NIA Project Annual Progress Report Document

Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total.
Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

Date of Submission

Jul 2024

Project Reference Number

NIA2_NGESO020

Project Progress

Project Title

Strength to Connect

Project Reference Number

NIA2_NGESO020

Project Start Date

October 2022

Project Duration

1 year and 6 months

Nominated Project Contact(s)

Dechao Kong (NGESO)

Scope

This project will develop:

- A Deeper understanding of the intricacies of grid strength: Avoiding sudden disconnection of load or generation because of inadequate system strength is a direct benefit to customers and a core duty of the NGESO. In the more complex world of an IBR-dominated network, this needs to be based on a deep and nuanced understanding of at least four distinct aspects of system strength and a change from the traditional one-size-fits-all approach. On the other hand, an over-cautious approach to system strength could put obstacles in the way of new connections, e.g., wind farms.
- New measures and compatibility levels for system strength: The new measures will allow NGESO to carefully judge the type and volume of service provided and avoid over-or under-provision. Similarly, opening up new service definitions that enable IBRs to provide aspects of strength rather than only traditional generators or synchronous compensators creates downward pressure on costs. Further cost savings can be realised by adjusting compatibility levels so that connecting parties do so at lower system strength where possible and by raising transfer limits (rather than reinforcing) where system strength and voltage regulation were previously considered a limit.
- Further considerations to prepare a plan for the trial of new measurers: The market will need to be prepared to bring forward new service types and resources to achieve these benefits from the project. Stakeholder engagement will help gauge the industry's readiness to provide further services, and a trial plan for the pathfinder projects will be prepared to facilitate the introduction of new services.

Objectives

This project will implement a total of four WPs within a pre-defined timescale and budget plan to:

- Find the best measures to assess each potential problem listed in Section 2.1 and define metrics as replacements or refinements for short-circuit level.
- Investigate the capabilities of IBR and other resources to add strength and methods to improve their abilities to work in low grid strength conditions.
- Verify the analytical results with EMT simulations.
- Propose a method to declare compatibility levels for grid strength and tools for locational metrics, including plotting heat maps showing the compatibility levels of the whole system.

The final outputs should include:

- Project Progress Reports for WPs 1-4 as listed in Section 2.2 (Total 4 Reports).
- Final Project Report as a documented guidance on the assessment of IBR capability to add strength and evaluation on their ability to work in low grid strength (Total 1 Report).
- A tool for locational metrics for compatibility level and heat maps to describe the compatibility of the whole system.
- 2-3 Training sessions and documented training materials concluded from the guidance mentioned above to ensure NGESO and relevant network licensees can independently implement grid strength assessment for those problems as mentioned in 2.1-Problem based on methods/tools developed from this project.
- Knowledge dissemination event(s) for NGESO, other relevant Network Licensees and stakeholders during and after delivery of this project.
- Where relevant, the project will seek to publish in well-recognised international journals and at conference events.

Success Criteria

The following will be considered when assessing whether the project is successful:

- Properly defined levels of grid strength for the four potential problems as mentioned in 2.1 - Problem.
- Properly defined levels to declare compatibility levels for grid strength.
- A developed tool for locational compatibility levels metrics and heat maps to describe compatibility of the whole system.
- Guidance on IBR capability to add strength and an evaluation on their ability to work in low grid strength.

Performance Compared to the Original Project Aims, Objectives and Success Criteria

National Grid Electricity System Operator (“NGESO”) has endeavoured to prepare the published report (“Report”) in respect of Strength to Connect, NIA2_NGESO020 (“Project”) in a manner which is, as far as possible, objective, using information collected and compiled by NG and its Project partners (“Publishers”). Any intellectual property rights developed in the course of the Project and used in the Report shall be owned by the Publishers (as agreed between NG and the Project partners).

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At present, this project is delayed due to prioritising the investigation into recent on-going system dynamic performance issues. Grid strength is decreasing in some regions in the GB system as thermal power plants with synchronous generators (SGs) are decommissioned in favour of inverter-based resources (IBRs) in the drive to meet the UK's net-zero targets. There are four emerging problems: substandard voltage regulation, increased recovery times from voltage dips, potential instability of grid-following inverters, and mal operation of protection. Conventionally used short-circuit level (SCL) or short-circuit ratio (SCR) may no longer a good all-purpose indicator because IBRs have different disturbance behaviours.

Each problem needs a separate assessment the future electricity system with a high penetration of IBRs or IBR-dominance. The composition of SCL and SCR may also need to be re-examined and potentially expanded to incorporate the input from IBRs. The “Strength to Connect” project aimed to examine what measures (small signal impedance, synchronising power, over-load current) best indicate stable and secure operation for each known type of network disturbance. The project originally comprised of four working packages, but these have been combined to form 2 work packages.

The two Working Packages (WPs) comprised:
WP1: Grid Strength Assessment and Small Signal Stability Metric
Objective: To review potential metrics for assessing system strength concerns and develop a metric for small signal stability.
Duration: 12 months
Activities and Steps Taken:
Comprehensive Review of System Strength Measures:
Conducted a thorough literature review to identify existing metrics and methodologies.
Engaged with industry experts and stakeholders to gather insights and practical experiences.
Classification of System Strength Measures:
Classified system strength measures into small-signal and large-signal categories based on their characteristics.

