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.

NIA Project Registration and PEA Document

Date of Submission

Aug 2022

Project Reference Number

NIA2_NGESO020

Project Registration

Project Title

Strength to Connect

Project Reference Number

NIA2_NGESO020

Project Licensee(s)

National Energy System Operator

Project Start

October 2022

Project Duration

1 year and 6 months

Nominated Project Contact(s)

Dechao Kong (NGESO)

Project Budget

£350,000.00

Summary

Short Circuit Level (SCL) is the standard measure of Grid Strength to indicate the electricity system's stability. However, Grid "strength" is decreasing in some regions of the GB system with a steady reduction of thermal power plants and increasing integration of Inverter-Based Resources (IBRs) in the drive to meet the UK's net-zero targets.

Consequently, various problems are starting to emerge such as: substandard voltage regulation, increased recovery times from voltage dips, potential instability of grid-following inverters, and protection faults. Short circuit level is no longer viewed as a good all-purpose indicator due to the different disturbance behaviours of inverter-based resources. Hence, this project will explore appropriate alternatives to short circuit level to measure Grid Strength in the future GB system, particularly with high penetration or dominance of IBRs.

Third Party Collaborators

Imperial College London

Nominated Contact Email Address(es)

box.so.innovation@nationalgrid.com

Problem Being Solved

Short Circuit Level (SCL) is a Standard Measure of Grid Strength to indicate the electricity system's stability. Grid "strength" is decreasing in some regions in the GB system with two key features: 1) a steady reduction of thermal power plants; 2) increasing integration of Inverter-Based Resources (IBRs) in the drive to meet the UK's net-zero targets. Due to those two features, they will potentially cause four emerging problems [1]:

1. Poorer voltage regulation
2. Poorer recovery times from voltage dips
3. Possible instability of predominant grid-following inverters
4. Maloperation of protection

However, SCL is no longer a good all-purpose indicator because IBRs have different disturbance behaviours (small and large). Moreover, Phase-Locked Loop (PLL) stability and voltage recovery also exhibit distinct features of grid strength. GB Connecting parties (onshore/offshore wind farms, HVDC interconnectors, battery storage) need detailed but digestible information and guarantees on grid strength, so they can design connections to meet grid codes and constraint limits, e.g. stability.

Additionally, this raises costs issues, as setting the grid strength guarantee (the compatibility level) too high puts a cost burden on National Grid ESO (NGESO) to provide strength services. Moreover, setting the guarantee too low puts a cost burden on connecting parties to make equipment compliant. Hence, each problem needs a separate assessment for the future GB electricity system with a high penetration of IBRs or IBR dominance.

[1]: National Grid ESO System Operability Framework Document "Impact of Declining Short Circuit Levels"

Method(s)

"Strength to Connect" will examine what measures (small-signal impedance, synchronising power, over-load current) best indicate stable and secure operation for each known type of network disturbance. It will test the measures analytically and on simulation of an example network with varying levels of inverter-based resources.

The opposite side is the strength services that IBR, Synchronous Compensators etc., can provide. This project will analyse how well each resource mitigates each stability problem, and a simulated example network will be used to verify the analysis.

This project will consist of the following four Work Packages (WPs) as listed below:

WP1: Grid Strength Assessment

As mentioned previously, SCL is no longer a good all-purpose indicator of grid strength. Since IBRs have different large and small disturbance behaviours, and PLL stability and voltage recovery measure different aspects of grid strength. This first work package will deepen our understanding of how each potential problem is influenced by grid strength and determine which candidate metrics give a more precise indication of problem onset than SCL. The following research areas have been identified:

- A candidate indicator is a small-signal impedance for stability issues caused by PLL, as measured by dv/di.
- The equivalent synchronising torque and large-signal impedance are promising for the angle stability of grid-forming inverters and grid-following inverters.
- For voltage collapse and recovery issues, a V against P&Q "nose" plots and current-overload availability could be used.
- For issues caused by low fault-current and maloperation of protection, the actual short circuit current with more detailed information (e.g., magnitude and phase angle, positive- and negative-sequence components, etc.) can be used as metrics to assess the strength of this.

Alongside general results from analytical methods, case study grids (using IEEE test systems modified to include IBR) will be analysed to compare and contrast the strength metrics for each problem.

