nationalgridESO

# System Operability Framework
# Impact of declining short circuit levels

We at National Grid ESO are identifying and quantifying system requirements which are affected by reductions in short circuit level and we share some of our work in this document. In 2019 we intend to invite technical and commercial solutions from across the industry to address needs in specific locations. Look out for more information as our Stability Pathfinder Project progresses

Short circuit level (SCL) is an important parameter for an electricity system. It is a measure of strength, a key parameter for protection systems and along with inertia determines how stable the electricity system is. A description of SCL can be found in appendix A.

A major source of SCL is synchronous generation. As the amount of synchronous generation continues to decline so does SCL. SCL is a regional property. Areas seeing decline in synchronous generation will also see the largest decline in SCL.

In this report we have been assessing the times when SCL is low and its impact on operability. Figure 1 shows the average rate at which SCL is set to decline across the four Future Energy Scenarios [1]. There is a steady decline out to the year 2025 where, in some scenarios, there is an increase due to new synchronous generation connecting.

We have investigated the impact of this decline in three areas;

- **Transmission protection.** This could take longer to operate or not operate as designed.
- **Phase Locked Loop.** Generators with converters have an increased risk of instability.
- **Whole system SCL.** These trends mean solutions are most effective at the same voltage as issues .

As well as these, other operability challenges from minimum and  maximum SCL can also be a driver for investment. Assets need to be able cope with high SCL during a fault. This requirement will continue in the future.

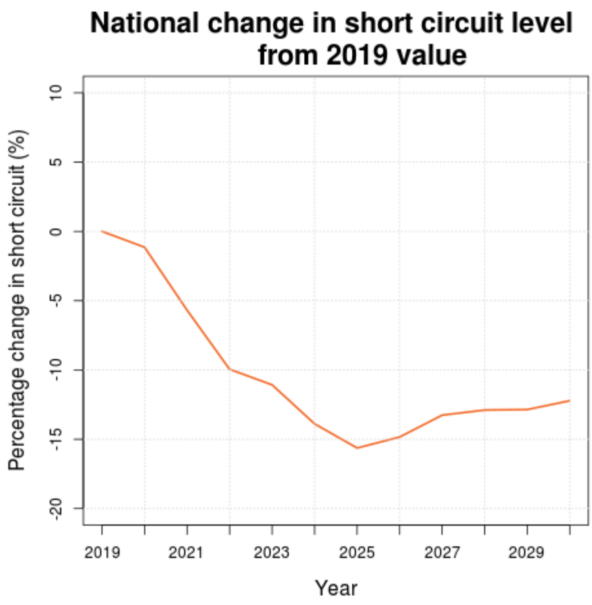



*Figure 1: National short circuit level 2019-2030*

To manage the decline in SCL we will be conducting a Stability Pathfinder Project in the South West and Northern regions of Scotland at 400kV, 275kV and 132kV. The areas have been chosen in collaboration with Scottish Hydro Electricity Transmission Limited and SP Transmission.

Throughout this analysis we will be defining a range of stability requirements including short circuit level and static and dynamic voltage. We will be investigating if there is a regional inertia requirement.

Once we have defined our requirements, we will be looking for solutions from across industry. These can be assets or commercial solutions. We will publish more about this in 2019 once we have defined our requirements.

# Short circuit level impact on transmission protection

- Transmission network protection relies on short circuit level to detect a fault to know when to operate
- The decline in short circuit level means that protection could take longer to operate or not operate as designed
- This would result in longer faults on the system, posing a risk to network safety and stability

National Grid Electricity System Operator (ESO) has been working in collaboration with the GB transmission owners (TOs):

- National Grid Electricity Transmission
- Scottish Hydro Electricity Transmission
- SP Transmission

Together we have been working to understand the impact of declining SCL on network protection.

Network protection systems are designed to detect and safely isolate faulty equipment as quickly as possible, limiting the fault affects on the wider system. Faults left on the system can pose a safety risk to people, damage equipment and lead to instability for users of the power system and the transfers of power upon the system. Protection systems are designed to have a very high degree of reliability and depend on the SCL being high enough to trigger a protection relay. If the closest protection relay does not detect the fault quickly, protection further away would act to clear the fault. This will disconnect more of the system and leave the fault on the system for longer.