Developed a framework to clearly differentiate between the impacts of small and large disturbances on system strength.

Development of New Metrics:

Created the Impedance Margin Ratio (IMR) to indicate small-signal system strength, focusing on stability against oscillatory behaviours and small-signal instability.

Proposed the Type-Dependent Short-Circuit Ratio (TDSCR) to address large-signal system strength, assessing the system's ability to recover from significant disturbances like short-circuit faults.

Evaluation and Validation:

Conducted simulations and practical tests to validate the effectiveness of IMR and TDSCR.

Delivered a detailed report summarizing the findings, methodologies, and implications for system strength assessment.

WP2: Evaluation of System Strength Metrics for Large Signal Stability

Objective: To assess the short-circuit contributions of IBRs and develop improved methods for measuring system strength beyond traditional SCL and SCR.

Duration: 14 months

Activities and Steps Taken:

Review of Large Disturbance System Strength Metrics:

Evaluated existing metrics and their applicability to systems with high IBR penetration.

Identified gaps and limitations in current methodologies.

Quantification of IBR Short-Circuit Contributions:

Analysed the short-circuit current contributions from various types of IBRs.

Assessed how these contributions alter the SCR values and overall system strength.

Investigation into System Strength Information:

Explored the capability of short-circuit current to provide meaningful information about system strength.

Developed new approaches to quantify and utilize this information effectively.

Development of a Detailed EMT Model:

Created a detailed electromagnetic transient (EMT) model to simulate and evaluate the dynamic behaviour of the system under large disturbances.

Used the EMT model as a benchmark testing platform for new metrics.

Evaluation and Comparison of Metrics:

Evaluated the performance of the new large-signal system strength metrics against traditional SCR.

Conducted comparative analysis to determine the suitability of new metrics in various scenarios.

Report and Recommendations:

Compiled findings into a comprehensive report, providing recommendations for future metric adoption and system strength assessment.

Delivered the EMT model and associated documentation for further use and validation by stakeholders.

The project has already made significant contributions towards avoiding sudden disconnections of load or generation due to inadequate system strength. This is a direct benefit to customers and a core responsibility of the Electricity System Operator (ESO). In an IBR-dominated network, a deep and nuanced understanding of system strength is essential, avoiding the pitfalls of traditional one-size-fits-all measures and over-cautious approaches that could hinder new connections, such as wind farms.

Current Status and Future Tasks

WP1 has been completed, establishing a foundation for assessing system strength specific to small and large disturbances. WP2 is currently underway, with tasks including:

Review and Development of Large Disturbance System Strength Metrics:

Continual evaluation of large-signal system strength metrics.

Quantification of IBR Short-Circuit Current and its Impact on SCR Values:

Ongoing analysis of IBR contributions to short-circuit current and their effects.

Investigation into the Ability of Short-Circuit Current to Provide System Strength Information:

Further exploration of new approaches and methodologies.

Development of a Suitable EMT Model:

Continued refinement and testing of the EMT model for large-signal system strength evaluation.

Evaluation and Comparison of Large Signal System Strength Metrics Against Standard Metrics (SCR):

Ongoing comparative analysis to determine the effectiveness of new metrics.

The progress made in WP1 indicates that the project's expected benefits are likely to be achieved. WP2 is working towards finding the most suitable metrics for assessing system strength in various contexts, potentially replacing traditional SCL and SCR measures.

This project is now due to complete in August 2024 because of the prioritization of investigations into the on-going system performance issue.

Overall, the project will have provided a deeper understanding of system strength and made significant progress into proposing and evaluating new metrics.

It is expected that there will be several parts that will be implemented into BAU for the ESO or that could be developed further. The first part that is expected to become BAU implementation will be improved calculation of short circuit current that is provided by IBRs, along with a corresponding index that can be used to assess the system strength for certain aspects at different locations within the system based on the short circuit calculation.

Required Modifications to the Planned Approach During the Course of the Project

The "Strength to Connect" project has faced delays due to prioritizing investigations into recent system dynamic performance issues. This reprioritization has prompted necessary modifications to the original planned approach to address emerging challenges associated with decreasing grid strength, driven by the decommissioning of thermal power plants in favour of inverter-based resources (IBRs).

Initially, the project was divided into four work packages (WPs). However, to streamline efforts and respond more effectively to the evolving grid dynamics, these have been consolidated into two comprehensive WPs. WP1 focused on assessing potential metrics for system strength and developing a new small-signal stability metric, the Impedance Margin Ratio (IMR). This task has been successfully completed, setting a strong foundation for the project's subsequent phases.

WP2, currently underway, involves evaluating system strength metrics for large signal stability. This includes reviewing and developing new metrics for large disturbances, quantifying IBR short-circuit contributions, and investigating the validity of traditional short-circuit ratio (SCR) values. The development of an Electromagnetic Transients (EMT) model to benchmark these metrics is also a critical component of WP2. A significant modification to our approach has been the reassessment of using short-circuit current and SCR values when incorporating IBR components. This reassessment aims to determine if these traditional metrics can still provide reliable information on system strength in a high IBR penetration context. This modified approach will serve as a benchmark for evaluating new metrics going forward.

