Study Committee C4

PS3 Challenges and Advances in Power System Dynamics

10204_2022

Implications of Reduced Fault Level and its Relationship to System Strength: A Scotland Case Study

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Motivation

- Fault levels in the Scottish region of the GB transmission system are expected to reduce.
- Fault level metrics are sometimes used synonymously with 'system strength' at a particular point in the network. However, they may not capture the behaviour of Inverter Based Resources (IBR).
- Additional fault level is being procured in the Scottish region of Great Britain (GB). However, with increasing penetration of IBRs, the use of a fault level metric, while it remains related, can become less effective to assess some of the issues classified under the term system strength.

This study has:

- ✓ Reviewed the use of fault level and its relationship with 'System Strength'.
- ✓ Evaluated fault levels in Scotland and the main factors influencing them.
- ✓ Discussed the challenges associated with procurement of fault level to address evolving system needs.

Fault level and how it's changing

- Fault level is a function of the equivalent system impedance (Thevenin) at a given point in the system.
- Provision of fault current is different from synchronous machines or IBRs.

Synchronous Generation	Inverter Based Resources
Voltage source behaviour	Behaves as a controlled current source
High short term current rating	Strict limiting of current to protect electronic components
Can be represented by a voltage source behind an equivalent impedance - based on 50 Hz equivalent	Non-linear current vs. voltage relationship during faults (FRT)
Produces zero sequence and negative sequence components for unbalanced faults	May not produce zero sequence and negative sequence components for unbalanced faults

System strength and established metrics

- The term 'system strength' is often used to describe many new and emerging challenges related to IBRs.
- Easy to find varied definitions of system strength.
- It is often assumed that a low fault level resulting from the use of IBRs means a low system strength and that, in turn, means voltages will be highly sensitive to changes in system operating conditions. However, this does not always follow.
- SCR metrics, based on fault level, have been, to date, the main method to quantify system strength. Various SCR metrics include those in the table below.

Metric (As defined in CIGRE TB 671: Connection of wind farms to weak AC networks, 2016)	Limitations
Short Circuit Ratio (SCR): $SCR = \frac{S_K}{P_n}$ S_K = Fault level P_n = IBR nominal power	Simplistic – does not account for presence of other converters
Weighted SCR: $WSCR = \frac{\sum_i^N S_{K_i} * P_{n_i}}{(\sum_i^N P_{n_i})^2}$ S_{K_i} = short circuit power P_{n_i} = nominal power of new IBR N = number of IBRs (full interaction) i is the IBR index	Aggregate SCR at a common point. Difficult to determine boundaries
SCR with Interaction Factors: $SCRIF_i = \frac{S_{K_i}}{P_{n_i} + \sum_j (IF_{ji} * P_j)}$ IF = change in voltage at bus i for a change in bus voltage at bus j, $IF_{ji} = \Delta V_i / \Delta V_j$	Low track record applying this metric in real world planning or operational practices

- The SCR metrics in use are all based on the equivalent Thevenin impedance at the fundamental frequency.
- Therefore, they may not capture the multi-frequency dynamics in IBR dominated systems.
- Often, a very broad set of potential operational challenges is quantified via the expression of a need for fault level.
- However, not all actions to mitigate 'low system strength' challenges require an increase in fault level, suggesting that the **single term 'system strength' can lead to ambiguity.**

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A need to classify issues

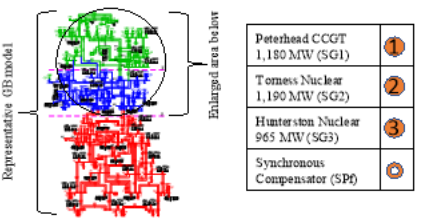
- IBRs are as able as similarly rated SGs to maintain voltages during non-faulted conditions (assuming the converter controls are properly tuned).
- However, IBRs are less able to supply fault currents during a short circuit fault.
- Therefore, a distinction should be made between the issues associated with voltage sensitivity during non-fault conditions, and the issues during fault conditions and a low fault level

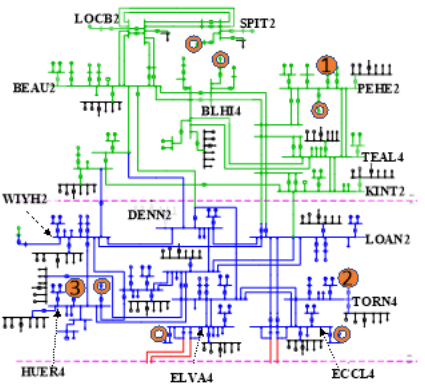
	Fault level	Voltage sensitivity
Description	The ability of the sources within the system to supply sufficient fault current to a short circuit fault.	The ability of the network voltage magnitude to resist changes due to variations in system states, during non-faulted conditions
Metrics	• Short circuit current • Fault level • Retained voltage	• Grid impedance • Voltage sensitivity
System conditions	• During major disturbances • fault inception to fault clearance (voltage outside of statutory range)	Normal operating conditions, including switching, etc., and fault recovery
Example challenges	• Increased severity of a voltage depression • IBR Fault ride through performance • Compromised performance of protection systems	• IBR steady state stability • IBR converter control interaction • Ability to perform voltage control • Quality of service, e.g. voltage flicker.