WP2: Capability investigation

In this work package, the project team will investigate the capabilities of IBR and other resources to add strength to the grid. Furthermore, an analysis of how well each resource mitigates each stability problem will be carried out. Hence, the second work package will:

- Assess the ability of various IBR control structures to enhance system strength, including types of voltage and reactive-power droop settings on both grid-forming and grid-following IBR.
- Assess the influence of various amplitudes and arrangement of IBR current-limit, including more sophisticated considerations of d- and q-axis currents, current angles, virtual impedances, etc., on system strength metrics.
- Assess the capabilities of other power electronic apparatus (e.g., STATCOM - Static Synchronous Compensator) to add strength.
- Map the capabilities of IBR and other resources to the four measures listed in WP1 to understand the mechanisms by which IBRs enhance grid strength and identify ways of mitigating each type of stability problem with the help of IBR.

- Analysis of how to balance the cost of maintaining a high grid strength against improving the ability of IBR to operate with low grid strength

The case-study networks from WP1 will be utilised in this analysis.

WP3: EMT simulations

Electro-Magnetic Transient (EMT) simulations will verify the analytical results in this work package. The EMT simulation is helpful for the transient and nonlinear analysis, which are the primary focuses of this project. The potential simulation software is MATLAB and Simulink. Besides, with the increased complexity of the system, a standard PC may not be capable of handling the simulation, so an OPAL-RT real-time simulator together with RT-LAB could be employed to carry out large-scale simulations. PSCAD, a widely used tool in industries, is also considered a candidate software. Three sets of simulations should be fulfilled, as below:

- The project team will build a case-study network in the simulator software. Candidates for this are the IEEE 39-bus transmission network, NETS-NYPS 68-bus network and the reduced GB 36-bus network. This ensures the simulations are consistent with a standard transmission network, offering credible results. Additionally, it guarantees the steady-state characteristics can be verified from power flow, and the dynamics can be verified from the eigenvalue plot.
- The standard model will then be modified to exhibit the different stability problems arising from low grid strength. Modifications will include line outages that increase impedance and substituting synchronous machines for the grid following IBR. The newly defined metrics (dv/di, large-signal impedance) will be assessed for their ability to predict the onset of instability and appropriate countermeasures. Four case studies showing four types of stability problems will be demonstrated. This series of simulations will be used to verify the analysis in WP1.
- Simulations will be carried out on the capabilities of IBR (including grid-forming capability) and STATCOM to add strength. This is to verify the capability analysis in WP2. The results are intended to show that by introducing a well-designed IBR, the four stability problems can be mitigated, and the strength can be improved.

The accuracy of simulations is influenced by two factors mainly: a) software solver; b) physical models. The numerical calculation algorithm of software determines the former factor; the latter aspect is determined by how the physical and control features of power apparatuses, lines, etc., are modelled. Cross-verification between two or more software suites (e.g., PSCAD and MATLAB/Simulink) could be used to validate analytical results further if resources permit.

WP4: Compatibility levels

Challenges arising from low grid strength can be addressed in three ways:

1. By changing or expanding grid equipment, such as adding STATCOMS or changing protection relays, from the grid side;
2. On the inverter side, by delivering a service such as a change to grid forming operation and;
3. Immunising against low grid strength by re-tuning vulnerable control functions such as PLL.

All three approaches have implications for local and system costs, and the objective is to find a system design that leads to minimum system cost. Thus, the following steps will be taken:

- Costs will be specified using a proxy for monetary costs, such as the apparent power rating of the additional equipment. For instance, modifying a grid following IBR to grid-forming to raise system strength attracts charges in extra control capability but also in physical terms, such as the need to expand the current rating of inverters. Also, in economic terms, if an operation below the optimal dispatch point is needed.
- Various "compatibility levels" will be tested for each metric. For example, a value of small-signal impedance could be declared as a maximum for the system. If so, what costs would the system bear adding equipment to keep the impedance below the compatibility level, and what costs would connecting parties pay in configuring a wind farm, for instance, to operate with grid impedances up to that compatibility level. Such considerations will be made to assess ways of declaring compatibility levels.
- Compatibility levels for grid strength are likely to be locational, so proposals will be made to express these, such as plotting heat maps showing the compatibility levels across the system.

In line with the ENA’s ENIP document, the risk rating is scored Low.

