




Assessment of Protection Functionality and Performance with Respect to Declining System Fault Levels and Inertia due to a Significant Increase of Inverter Based Generation on National Grid's Transmission System in the United Kingdom (Transmission Owners perspective)

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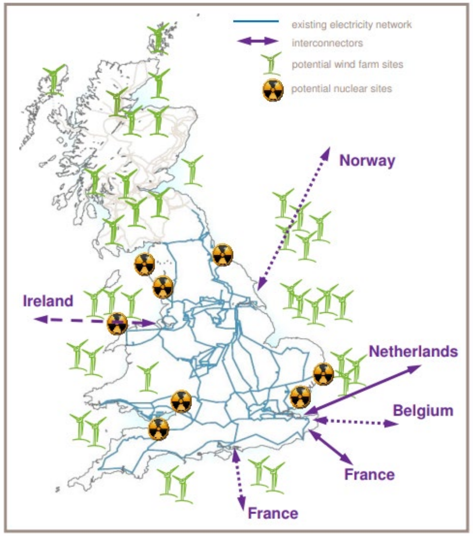
Smart Solutions, Practical Results

Overview

- Renewable Generation Growth in the UK
- Issues
- Impact of declining fault currents on protection
- Mitigation for declining fault current issues
- Impact of declining system inertia on protection
- Mitigation for declining system inertia issues
- Summary

Significant Growth of Inverter Based Generation across the UK

- Peak transmission system demand for UK high summer 2018 to reach around 33.7 GW, with a minimum of 17 GW
- The UK's cumulative solar PV installed now stands at more than 13 GW connected directly to local distribution networks
- The nation is still expected to add a further 1 GW annually for the next few years
- Total installed capacity of wind is approx. 19GW
  - 12GW of onshore capacity and 7GW of offshore capacity
- Wind farms dotted across the U.K. are expected to add an additional 5.7 GW of distributed power to the grid, thus pushing gas and nuclear power further down the line as demand for electricity from centralized power stations wanes. (PV Magazine)



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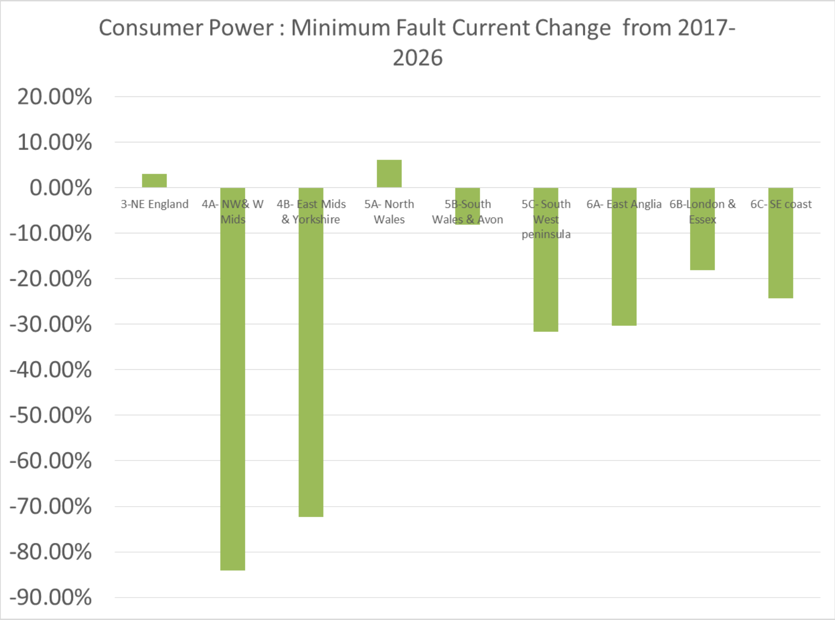
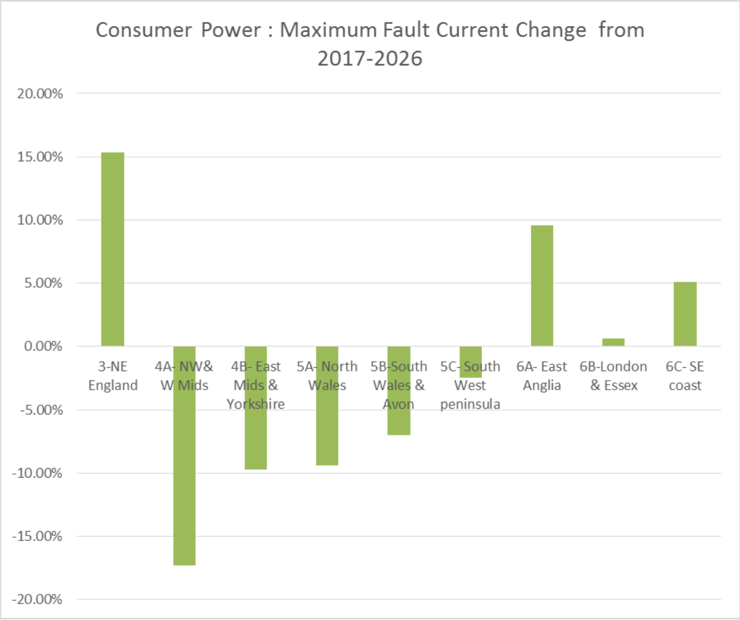
Issue