Typically, circuits will have two main protections and one back up protection, which is different from the main protection. Overcurrent protection is a type of protection typically used as back-up. Maintaining a level of redundancy in protection is important to ensure a safe and reliable system.

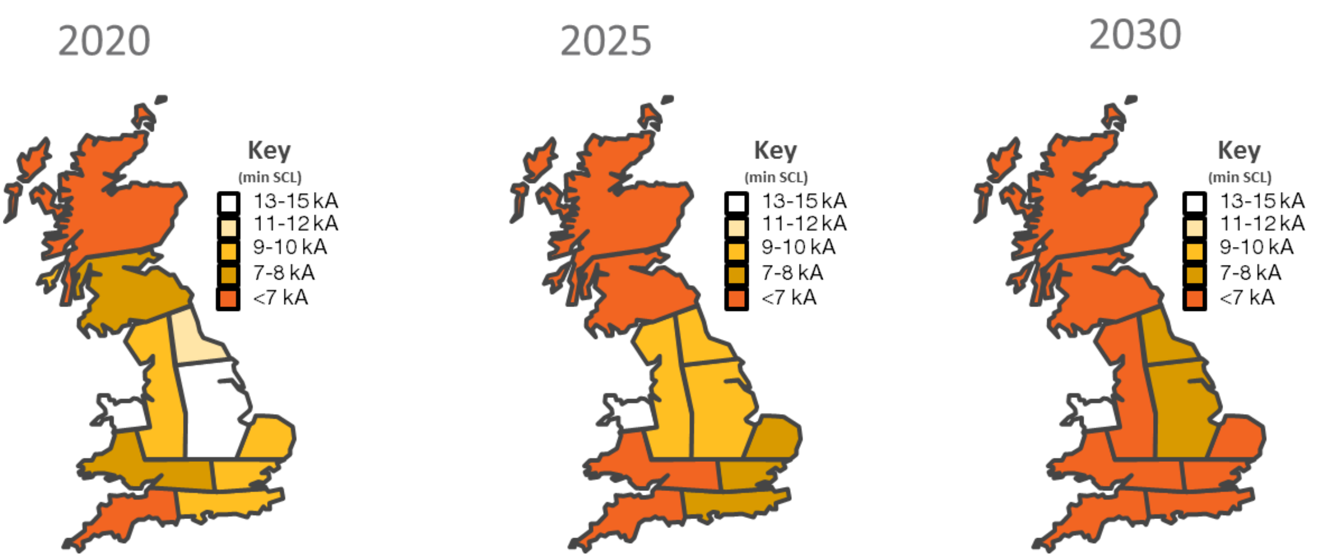
The SCL decline is not driven by a specific network change. It is driven by broader a trend of increasing non-synchronous generation growth, driving a decline in synchronous generation running and availability to run across the year. This trend changes the locations of SCL sources across the system. This affects the protection in different locations of the transmission system differently.

Figure 2 shows how SCL is declining at different rates across the country. In Scotland, the value starts at a low point and further declines in the South of Scotland by 2025. The largest decline is seen in the North-East and East Midlands regions.

To understand what this means for protection each TO selected some case studies to analyse in detail. These have been selected for times and regions with the lowest SCL identified through our year round analysis out to 2030. These case studies examine how the protection will operate with the declining SCL. The case studies have identified some circuits where back up overcurrent protection and earth fault protection may be at risk due to declining SCL. This will start to a reduce the redundancy of the protection system.

The number of overcurrent back up protection systems affected by declining SCL varies around the country depending on how common they are, how low SCL is and how much SCL has declined. Initial results show that Scotland will see this impact on protection first.

*Figure 2: Regional short circuit level over the next 10 years*



# Short circuit level impact on Phase Locked Loop (PLL) converters

- Short circuit level is required to maintain a stable voltage during a fault period which then informs the PLL
- The decline in short circuit level means that the PLL converters may not keep refence with the system during a fault period
- This poses a risk that multiple generators will be affected by a fault adversely

Phase locked loops (PLL) are a converter technology commonly used on non-synchronous generation such as wind, solar and HVDC.

