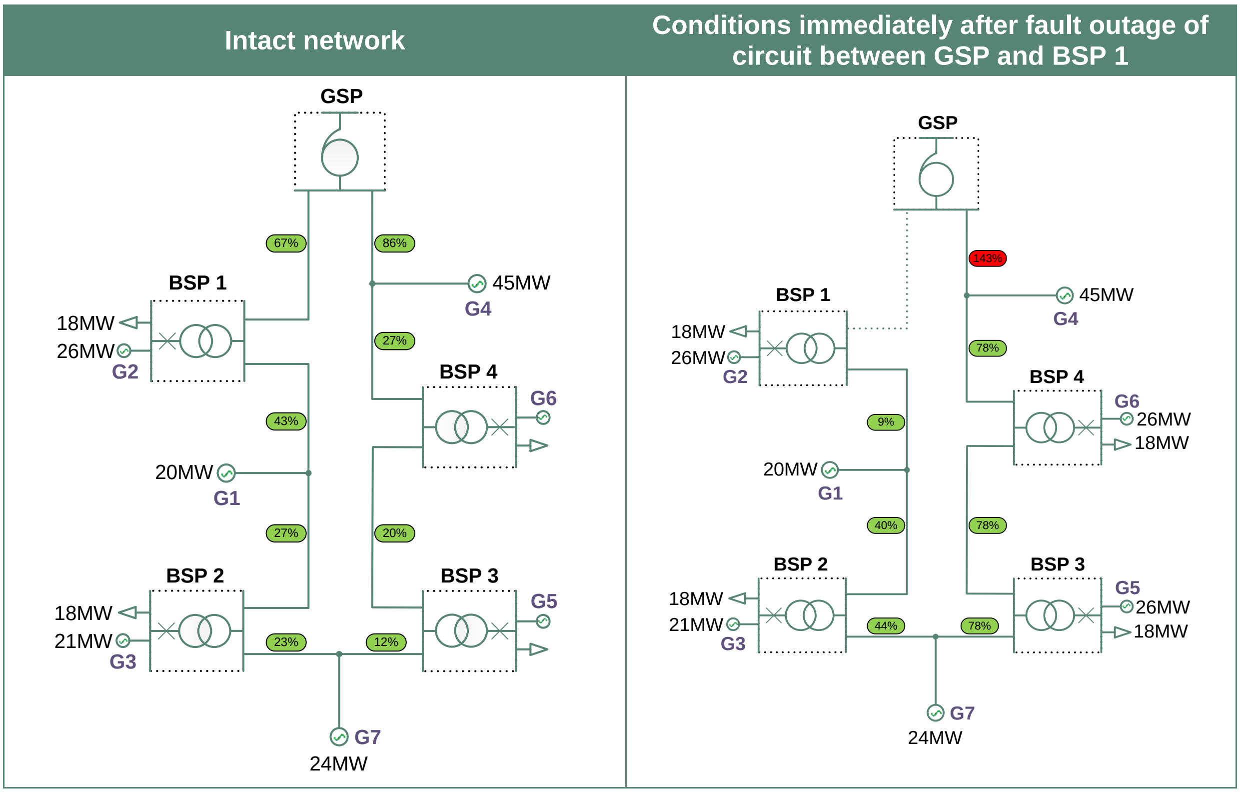


Figure 9: Post-event curtailment example

In the immediate aftermath of the fault, the circuit between the GSP and BSP1 is loaded to 142% of its steady-state rating, i.e. overloaded. Since this is beyond the circuit's capabilities, it is necessary to curtail generator output near-instantaneously (within less than one second of the fault occurring) to reduce the circuit loading to within 100% of its steady-state rating. To achieve this, G7, G6 and G5 are sent a pre-determined instruction to disconnect immediately from the network, resulting in a total of 76MW of curtailment.

A disadvantage of this strategy is that it does not allow time for calculation, so relies on pre-determined rules to decide which generators to curtail and by how much. This can lead to more curtailment being used than would otherwise be necessary. It is more suitable for implementing simple 'hard-wired' intertripping schemes than complex ANM schemes. An advantage is that generators are not curtailed until an event occurs, reducing the time spent curtailed.

Partial Pre-event Curtailment

This strategy combines aspects of full pre-event curtailment and post-event curtailment. It relies on the ability of some circuit components such as transformers to withstand minor short-term overloads. Under this strategy, a short-term rating is assigned to each circuit. The ANM system determines what the loading of each circuit would be after each credible fault and curtails the generation in LIFO stack order to ensure that post-fault circuit loading cannot exceed short-term ratings.