- Increase of inverter based generation causes changes in fault currents and system inertia:
  - Decline of fault current levels
    - Inverters limit fault current to 1.0-1.5 pu of rated inverter current
  - Decline of system inertia
    - Inverters have no inherent inertia
  - Change of fault current characteristic (needs further work and was only partially addressed in the study)
    - Due to missing or changed zero sequence and negative sequence contribution
    - Fault current determined by manufacturer programmed control algorithm
    - Reliable inverter models for fault current analysis are not available today but in development

Impact of Declining Fault Current Levels on Protection

- Impact on Over Current Protection
  - Minimum fault current is critical for pickup settings in overcurrent functions
  - The overcurrent function is typically used as backup protection or for the supervision of unit (differential) and non-unit (distance) protection
  - During protection studies, the minimum current is determined by selecting an N-1 contingency that provides the lowest fault current
  - Maximum fault current is used for inverse overcurrent elements to determine the correct time dial (time grading) setting





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National Grid Future Energy Scenarios

- Impact on Non-Unit (Distance) Protection
  - Fault current contribution is limited to 1.0-1.5 pu of rated inverter current
  - Source impedance of inverter based generation is higher than classical synchronous generation
  - The source-to-line-impedance-ratio (SIR) is a value that is used by National Grid to determine whether non-unit protection (distance elements) can be used on a particular line.
  - The SIR ratios will increase in relation to the growing amount of inverter-based generation
  - This is important as when the SIR ratio is above 30, non-unit protection becomes unreliable due to that as the accuracy decreases and operating time increases.

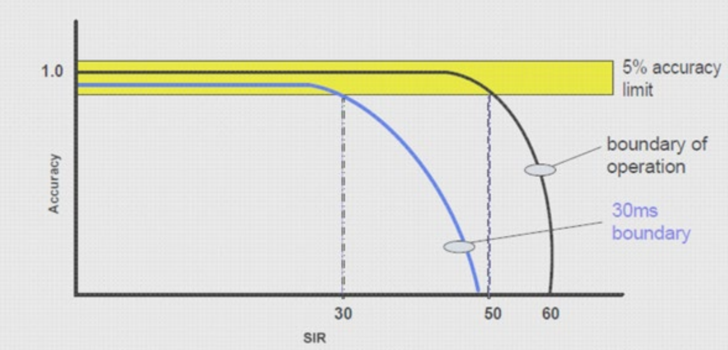

Figure showing the effect of SIR on distance relay performance

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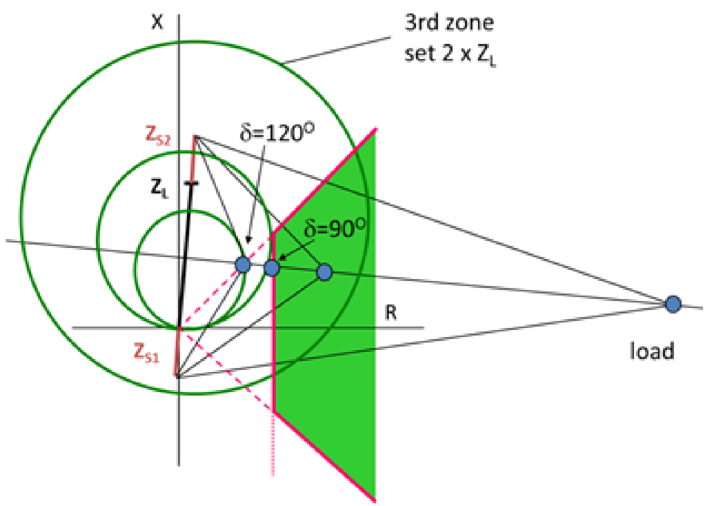
Mitigation of Declining Fault Current Issues

- Revision of Settings
  - It is common practice in some countries, and mandated by regulation in others, that overcurrent protection settings and coordination need to be reviewed if fault currents change above a certain level
  - This project used a minimum fault current change of 10 to 15% as recommended and required by NERC reliability standard PRC-027 and National Grid guidance documentation as a criterion to review and modify the existing relays' settings
- Replacement of Relays
  - In some instances, the revision of settings on existing relays may not be able to mitigate the effect of the decrease in fault current and increase in SIR ratios. In these cases, replacement of protection relays is required

Impact of Declining System Inertia on Protection

- Minimum Fault Clearing Time for Power System Stability
  - The requirements on minimum fault clearing time would have to change, and faster protection operations would be required to maintain stability in power systems with low inertia
  - The existing requirement in the UK for fault clearing time is about 120 to 150 ms
  - Much faster fault clearing times cannot be achieved with the existing protection and breaker equipment
  - Therefore, the system inertia should be maintained at a level that allows for the presently-required fault clearing times.