Despite the project's delays, significant progress has been made towards achieving the goals of WP2. The development of the EMT model and the evaluation of large signal system strength metrics are advancing well. This project is now scheduled to complete in August, with several components expected to be integrated into business-as-usual operations for the Electricity System Operator (ESO). The enhanced calculation of short-circuit current provided by IBRs and the corresponding index for assessing system strength are likely to be among the first outcomes to be implemented.

In summary, the project has adapted to emerging challenges by consolidating work packages and reassessing traditional metrics, ensuring it remains on track to deliver innovative solutions for the GB power grid's evolving needs.

Lessons Learnt for Future Projects

WP1 set out to find the best system strength metrics to assess each potential problem as replacements or refinements for short-circuit level.

During WP1, measures of system strength were fully reviewed and newly classified as a small-signal system strength and large-signal system strength based on the different characteristics. Such classification separates the problems under study, making explicit difference in strength evaluation towards different problems. This is recognised as a milestone of this project and influences the way the project is going to proceed in the following WPs, i.e., studies on small-signal system strength and large-signal system strength will be carried out in parallel. A new metric to indicated strength in terms of avoidance oscillatory behaviours and small-signal instability is described as small-signal system strength metric and named Impedance Margin Ratio (IMR). Accordingly, a new metric to address large-signal system strength, which is the ability of a system to recover well from large disturbance such as a short-circuit fault at a given node, named as type-dependent short-circuit ratio (TDSCR) was proposed. This progress also leads the direction for WP2, in which the service that an IBR can provide to add strength will be investigated.

One of the three expected benefits of this project was stated as:
Avoidance of sudden disconnection of load or generation because of inadequate system strength is a direct benefit to customers and a core duty of the ESO. In the more complex world of an IBR dominated network, this needs to be based on a deep and nuanced understanding of at least four distinct aspects of system strength and the putting aside of the traditional one-size-fits-all measures. On the other hand, an over-cautious approach to system strength could put obstacles in the way of new connections of, for instance, wind farms.

Overall, The work conducted in WP1 and WP2 has made a significant contribution toward this benefit already through analysing system strength in ways specific to small and large disturbances. The new metrics for system strength offer a way of assessing the system voltage stiffness towards different dynamics: small perturbations which can cause voltage oscillations, and large perturbations which can cause voltage dips, so that ESO can carefully judge whether newly connected devices can increase the risk of system being unstable and discover the 'weak point' in the system. Overall, the progress made in WP1 indicating that the expected benefits are likely to be achieved.
There are also several points that warrant further exploration:
The TDSCR is a variant of, and an expected improvement on SCR but it does not consider the interactions among adjacent IBRs during large disturbances. To include the interactions, the principles of ESCR could be adapted but the types of the interreacting IBRs will need to be considered, i.e., different combinations of voltage-type and current-type sources in electrical proximity. Such an extension of TDSCR will be an item of further work within "Strength to Connect"

Further, TDSCR treats IBR as an ideal source (voltage to current) with an associated impedance but omits the internal control design of the IBR. The influence of PLL, droop controller and other control loops should be included to study the interactions among IBRs in large-signal conditions in a more accurate way.
The situation that the limited fault current IBR (low fault-current system strength) may lead to mal-operation of protection and failure to properly clear faults has not yet been discussed. This needs to be included in future work.

Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

The project has achieved several outputs to date. WP1 has been completed and WP2 is nearing completion at the time of reporting. The learning to date from the project has been disseminated through:

1) ESIG 2023 Spring Technical Workshop, 29/03/2023 Tucson, AZ, US.
2) 2023 ESO External Engagement Webinar - System Operability Framework (SOF) Development, 27/04/2023 Faraday House, Warwick, UK.
3) Technical report for the ESO covering WP1
4) IEEE Transactions on Power Systems publication: Impedance Margin Ratio: a New Metric for Small-Signal System Strength
5) Knowledge exchange with proposed SIF projects to incorporate the learnings from this project
6) Method for evaluating short circuit contribution from IBRs shared with the ESO via recurring project progress review

All of the reports will be made available on the Smarter Networks Portal.

Data Access

Details on how network or consumption data arising in the course of NIA funded projects can be requested by interested parties, and the terms on which such data will be made available by National Grid can be found in our publicly available "Data sharing policy related to NIC/NIA projects" and www.nationalgrideso.com/innovation.

National Grid Electricity System Operator already publishes much of the data arising from our NIC/NIA projects at www.smarternetworks.org. You may wish to check this website before making an application under this policy, in case the data which you are seeking has already been published.

Foreground IPR

The following reports are expected to be released on to the Smarter Networks Portal:

- Technical reports on each working package which will give detailed introduction and analysis on the issues being studied and solutions that have been provided.
- Matlab codes for new system strength calculation.
- Presentation slides that have been given in public.