In this example, the short-term rating of the circuit between the GSP and generator G4 is 125% of its steady-state rating for up to three minutes. Figure 10 shows how this strategy manages the fault outage of the circuit between the GSP and BSP 1, applying partial curtailment under intact network conditions to ensure that post-fault loadings are within short-term ratings.

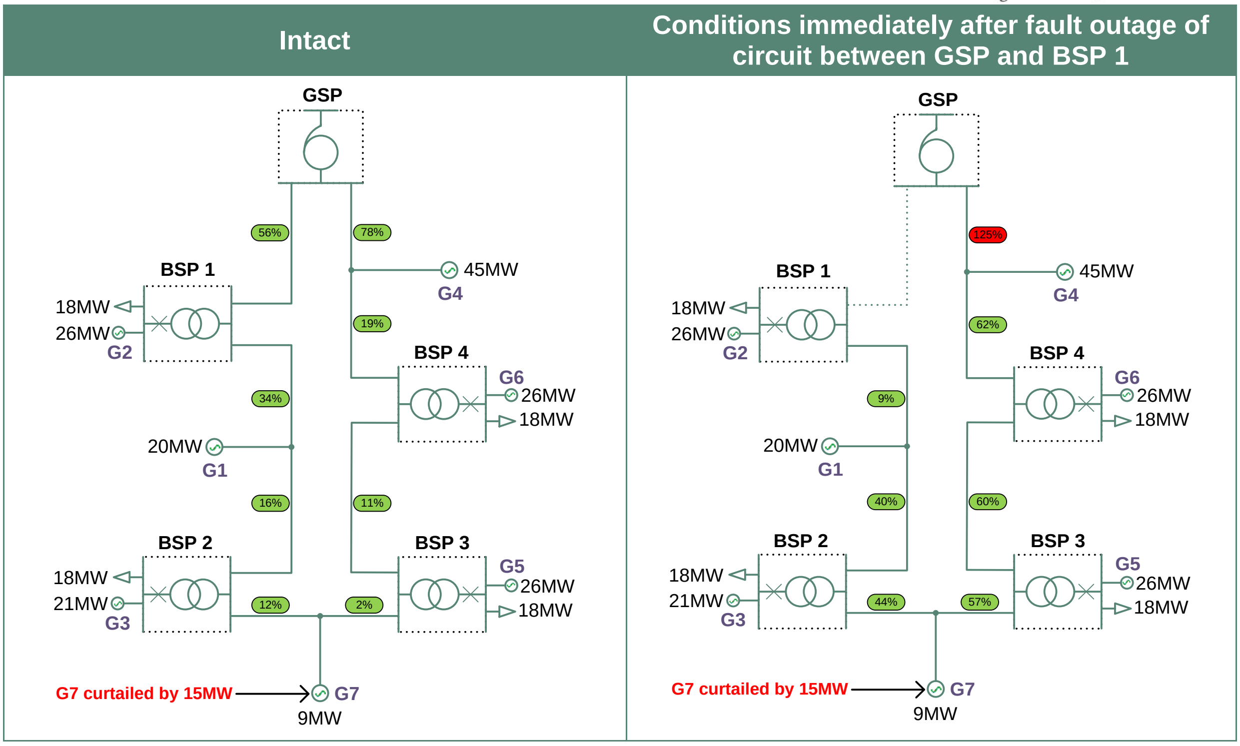


Figure 10: Partial pre-event curtailment

Under intact running, generator G7 has to be curtailed by 15MW (from 24MW to 9MW) in anticipation of a fault between the GSP and BSP1 overloading the circuit between the GSP and generator G4. In the immediate aftermath of the fault, the circuit between the GSP and generator G4 is loaded to 125% of its steady-state rating, i.e. up to its short-term rating.

It is then necessary to curtail a further 21MW of generation within the three-minute limit of the short-term rating to reduce the circuit loading to within 100% of its steady-state rating:

- G7 is curtailed by a further 9MW (its full output); and
- G6 is curtailed by 12MW (from 26MW to 14MW).

This strategy strikes a practical balance between full pre-event curtailment and post-event curtailment, but relies upon the availability of practical short-term ratings for constrained circuits and fast calculation, communication and curtailment.

Curtailment Summary

Table 1: Comparison of curtailment under the three ANM strategies

Strategy	Pre-fault curtailment	Post-fault curtailment	Total curtailment
Full pre-fault curtailment	36MW	0MW	36MW
Post-fault curtailment	0MW	76MW	76MW
Partial pre-fault curtailment	15MW	21MW	36MW

Power curtailment does not give a full picture of the advantages and disadvantages of the three strategies. The energy curtailed under each strategy would depend upon the profiles of the generators and demands connected to the network, and the likelihood of a fault between the GSP and BSP1.