- The most cost-effective mitigation of high sensitivity of voltage may or may not require an increase in the fault level.
  - E.g. damping control methods for existing or new IBR, or grid forming inverters.
- During a fault, a grid forming converter may utilise a current control mode to limit the current and, like grid following converters, is likely to still provide limited and balanced fault currents only in the positive sequence (depending on the Grid Code).
- Therefore, the grid forming converter might not mitigate a low fault level issue.

Fault levels in the Scottish transmission area

- In response to an expected drop in fault levels in Scotland, the system operator in GB, NGESO, has launched the 'Stability Pathfinder Phase 2' (or SPf2) tender that is seeking new sources of fault current.
- Using a representative model of the GB power system, an independent assessment of fault levels has been performed to gain a better understanding of the nature of the fault level challenge in Scotland.





Case Studies

- A base case day is selected of 4th April 2021, which exhibits low fault levels.
- From this base case, line outages and synchronous generator outages are tested, as well as assessing the effects of the SPf2 on fault levels
- A second case study is the 24th August 2021, when there was a sub-synchronous oscillation (SSO) event in the north of Scotland. During this event, voltages on the 400 kV network oscillated between 355 kV and 435 kV at a frequency of 8 Hz, and some users tripped off the system.

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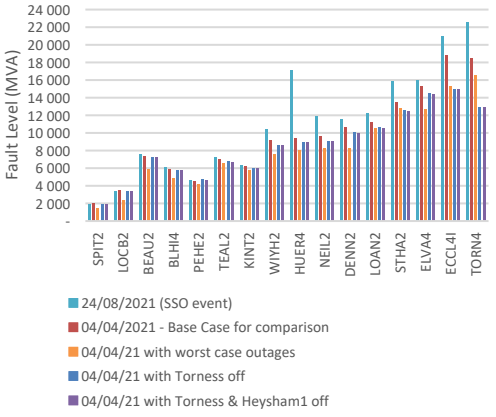
Effects of line and generator outages

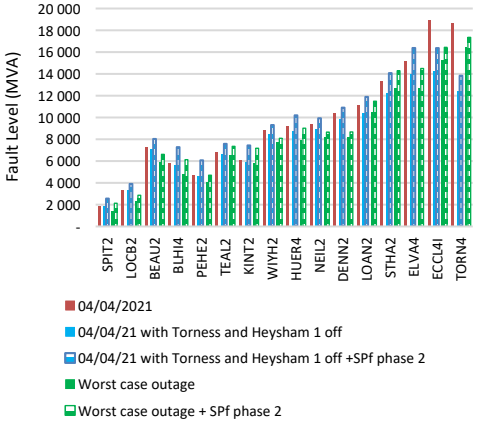


- Outages of main transmission lines can lead to a considerable reduction in local fault levels. In some cases, the outages can reduce the fault levels more than a change in the status of the available large synchronous generating units.
- These cases show that, in some locations, the closure of the main synchronous generating plant in Scotland may not reduce the three-phase fault levels much below those that are already being experienced during credible system conditions.

Fault levels during the 24/08/21 SSO event

- Very low active power generation in the region with the highest oscillations.
- Fault levels were low in some locations, but not below those considered credible (e.g., compared to the 4th April). In fact, faults levels were relatively high in the central Scottish region, compared with the base case, due to local large synchronous generation being online.
- A minimum fault level threshold may not have been a useful indicator / preventative measure for the SSO event. Information on other potential triggers or critical system states has not yet been made publicly available.

Effects of Stability Pathfinder phase2



- Under a worst-case generation dispatch and outage conditions, synchronous compensators added under SPf2 can be seen to increase the fault level throughout the network. However, the increase is marginal and the lowest fault levels remain low.

Conclusions

- A system is commonly described as having "low system strength" either when fault levels are low, or when there is high voltage sensitivity. However, a low fault level at a given location does not necessarily mean that the quasi-steady state voltage sensitivity is high.
- Existing common metrics for system strength, which are based on the fault level, may not properly represent the system's behaviour in the context of high converter penetration. Hence, it is argued that there is a need to make a clearer distinction between low fault level issues and high voltage sensitivity, such that the most cost-effective mitigations can be implemented.
- The closure of the main synchronous generating plant in Scotland may not reduce local fault levels much below those that are already being experienced.
- After the SPf2 tender, fault levels are not increased by a significant amount.
- Analysis suggests little correlation of the oscillation event with low fault level alone, and additional triggers for the event should be identified. Hence, procurement of fault level alone may not be adequate to address some of the operational issues in the Scottish transmission system with further integration of IBRs.