TRL Steps = 2 (3 TRL steps)

Cost = 1 (£350k)

Suppliers = 1 (1 supplier)

Data Assumptions = 2

Total = 6 (Low)

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.

Objective(s)

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.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

NGESO does not have a direct connection to consumers, and therefore is unable to differentiate the impact on consumers and those in vulnerable situations.

This project has been assessed as having a neutral impact on customers in vulnerable situations because it is a transmission project.

Benefits to all consumers are detailed below.

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.

Project Partners and External Funding

Imperial College will be carrying out the work, no external funding required.

Potential for New Learning

This project will develop understanding of:

- How to assess grid strength for the emerging problems highlighted in 2.1 - Problem, relevant to high potential penetration of IBRs or IBR-dominance.
- How to develop a fit-for-purpose and cost-effective grid strength standard instead of the one-size-fits-all approach to short circuit level.
- Determine the need for grid strength in a particular location and how to assess this without comprehensive EMT simulation.
- How to efficiently use system services to deliver appropriate grid strength instead of an all-encompassing short-circuit level.

Scale of Project

The project spans 18 months with one project partner. The project consists of desktop-based research and workshops with the relevant teams across NGESO.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

We will be based upon the GB ESO area of operations.

Revenue Allowed for the RIIO Settlement

None

Indicative Total NIA Project Expenditure

£350,000

Project Eligibility Assessment Part 1

There are slightly differing requirements for RIIO-1 and RIIO-2 NIA projects. This is noted in each case, with the requirement numbers listed for both where they differ (shown as RIIO-2 / RIIO-1).

Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations (Please complete sections 3.1.1 and 3.1.2 for RIIO-2 projects only)

Please answer **at least one** of the following:

How the Project has the potential to facilitate the energy system transition:

- The project will help NGESO and other relevant network licensees to improve their understanding of the intricacies of grid strength. Thus, ensuring that grid strength levels can be tailored to operational circumstances and services as strictly needed are procured to maintain secure and reliable operation. Doing so will help reduce relevant operational and investment costs for GB's energy system transition, particularly when introducing decentralised and decarbonised IBR technologies/applications within and in connection to the GB electricity system.
- This project can potentially reduce constraints on connections of decentralised and decarbonised IBR installations and boundary flows with refined definitions of limits to help the GB energy system transition towards Net-Zero.
- This project will prepare the market for a trial deployment in a pathfinder project by raising awareness of services likely to be needed. If the trial is successful, then learning from this trial can be rolled out for business model evolution of the GB market, ensuring accuracy and transparency of services as procured to facilitate GB energy system transition.

How the Project has potential to benefit consumer in vulnerable situations:

n/a

Requirement 2 / 2b

Has the potential to deliver net benefits to consumers

Project must have the potential to deliver a Solution that delivers a net benefit to consumers of the Gas Transporter and/or Electricity Transmission or Electricity Distribution licensee, as the context requires. This could include delivering a Solution at a lower cost than the most efficient Method currently in use on the GB Gas Transportation System, the Gas Transporter’s and/or Electricity Transmission or Electricity Distribution licensee’s network, or wider benefits, such as social or environmental.

Please provide an estimate of the saving if the Problem is solved (RIIO-1 projects only)

N/A

Please provide a calculation of the expected benefits the Solution

Not required as research project.

Please provide an estimate of how replicable the Method is across GB

- In terms of short-term urgency, NGESO will work closely with relevant transmission licensees to scan for suitable candidate regions in the GB Transmission Networks, e.g., areas with relatively high levels of IBR integration. Doing so will help validate whether the methodologies and tools to be developed are cost-effective for grid strength-related risk management in those regions.
- Once the methodologies and tools are validated, they will be implemented across the electricity system, including transmission and distribution networks. Training will also be provided to ensure that all network licensees can use the tools and methodologies in other identified risk areas.

Please provide an outline of the costs of rolling out the Method across GB.

The method will be run for GB and Western Europe.

Requirement 3 / 1

Involve Research, Development or Demonstration

A RIIO-1 NIA Project must have the potential to have a Direct Impact on a Network Licensee’s network or the operations of the System

Operator and involve the Research, Development, or Demonstration of at least one of the following (please tick which applies):

☐ A specific piece of new (i.e. unproven in GB, or where a method has been trialled outside GB the Network Licensee must justify repeating it as part of a project) equipment (including control and communications system software).