Impact on Operability

The current generation of ANM systems use full pre-event curtailment. They are complemented by ‘hard-wired’ intertripping schemes, which use a form of post-event curtailment. Both strategies curtail more generation than would be ideal. Moving to the partial pre-event curtailment strategy may reduce energy curtailment, but will require the determination of short-term ratings for a wide variety of circuit components. It will also require faster calculation, communication and curtailment than are currently necessary for full pre-event curtailment.

Future Modelling and Analysis

The implementation of these real-time control systems and other flexibility services will require design stage analysis capable of replicating their complex behaviour and interaction with other systems. Existing modelling tools are focused on modelling a passive network and do not have the ability to model ANM and other innovative control systems.

As flexibility services and smart solutions are integrated into business-as-usual, their behaviour will need to be incorporated into design modelling and analysis. In some cases, this may require new types of analysis such as dynamic analysis. The services defined in WPD’s DSO strategy document are given in Figure 11.

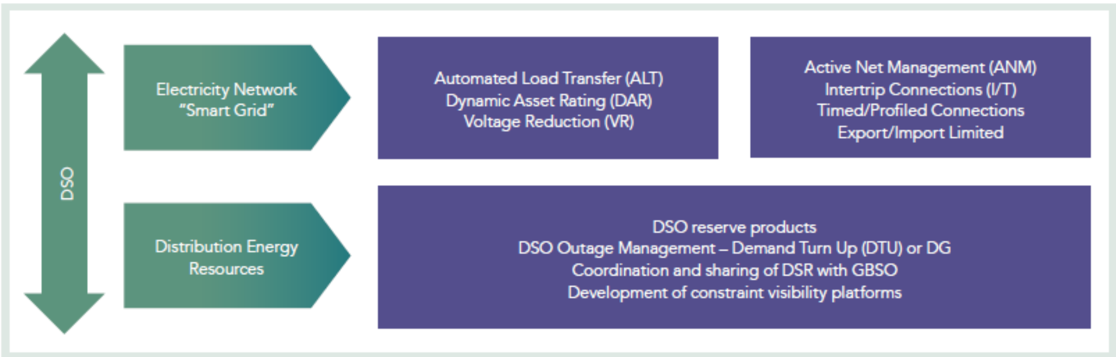


Figure 11: DSO Flexibility services as defined in WPD's DSO strategy document

The modelling of a smart network will require long-term modelling software, with functionality that enables these studies to be undertaken prior to connection to the real-time system. Existing power system software has limited functionality to assess the majority of these services. The innovation projects are utilising custom scripts to replicate the flexibility behaviour in the design software. These are currently being developed in relative isolation from each other. There will be a point where these add-ons will require interaction or integration into the native functionality of the software. Too many add-ons improperly coordinated will lead to a design process that is too complex.

This is a challenge faced across the Distribution Network Operators (DNOs), due to the speed at which the distribution network is changing and the requirements from modelling software struggle to keep up with the speed of innovation.

Impact on Operability

By having the ability to analyse how ANM, flexibility services and other control systems will interact at the design stage will help to:

- Determine where there is likely to be control system conflicts;
- Highlight where existing smart solutions are not sufficient to resolve a network constraint; and
- Reduce the risk of inadvertent operation of systems, through a more coordinated design approach.

Short Term Mitigation and Solutions

There is not one simple modelling and analysis innovation that will enable WPD to transition to a DSO role. Instead it will be a combination of incremental improvements that will look at when and how the network is modelled and analysed.

Network Design Analysis

WPD will continue using time-step analysis for the subtransmission strategic reports. These studies are being used to help guide low regret investment decisions. It will also help guide where this type of analysis would be most beneficial within the business. The reports for round 1 of these studies for all licence areas can be found on our website.

Time-step analysis will aid in assessing network curtailment and the balance between conventional reinforcement and innovative solutions. This can be done using a combination of time-step analysis and an understanding of generation and demand persistence. This type of analysis has been trialled between National Grid and WPD as part of the Regional Development Plan (RDP) work that is part of the ENA Open Networks work stream. This collaborative work is looking at how the GBSO can interact with a DNO/DSO to design the wider network in an efficient and coordinated manner.

WPD are currently investigating how this type of analysis could be further used to determine curtailment requirements for distribution constraints that are not currently covered by ANM.

Operational Planning Analysis

Learning from Network Equilibrium’s APT will be used to inform future operational planning analysis. As new technologies such as ANM are rolled out, it will become necessary to consider their behaviour in operational planning.