The impact of declining system strength on PLL converters was first explored in the System Operability Framework: Performance of Phase Locked Loop converters [2].

The PLL of a converter provides network information by taking measurements of the voltage waveform. The converter uses this information to know what is happening on the system and to know if it needs to change its output. The PLL plays an important role in keeping converters connected to the system during normal operation and during a fault.

SCL is important during a fault as it helps to maintain voltage. As SCL declines the voltage waveform will become more disturbed during a fault. When the PLL measures a more disturbed voltage waveform it might not provide the right information back to the converter and the converter might not respond in the right way to the fault. In this situation there is a risk that the converter will lose connection to the network.

For this analysis we have continued to use the Cigre developed model [5]. We have amended it to be Grid Code compliant. We have run a series of studies to understand the minimum SCL required for a converter to remain connected to the grid during a fault. We have compared this minimum SCL with our year round analysis of SCL and identified where and in what year there is a risk to converters.

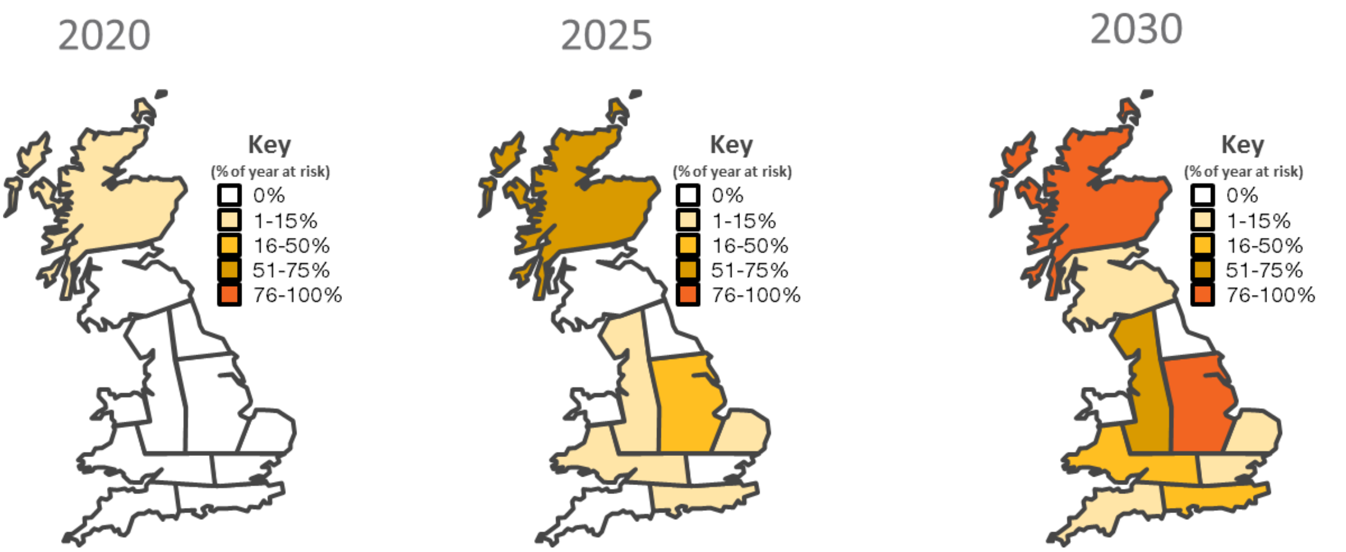
There are two factors that drive this risk; the decline in SCL and the growth in PLL converters. Areas that see both of these trends will see the largest risk. Figure 3 below shows how the risk emerges over the years.

The PLL risk first emerges at the edges of the network where there is a significant growth in non-synchronous technologies like wind and interconnectors. The risk emerges first in North Scotland, and is present for a larger proportion of the year in comparison to other areas.

This risk emerges at a slower pace than the protection risk. This is because minimum SCL required by PLL is lower than the minimum SCL required for overcurrent protection.

This means that when we are considering solutions for both the PLL and protection risks, we need to look at both together. This will allow the best long term solution to be used and not just fixing the immediate issues now, only to find secondary issues in the near future.

