

# Voltage and Frequency Dependency

The demand and generation we see on the electricity network has been changing in recent years and is set to continue to change into the future. One of the affects of this change is how frequency and voltage disturbances interact with each other. They will interact more in the future, driving a dynamic voltage requirement.

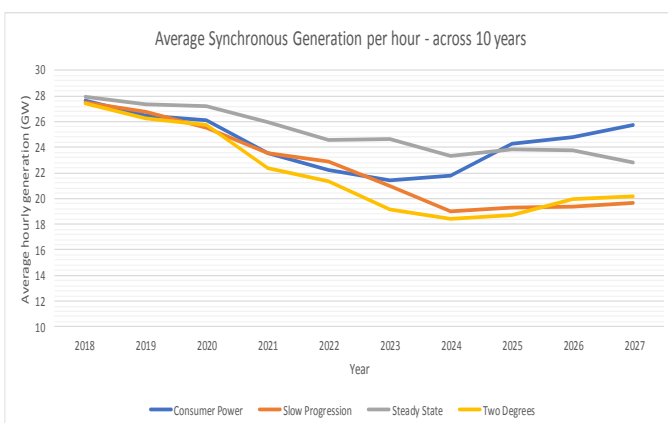
## Executive Summary

Frequency and voltage are usually considered and assessed independently in the design and operation of electrical networks. However, they are intrinsically linked. This investigation seeks to understand this relationship, how it is changing over time and how it may behave in different regions of Great Britain (GB).

All faults on our system, such as a line or generator tripping, will have a combined frequency and voltage effect. In the future, with the reduction in synchronous generation, combined events will be more significant and will need to be considered.

Each area studied in this assessment has a unique set of results. This shows different regions of Great Britain can display different behaviours based on the local network and generation mix. As the generation mix in each region

Figure 1: average synchronous generation per hour, across 10 years.



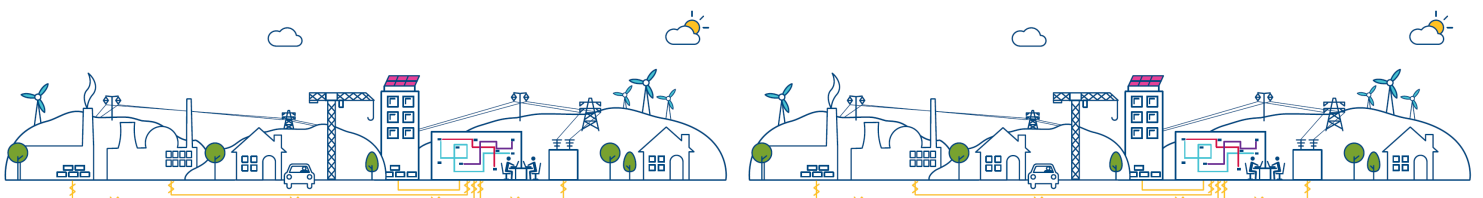
changes in the future, so will the combined frequency and voltage effect change.

Figure 1 summarises the decline in synchronous generation likely to be seen in the next 10 years, according to current trends. Our Future Energy Scenarios (FES)[1] details this further.

This study has found that to support frequency and voltage recovery, additional dynamic voltage support will be required to replace that which is currently provided by synchronous generation. Distributed energy resources (DER) could also provide this in the future, in addition to other technologies.

National Grid has recently published a road map for Network Options Assessment (NOA)[2] and Product Roadmap for Reactive Power[3] laying out a path to include more operability issues in it's considerations. We are currently considering various alternatives for dynamic voltage support as part of this process.

We hope that you find this document, along with our other system operator publications, useful as a catalyst for wider debate. For more information please contact us: [sof@nationalgrid.com](mailto:sof@nationalgrid.com)



# Background

When a generator trips off the system, the frequency drops as the demand is no longer being met. This event disturbs the voltage as the power flow across the transmission system changes.

If there is an overhead line fault there will be a voltage disturbance. This change in voltage will affect the power flow and can create a frequency disturbance.

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- When the power flow is low, the transmission line/cable is capacitive, generating extra reactive power and lifting the voltage level. This needs the System Operator to facilitate absorption of the extra reactive power, e.g. switching on a shunt reactor.
- When the power flow is high, the transmission line/cable becomes inductive, absorbing reactive power from the network and reducing the voltage level. This requires the System Operator to facilitate generation of reactive power, such as switching on a capacitor bank.