Real-Time Analysis

WPD will continue to rollout ANM and other innovation projects in a coordinated manner, ensuring they continue to integrate with existing control systems. The conclusions of the innovation projects will help guide WPD towards the best method of integrating all of these online control systems.

The SVO system will be taking central control over the previous local AVC system and any interaction, specifically with the ANMs, will simply be revised real-time voltages fed in to the ANM system to adapt its outputs time delay. It would be optimal to have a more integrated SVO and ANM system whereby the reduction / increase in voltage set point at the substation was the first (or at least one) mitigating action.

The FPL will be fully integrated with the SVO so that they do not conflict in their control of voltage on the wider system. A key local control point that the FPL needs to co-ordinate with is the wider systems’ tap changers and this has been managed by ensuring that the FPL is vastly quicker than that of a tap change operation and to stabilise long enough to ensure that the tap changers can ‘catch up’ if and when required.

ANM Modelling and Design

The active ANM zones within WPD currently use the full pre-event curtailment strategy; we also operate several ‘hard-wired’ generator intertrip schemes which use the post-event curtailment strategy. We are now developing a scheme which will use partial pre-event curtailment to manage Super Grid Transformer (SGT) loading at Alverdiscott GSP in cooperation with National Grid.

Future Modelling

WPD will continue to assess what level of modelling and analysis is needed at the design, operational and real-time stage so flexibility services can be incorporated as they become viable. This will include considering where dynamic analysis may be necessary.

Long Term Solutions

The long-term solutions for network modelling and analysis are not as clearly defined, as they will heavily depend on what flexibility services and systems will end up interacting with the distribution network.

Network Design Analysis

The long-term aim is to have design stage tool capable of modelling all DSO and ANM requirements. To reach this will need power system software packages that are capable of modelling the array of services and systems that are being utilised on the network. As stated, a balance must be found between the specialist features of application-specific tools and the closer integration offered by a single general-purpose package.

Operational Planning Analysis

The transition to a DSO will see more operational analysis undertaken as energy flows are managed in real-time. This will mean that short-term operational forecasting will become a crucial part of running the network.

Real-time Analysis

WPD is reviewing the ability of the current DNMS system, to determine what functionality could be incorporated within the DNMS. This will also look at how the DNMS could be used to coordinate third party packages. To make certain that the modelling and analysis tools will not limit the rollout of flexibility services, WPD will continue to refine the method for coordinating these online systems.

Depending on the success of SVO and FPL projects, these could be rolled out as business-as-usual, potentially releasing further network capacity and giving increased flexibility in real-time. If rolled out beyond the trial network, further integration with the ANM and DNMS would be assessed.

ANM Modelling and Design

We have committed to having ANM available where required across all WPD licence areas by 2021. At present, ANM can manage thermal and voltage constraints within the limits of the ANM system by constraining generation. In the future ANM might be extended to manage other network limitations such as voltage step change, power quality, losses and fault level. If the partial pre-event curtailment strategy is adopted, it will be necessary to determine appropriate short-term ratings for network components including overhead lines, cables, transformers and protection systems.

As discussed in Real-time Analysis, there is also the possibility of incorporating the ANM system within the DNMS. This comes with a number of data challenges that are discussed in the data and forecasting section.

Supporting Data and Systems

Identifying when and how we undertake the modelling is only part of the challenge of transitioning to a DSO. The following supporting data and systems must be in place to enable the complexity of modelling that will be required:

- Appropriate monitoring equipment capable of recording the granularity and correct analogues needed to undertake the real-time or network design modelling;
- A communication system with sufficient capacity to handle the increased data transfer needed from a smarter, more flexible network; and
- Data systems that can interpret and store the data. That can then be interrogated to determine network conditions.

The challenges of providing inputs to network modelling and analysis are covered in the DSOF articles on Network Monitoring and Visibility, and Data and Forecasting.

Bibliography

[1] The Energy Networks Association, “Engineering Recommendation P2/6: Security of Supply,” July 2006.

[2] The Energy Networks Association, “Engineering Recommendation G74: Procedure to Meet the Requirements on IEC 909 for the Calculation of Short-Circuit Currents in Three-Phase AC Power Systems,” 1992.

[3] The Energy Networks Association, “Engineering Recommendation G5/4-1: Planning Levels for Harmonic Voltage Distortion and the Connection of Non-linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom,” October 2005.

[4] The Energy Networks Association, “Engineering Recommendation G59/3-2: Recommendations for the Connection of Generating Plant to the Distribution Systems of Licenced Distribution Network Operators,” September 2015.