*Figure 3: Regional Phased Locked Loop risk over the next 10 years*



# Short circuit level impact on the whole system

- Short circuit level decline at transmission will have an impact on distribution short circuit level
- There is an increase in short circuit level contribution at distribution, from the growth of distributed generation. There is also a declining transmission contribution
- Increasing short circuit level at transmission voltages will be more effective than at distribution to resolve transmission issues

National Grid Electricity System Operator has been working in collaboration with Electricity North West Limited, SP Energy Networks, and Western Power Distribution to understand what is happening with SCL across the whole system.

Together, we have looked at the impact of year-round variation and future decline in transmission SCL on maximum and minimum SCL on the distribution networks [3].

Distribution systems are expected to see an increase in demand and distributed generation which will increase their maximum SCL. On the transmission system we are expecting to see a decrease in SCL due to the decline in synchronous generation running.

These two trends cause opposite effects on the SCL of the transmission and distribution system. In this work we looked at how the combined effect manifests on the whole system.

On the distribution system, the net effect is that the maximum SCL is increasing with the contribution from distributed generation. This may drive asset investment. The minimum SCL on the distribution is declining as the contribution from transmission SCL also declines. On the transmission system, the contribution to SCL from the distribution system is small but is increasing. It does not affect the overall trend of declining transmission SCL.

If we look at the impact of each network on the other, we can see in Figure 4 that on the distribution system the contribution from transmission is between 75-95% of distribution SCL. In 2027 this reduces to 65-95%. We can see that transmission SCL remains the largest contributor to distribution SCL but its contribution is reducing.

In Figure 5 we see the impact of distribution contributions on transmission SCL. We can see that the contribution from distribution is 0-7% of transmission SCL and that this increases to 0-15% by 2027. This shows that although the contribution from distribution is increasing it remains small.

The above trends mean that when seeking to solve transmission issues related to the declining SCL, such as protection or PLL, the most effective solutions will be connected at the same voltage level as the stability risk. Solution at other voltages may contribute but their effectiveness will be reduced by the physics of the system.

*Figure 4: Contribution of transmission to distribution short circuit levels*

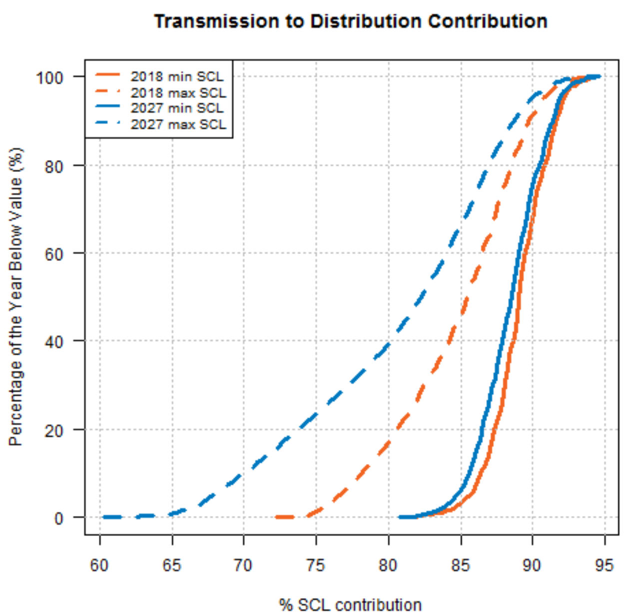
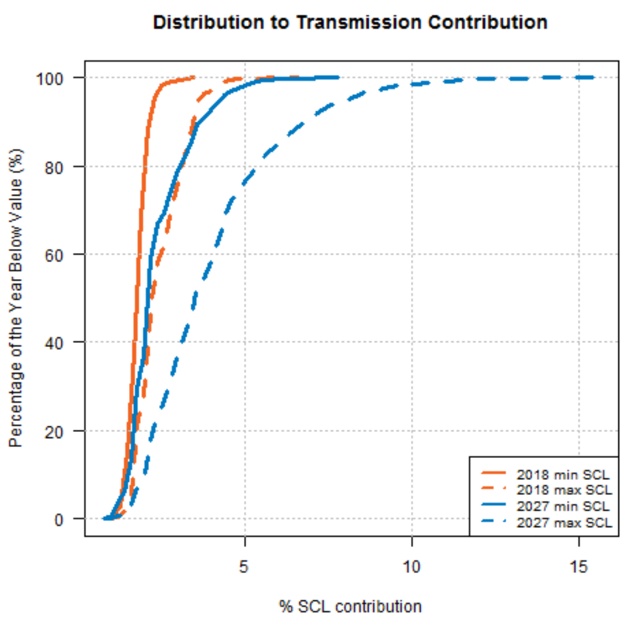