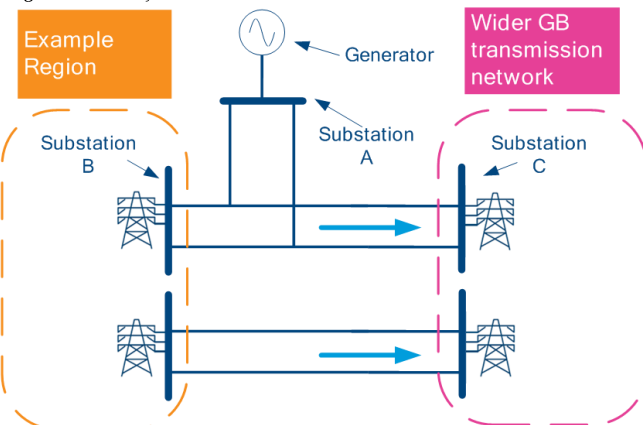
Each region of the country is unique with different transmission lines, generation and voltage support. This will also affect how the frequency and voltage recover regionally.

Figures 2 through 5 show an example of a combined frequency and voltage event.

## The steady state

Figure 2 shows an example transmission network where the generation in the example region is higher than the demand so the area is exporting across four circuits. This is described as the steady state.

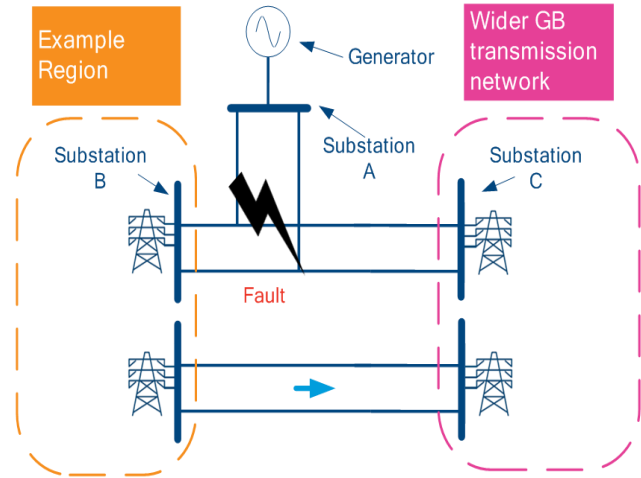
Figure 2: steady state.



## Electrical fault occurs

Figure 3 shows what happens when a fault occurs, before **protection** has operated to clear the fault.

Figure 3: during the electrical fault.



At the fault location, the voltage will reduce to zero. This will affect each generation and demand type differently. The result will be a lower export from the region, which is represented by a smaller arrow, indicating the flow.

**Synchronous generation** will provide more **fault current** and **reactive power** than **non-synchronous generation**.

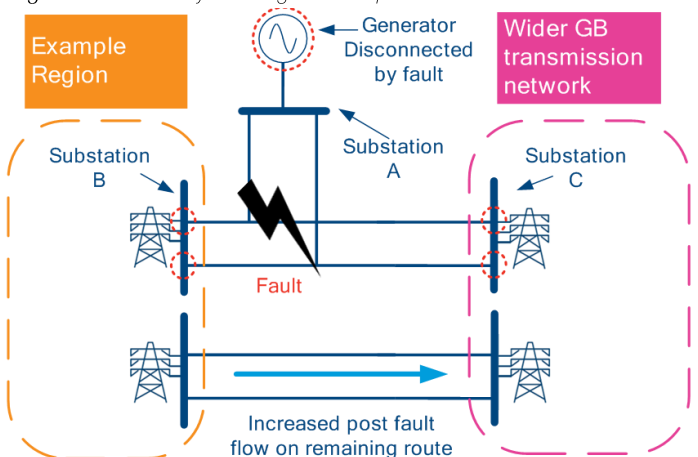
This situation will last for no longer than 140ms before protection operates to remove the fault from the system.

## Immediately following action of protection

Figure 4 shows that the fault has been cleared from the system by disconnecting the affected transmission lines and the generator.

The voltage will now start to recover, with fewer

Figure 4: immediately following action of protection.



transmission lines and less generation. This will affect each generation and demand type differently. The result will be an increased export from the region compared to before the fault was cleared, which can be seen in Figure 4. The overall export from the region is less than before the fault happened due to the loss of generation.

