# 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 2023

### 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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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) is no longer a good all-purpose indicator because IBRs have different disturbance behaviours. Each problem needs a separate assessment for a future electricity system with a high penetration of IBRs or IBR-dominance.

"Strength to Connect" project aims 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 will be implemented following the four Working Packages (WPs) listed in the Objectives section and repeated here:

- WP1: Grid Strength Assessment - To find the best measures to assess each potential problem and define metrics as replacements or refinements for short-circuit level (9 months).
- WP2: Capability Investigation - To investigate the capabilities of IBR and other resources to add strength, as well as methods to improve their capabilities to work in low grid strength (4 months).
- WP3: EMT Simulations - To verify the analytical results with EMT simulations (4 months).
- WP4: Compatibility Levels - To 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 (4 months).

At the time of reporting WP1 has been completed and WP2 is being initiated. In WP1, the flowing items have been investigated and analysed:

1. The concept of system strength has been reviewed and a distinction has been drawn between small-signal system strength and large-signal system strength.
2. The traditional metric of SCR and new metrics including CSCR, WSCR, ESCR, GSIM were reviewed in terms of their definitions and features, and analysed to establish their pros and cons.
3. Since existing metrics were found to capture only local interactions between IBR, or, in the case of GSIM are system-wide but do not include the dynamics of the connecting IBR, a proposal has been made to establish a new metric to indicated strength in terms of avoidance of oscillatory behaviours and small-signal instability. It is described as small-signal system strength metric and named Impedance Margin Ratio (IMR). It is a whole-system assessment that accounts for the dynamics of apparatus at all nodes, local and remote to the node in question. A modified IEEE-14 bus system was employed to demonstrate the effectiveness of IMR in indicating onset of small-signal instability and instances of poor mode damping.
4. To address large-signal system strength, which is the ability of a system to recover well from a large disturbance such as a short-circuit fault at a given node, a new metric name type-dependent short-circuit ratio (TDSCR) was proposed. It extends the principles of SCR to account properly for the current-source nature of some IBR in system, GFL IBR in particular, and to account for the voltage source nature of GFM IBR even if their traditional fault current capability is limited. A 4-bus example system was employed to illustrate the effectiveness of TDSCR in recognising the contribution of IBR to large-signal system strength.

The progress that has been made fulfils the original goals of WP1, i.e., to find the most suitable metric for system strength towards different issues, as replacement for SCL/SCR.

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

No modifications have been required to the planned approach to date.

## Lessons Learnt for Future Projects

WP1 aims 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:

1. 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.

The work conducted in WP1 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:

1. 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”.
2. 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.
3. 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.

In addition to progressing the further work identified here, the “Strength to Connect” team will now progress to WP2 in which the services which IBR can provide to the system to increase the strength will be investigated. This prepares the way for implementation of

new system services and new means of maintaining adequate system strength in normal business operation

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 progress made in WP1 has already benefited some researchers and engineers from academia and industry in creating a better understanding of system strength assessment.
A detailed technical report has been compiled to describe the work of WP1. An academic paper on the new metrics is being drafted and with the aim to submit in the following months. In addition, the progress of WP1 has been demonstrated by Dr Yue Zhu in the following events/conferences as invited speaker:

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.

## 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/SIF projects on the Smarter Networks Portal (www.smarternetworks.org) and National Grid ESO Data Portal (data.nationalgrideso.com). You may wish to check these websites 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:

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