*Figure 5: Contribution of distribution to transmission short circuit levels*



# Conclusion and next steps

- The decline in short circuit level will present risks for protection and PLL operation
- Increasing short circuit level at transmission will be more effective than at distribution to resolve transmission issues
- We will be defining requirements and seeking solutions through our Stability Pathfinder Project

In this report we have highlighted some operability risks of declining SCL. Previous sections explain how the risk will appear in different areas of the network in the future.

In Scotland, both the protection and PLL risk emerge in the early 2020s as levels of synchronous generation decline. Across England and Wales, the PLL risk emerges later than the protection risk due to the SCL requirement for PLL being lower than for protection.

Throughout the report, we have identified ways that declining SCL can affect the transmission and distribution networks. However, there may be other impacts because of this trend on the whole system, including impacts to network users.

To manage the risk from declining SCL, we will be conducting a Stability Pathfinder Project in the South West and Northern regions of Scotland at 400kV, 275kV and 132kV. See Figure 7 for the area of study. These areas have been chosen in collaboration with Scottish Power Transmission and Scottish Hydro Electricity Transmission Limited.

This Stability Pathfinder Project is part of the Network Development Roadmap which is looking to enhance the Network Options Assessment process. It is seeking to do this by introducing operability requirements, like voltage and stability, and looking at a wide range of solutions from transmission owners, distribution owners and commercial solution providers. More information can be found in Network Development Roadmap [4].

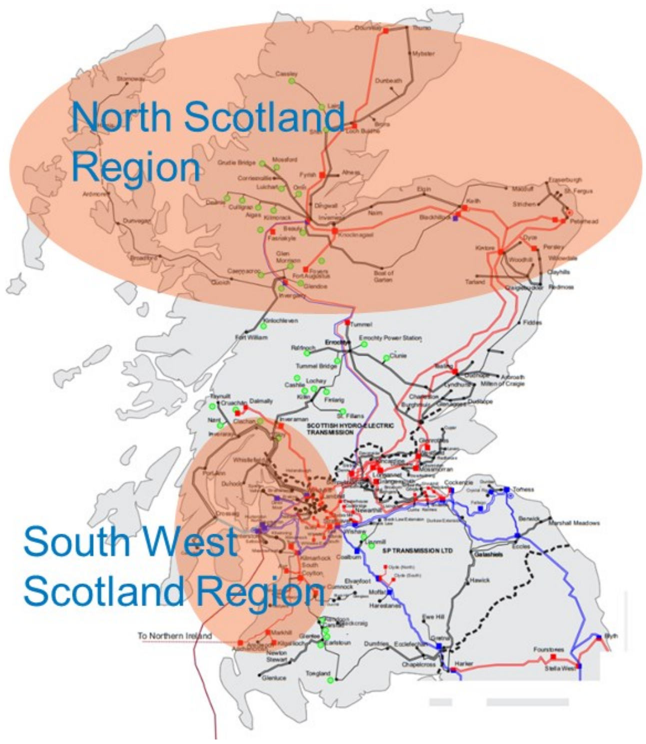
Through this project we will be defining a range of stability requirements including short circuit level, dynamic and static voltage support across system disturbances, and investigate if there is a regional inertia requirement.

The areas that are to be studied have been selected as they will face the largest decline in SCL and will see the risk emerge first. Solutions outside of this area will be considered although their effectiveness may be reduced. More details of the effectiveness of solutions outside of the study area will be released in 2019.

Once we have defined our requirements we will be engaging with the energy industry to help shape the balance of operational, physical and commercial solutions that may meet these. More information will be published in 2019 once our requirements are finalised. At this time we will also share more details on how asset and commercial solutions will be assessed.