The flow on the remaining two lines will be higher than

before the fault. This loading on the line will lead to a further decline in voltage.

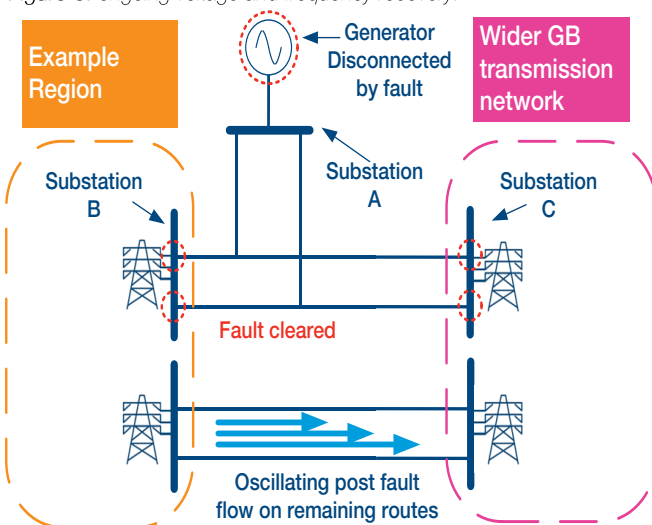
The rate at which the frequency is falling will start to slow as power out of the area begins to increase. The frequency will continue to fall due to the overall loss of generation.

### Ongoing voltage and frequency recovery

Figure 5 shows the interaction between frequency and voltage recovery after the fault.

As the voltage declines, with the increasing loading on

Figure 5: ongoing voltage and frequency recovery.



the lines, the power out of the area declines. This in turn affects the frequency causing it to decline.

As the power out of the area declines, the voltage starts to recover again. As the voltage increases so does the power out of the area and frequency then increases.

This oscillation of power, voltage and frequency can last for several seconds. During this time **frequency response** will start to act to recover the frequency.

To help reduce the impact of this combined effect **dynamic voltage support** can be used. This will help to recover and maintain the voltage which in turn will support the recovery of frequency.

## Assessment

Three case studies, that represent different types of region found in Great Britain have been considered:

- area 1 has the highest proportion of distribution connected non synchronous generation
- area 2 has the highest transmission connected non synchronous generation

- area 3 has the highest proportion of synchronous generation.

For each of these areas, a series of studies have been run to look at how the frequency and voltage are interacting following a fault. Figure 6 shows the results for area 2 in 2020.

For this study the fault is a loss of a transmission line and a generator tripping off which is shown at the red line. Following the loss of generation, the frequency falls, due to the imbalance in generation and demand, and the voltage falls due to a reduced number of circuits out of the area. At the same time the amount of power out of the area also reduces and the rate of change of frequency is high.

At the blue dotted line, you can see the voltage recovering. This helps to increase the amount of power coming out of the area which in turns helps to stop the frequency falling.