☐ A specific novel arrangement or application of existing licensee equipment (including control and/or communications systems and/or software)

☐ A specific novel operational practice directly related to the operation of the Network Licensees system

☐ A specific novel commercial arrangement

RIIO-2 Projects

☐ A specific piece of new equipment (including monitoring, control and communications systems and software)

☐ A specific piece of new technology (including analysis and modelling systems or software), in relation to which the Method is unproven

☑ A new methodology (including the identification of specific new procedures or techniques used to identify, select, process, and analyse information)

☐ A specific novel arrangement or application of existing gas transportation, electricity transmission or electricity distribution equipment, technology or methodology

☐ A specific novel operational practice directly related to the operation of the GB Gas Transportation System, electricity transmission or electricity distribution

☐ A specific novel commercial arrangement

Specific Requirements 4 / 2a

Please explain how the learning that will be generated could be used by the relevant Network Licensees

- The increasing penetration of IBRs are into the GB's transmission/distribution networks will be a common issue across Network Licensees in the future.
- Tangible deliverables will include final technical reports and publications, e.g., conference/journal papers, which will be shared with the Network Licensees.
- During and after project delivery, all relevant Network Licensees will be invited for a series of knowledge dissemination events based on work-package deliverables.
- The relevant Network Licensees will then be invited to training opportunities on the developed tools and methods.

Or, please describe what specific challenge identified in the Network Licensee's innovation strategy that is being addressed by the project (RIIO-1 only)

n/a

Is the default IPR position being applied?

☑ Yes

Project Eligibility Assessment Part 2

Not lead to unnecessary duplication

A Project must not lead to unnecessary duplication of any other Project, including but not limited to IFI, LCNF, NIA, NIC or SIF projects already registered, being carried out or completed.

Please demonstrate below that no unnecessary duplication will occur as a result of the Project.

The project's first phase will include a thorough literature review and scanning of other relative projects. Initial research indicates that previous methods have developed more accurate representations of SCL in the GB system. However, they have not considered an appropriate alternative to SCL to measure grid strength in the future GB system, particularly with high penetration or dominance of IBRs. Hence, the proposed project will be the first of its kind.

If applicable, justify why you are undertaking a Project similar to those being carried out by any other Network Licensees.

N/A

Additional Governance And Document Upload

Please identify why the project is innovative and has not been tried before

Previously, methods have developed more accurate representations of SCL in the GB system. However, this project will be the first to consider an appropriate alternative to SCL to measure grid strength in the future GB system, particularly with high penetration or dominance of IBRs, supporting the UK government's ambitious targets for Net Zero by 2050.

Relevant Foreground IPR

The following Foreground IPR will be generated from the project:

- 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.

Data Access Details

Data for this project and all other projects funded under the Network Innovation Allowance (NIA), Network Innovation Competition (NIC) or the new Strategic Innovation Fund (SIF) can be found or requested in a number of ways:

1. A request for information via the Smarter Networks Portal at https://smarter.energynetworks.org, to contact select a project and click ‘Contact Lead Network’. National Grid ESO already publishes much of the data arising from our innovation projects here so you may wish to check this website before making an application.
2. Via our Innovation website at https://www.nationalgrideso.com/future-energy/innovation
3. Via our managed mailbox innovation@nationalgrideso.com

Details on the terms on which such data will be made available by National Grid ESO can be found in our publicly available “Data sharing policy relating to NIC/NIA projects” at https://www.nationalgrideso.com/document/168191/download

Please identify why the Network Licensees will not fund the project as apart of it's business and usual activities

As this project is early-stage research and development with high levels of uncertainty and risk, this does not fall into the scope of BAU activities.

Please identify why the project can only be undertaken with the support of the NIA, including reference to the specific risks(e.g. commercial, technical, operational or regulatory) associated with the project

The TRL of the overall framework is relatively low. Therefore, innovation funding is more suitable for exploring the project's potential and increasing the TRL before transferring into BAU activities.

Conducting this project with NIA funding will ensure that the project findings can be shared more widely with other interested network licensees in TO/DNO, as it will be a common issue when increasing IBRs are integrated into the GB's transmission/distribution networks in the future

This project has been approved by a senior member of staff

☑ Yes