It is important to consider all of the SCL based risks found in the report together, as a solution to one risk may affect others. We aim to find solutions that provides best value for consumers. In order to do this we need to consider whether a single solution that solves all the risks together is best, or whether individual solutions best deliver this value. The Stability Pathfinder Project seeks to identify a framework for the delivery of the most efficient overall approach to meet our needs going forward.

*Figure 7: Map of areas of focus for Stability Pathfinder Project*



# References

[1] http://fes.nationalgrid.com/

[2] https://www.nationalgrideso.com/sites/eso/files/documents/Phase%20locked%20loop%20FINAL.pdf

[3] To be published November 2018 at https://www.nationalgrideso.com/insights/system-operability-framework-sof

[4] https://www.nationalgrideso.com/sites/eso/files/documents/Network%20Development%20Roadmap%20consultation.pdf

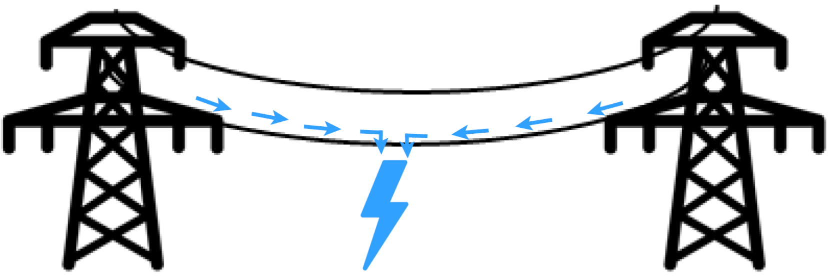
[5] Guide for the development of models for HVDC converters in a HVDC grid, Cigre working group B4.57

# Appendix A– description of short circuit level (SCL)

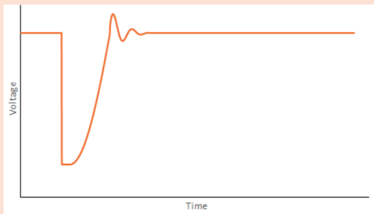
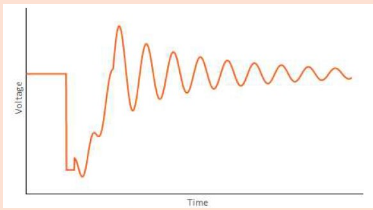
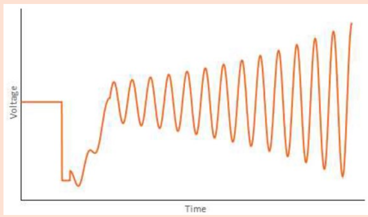
## What is SCL?

Short circuit level is the amount of current that will flow on the system during a fault. These faults can be caused by a tree hitting a over head line, an equipment failure or something else. During the fault, the system see a direct connection to earth and current flows from all the sources into it. We show this affect in figure A1.

*Figure A1: SCL flow on system*



SCL is also used as a description of the strength of the system. When SCL is high we say the system is strong and when SCL is low we say that the system is weak. The strength of the system is a key factor in how stable the system is when it experiences a fault. Table A1 shows how stability is affected by different levelsk of SCL.

| SCL | Effect on the system |
|---|---|
| High SCL<br>In a high SCL system during a fault voltage will fall, but it will quickly recover once the fault is fixed. The voltage will settle down to normal condition quickly with only small oscillations. |  |
| Low SCL<br>In a low SCL system the voltage will still fall during a fault, however it will experience oscillations as it starts to recover. The voltage will settle down to normal conditions but this will happen slowly and voltage will fluctuate during this period. |  |
| Very low SCL<br>In a very low SCL system, the voltage behaves in a similar manner to the low SCL system, however instead of recovering to normal conditions the oscillation will continue or increase. |  |

Declining SCL can impact operability in several ways:

**Protection**

Lower SCL means protection sees smaller (or different) currents than it was expecting and may not work

**Voltage**

Lower SCL means that voltage moves faster and to a greater extent when there is a disturbance on the system

**Stability**

The lower system strength means that the system may not be able to return to normal operation after a disturbance

**Converters**

The faster moving voltage caused by low SCL can mean that converters may not know what the system is doing and how to respond

# Disclaimer



# Continuing the conversation

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