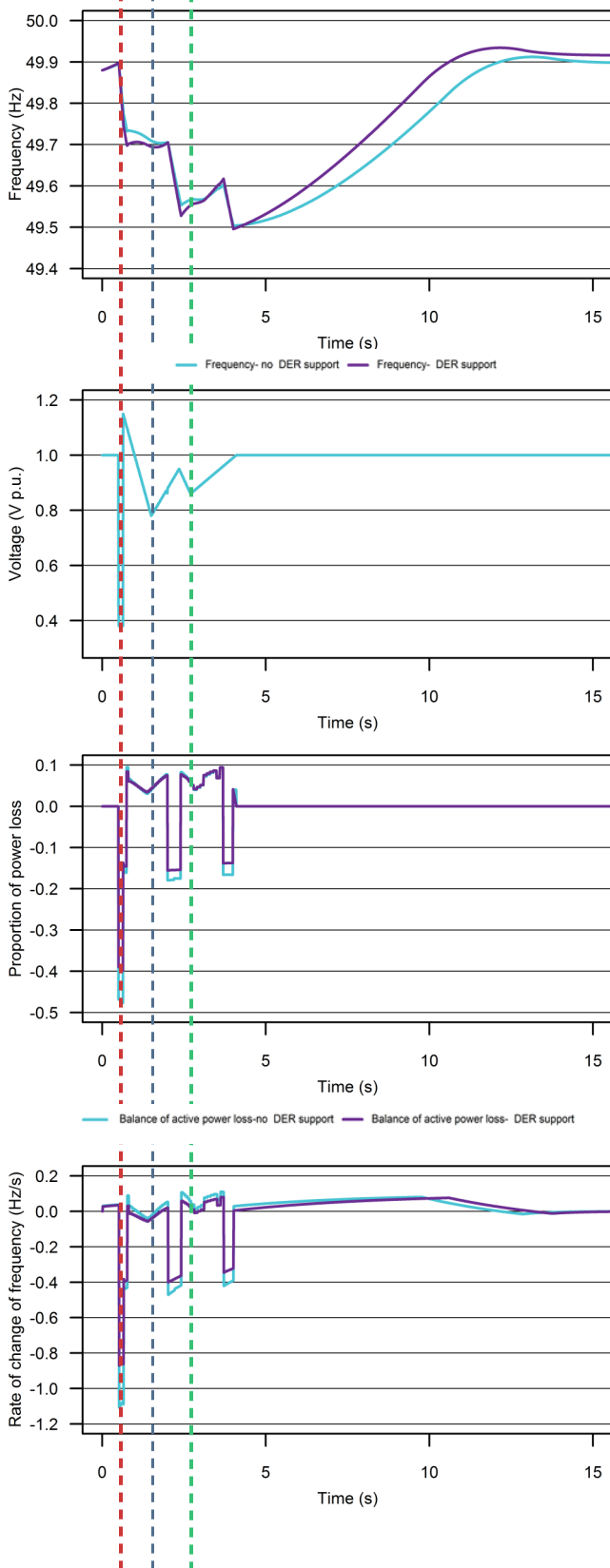
The power out of the area is now using fewer transmission circuits, as the power increases the **impedance** of the circuits increase and drives the voltage down again, seen at the green dotted line. This has the effect of decreasing the power out of the area and the frequency falls again and there is a corresponding rate of change of frequency event. This effect can be seen again with a further voltage dip.

From 2 seconds onwards, frequency response is having an effect and the frequency and the voltage recover to pre-fault conditions. The final part of the study looked at how quickly the frequency returned to pre-fault levels with different amounts of dynamic voltage support. This dynamic voltage support is coming from distributed energy resources (DER). The light blue line shows the recovery with no support from DER and the purple line shows the recovery with DER support. If DER dynamic voltage support is available it will help recover the frequency quicker and support the recovery of the power export out of the area.

Currently frequency and voltage events are considered separately and not combined as we have done through this study. Moving forwards, with a decline in synchronous generation, a combined event will become more significant and will need to be considered.

Figure 7, shows the results for all three areas studied. In areas 1 and 2, where there is a higher penetration of non-synchronous generation, there is an increasing

Figure 6: assessment results for area 2 in 2020.

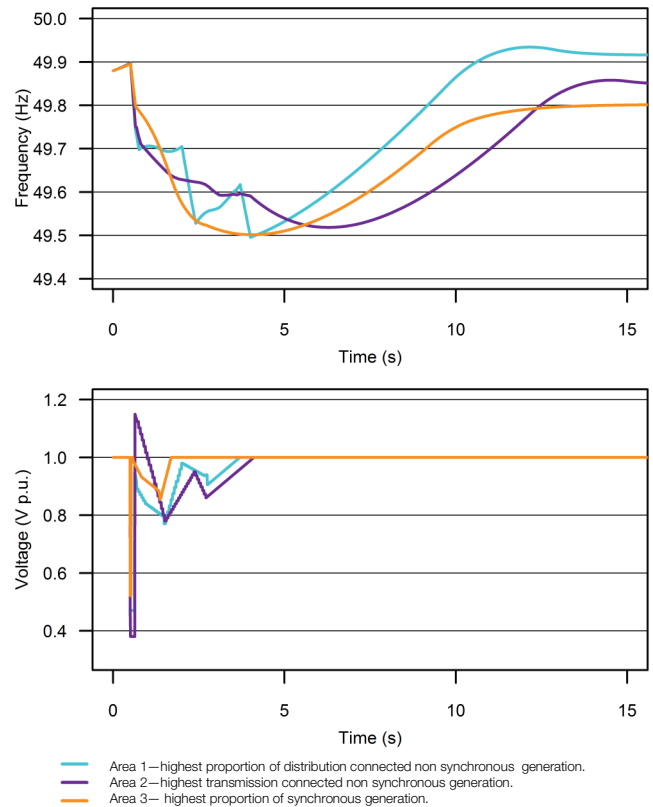


need to consider combined frequency and voltage events and this combined effect will drive a dynamic voltage requirement. In area 3, where synchronous generation remains dominant, the combined event drives little value. Therefore, the additional dynamic voltage requirement will be lower.