- Stability during Power Swings
  - After power system events where the load/generation balance is changed temporarily or permanently, the power system must adapt to the new conditions
  - This causes power swings in the system until a new stable operating point is found
  - These swings will be more severe in a system with low inertia. The power swing blocking function may be required in non-unit (distance) protection relays, particularly on long transmission lines where the resistive-reach of the distance element is extended and may cover an area that can be entered by a power swing impedance trajectory



Impact of Declining System Inertia on Protection

- Rate of Change of Frequency (RoCoF)
  - Generator protection functions that use the RoCoF criteria for the detection of islanding conditions to trip the generator must be set with lower sensitivity in order to not misoperate in response to the higher RoCoF values in the future

- Frequency Excursions
  - Wider frequency excursions have the potential to affect relays that do not have an adaptive frequency feature
  - If the protection function is tuned to the fundamental frequency, then a deviation of the power system frequency will create inaccurate results that could lead to under-functions or over-functions of protection relays

Mitigation of Declining System Inertia Issues

- Revision of Settings and/or Configuration of Existing Relays
  - Non-unit line protection relays may require the use of power swing blocking functions to avoid operating on power swing events
  - The settings of RoCoF relays used on generators may need to be reviewed and adjusted to the new system conditions. The settings must be able to securely detect an islanding situation, but not operate for system disturbances that create frequency excursions

- Replacement of Equipment
  - The replacement of equipment must be considered if the system inertia reduces to a level that would not allow the typical fault clearing times of today's equipment

Mitigation of Declining System Inertia Issues

- *Wide-Area-Based Protection and Control System*
  - Relays are set based on predetermined, *static* system conditions that are typically either maximum or minimum
  - However, the configuration of the system constantly changes and may not necessarily be at its maximum or minimum, but somewhere in between, as the system conditions vary due to changing loads, network switching operations, or faults
  - Therefore, the relay settings based on the extreme system conditions may not necessarily result in a correct relay operation for a given system condition in a *dynamic* state
  - The relays that are set to make a trip decision based on synchrophasor measurements constitute a class of adaptive or predictive protective devices

- ***Traveling Wave Protection***
  - The present development of modern traveling wave line protection provides the potential for faster fault detection with higher sensitivity than conventional relay principles
  - Both of these features will be beneficial for system conditions with low inertia
  - The traveling wave relays also offer the advantage of the settings being largely independent of system topology, and would therefore not be sensitive to large shifts in system inertia when blocks of generation are online or offline

System Dynamic Monitoring

- Real-time synchrophasor measurements are already being applied to system monitoring and, eventually, may enhance or even replace the state estimator in system operations
- Tasks associated with visualizing, storing, and retrieving the phasor measurement data are being worked on by the industry, and the application of the synchrophasor measurement technology in the area of system protection is now also a reality
- Time-stamped synchronized measurements offer a tremendous benefit for protective relay applications. These real-time measurements represent actual system conditions at any given time and can potentially be utilized in relay protection

Mitigation of Declining System Inertia Issues

- *Improvements to the Grid Code*
  - *Defining Inverter Requirements*
    Wind generators have the capability to provide inertia to the system as the rotor blade is a rotating mass.
    Today, grid codes do not typically require the contribution of inertia, and, therefore, the wind farm interconnection does not provide the more complex interface that would provide inertia
  - *System Planning/Dispatch*
    Through controlling the penetration level of the Power Electronic Interfaced Power Sources (PEIES), however this will cause the restriction of using renewable energy resources

! However, new regulation may change business benefit for renewable energy and discourage investments

Summary

- Impact of Declining Fault Current Levels on Protection can be mitigated by protection settings revisions
  - However studies are needed to understand impact of Inverter generation and could be ongoing
- In some applications, replacement of protection devices may be needed
  - Potential impact on capital investment and could be too late
- More detailed studies are still needed to determine the impact of changed negative and zero sequence contribution in the fault current
  - Distance loop selection and directional elements may be impacted
- Impact of Declining system Inertia on Protection can only be mitigated with existing equipment if inertia does not fall below critical level

Thank you!

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