These results show us that the network and generation

mix in each region directly relates to the size of this effect. Synchronous generation provides more dynamic voltage support than non synchronous generation does. This means to continue facilitating non synchronous connection, additional dynamic voltage support will be required. The amount of dynamic voltage support needed will vary between regions.

Figure 7: frequency and voltage during the fault, for all three areas.



## Conclusion

All faults on our system will have a combined frequency and voltage event. In the future, with the reduction in synchronous generation, combined events will be more significant and will need to be considered.

To support frequency recovery additional dynamic voltage support will be required to replace that currently provided by synchronous generation. Distributed energy recourses could provide this in the future, in addition to other technologies.

Each area studied had a unique set of results. This shows how each region of Great Britain will display different behaviour based on local network and generation mix. As the generation mix in each region changes in the future, so will the combined frequency and voltage effect change in each area.

National Grid has recently published a road map for

Network Options Assessment (NOA)[2] and a Product Roadmap for Reactive Power laying out a path to include more operability issues in this process. This effect, along with other operability challenges will be investigated this year to understand the suitability of being included in this process. Look out later in the year for further updates.

We hope that you find this document, along with our other system operator publications, useful as a catalyst for wider debate. For more information please contact us: [sof@nationalgrid.com](mailto:sof@nationalgrid.com)

## Glossary

**Protection** - a device which tells circuits where faults are located so they can be isolated from the rest of the system using circuit breakers.

**Synchronous generation** - a machine that generates an alternating voltage coupled to the system with the ability to provide immediate fault level and inertia, without the need to measure the grid system.

**Non-synchronous generation** - generation technologies which are de-coupled from the grid via a converter or control system and do not contribute to system inertia. Their ability to provide support to the grid system is dependant on having the time to measure the system accurately and being able to respond appropriately.

**Fault current (Short Circuit Level)** - when there's a short circuit, there's a flow of current towards the ground which must be isolated from the system as soon as possible. The size of this fault current is determined by the size of the generation producing a voltage, which is coupled with the system and how far away this generation is electrically (this being the impedance of the grid system). Fault level is a good indicator of system strength.

**Reactive power** - In order to transmit active power across the grid system, it is necessary for the system to have a set of voltages which support the power transfer. These sets of voltages have to be controlled within time limits in order for the power to be supplied securely and efficiently. Voltage is increased by supplying reactive power to the grid system and is decreased by absorbing reactive power from the grid system. Devices that store energy through a magnetic field produced by a flow of current are said to absorb reactive power; those that store energy through electric fields are said to generate reactive power. There are some devices e.g.

generators which can do both.

**Frequency response** - the power response of the power system (or a section of the power system) to a frequency deviation; they can be dynamic (continuous and proportionate) or non-dynamic (discrete) responses.

**Dynamic voltage support** - devices that can modify their behaviour according to voltage level and provide variable reactive power, in various time scales. Typical devices that can do this immediately, without the need for measurement, include synchronous generators and synchronous compensators. These immediate forms of support are important during a short circuit fault and in the immediate period after the fault has been cleared (0-80 milliseconds). Non-synchronous generators, static compensators and static var compensators can all further assess after that immediate period provided they are controlled carefully to support voltage recovery. Sufficient dynamic voltage support is critical to contain and recover the voltage following a disturbance, as well as to manage changes in the reactive power demand in real-time.

**Impedance** - the total opposition to the current flow in an electrical circuit. The Impedance includes the resistance (this often being referred to as transmission losses) and the reactance (magnetic losses that can reduce voltage).

## References

1. Future Energy Scenarios (FES) - <http://fes.nationalgrid.com/fes-document/>
2. Network options assessment—<https://www.nationalgrid.com/uk/publications/network-options-assessment-noa>
3. Product Roadmap for Reactive Power—<https://www.nationalgrid.com/uk/electricity/balancing-services/future-balancing-services>

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