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## NIA Project Registration and PEA Document

### Date of Submission

Sep 2019

### Project Reference Number

NIA\_NGTO038

## Project Registration

### Project Title

Economic Ageing of Transformers

### Project Reference Number

NIA\_NGTO038

### Project Licensee(s)

National Grid Electricity Transmission

### Project Start

October 2019

### Project Duration

1 year and 10 months

### Nominated Project Contact(s)

Gordon Wilson

### Project Budget

£544,000.00

## Summary

Transformers limit 38% of all circuits in the England and Wales electrical transmission network, and ultimately limit transmission boundary power flows. Where there is a need to remove network constraints, investment in increased capacity is necessary, this project seeks to investigate whether increased capacity at the same time as allowing an increased rate of transformer ageing could be justified economically.

Transformers are rated using a tool called TRALC3, which has been developed within NGET over the course of many years (original work was conducted by the Central Electricity Generating Board). The nameplate rating is determined on the basis of the maximum load which could be applied, under certain environmental conditions, to achieve the desired life expectancy of the transformer. This means solving a thermal model, on the basis that the operating temperature of the insulation is one of the primary factors which determine the rate of ageing of a transformer. For the majority of the time, the load on the transformer is less than 75% of its nameplate rating. This means that the insulation system within the transformer ages more slowly than its standard life expectancy would suggest. However, under emergency scenarios they can carry up to 150% of their maximum rating.

National Grid is interested in investigating methods of 'uprating' transformers at specific points in the network where investment is likely to replace the assets in the short to medium term, allowing constraints to be removed earlier. This creates a more competitive electricity market and would allow National Grid to meet a key challenge, which is getting new customers (i.e. generators or major loads) connected sooner and/or with less ponderous investments in the expansion of the infrastructure. This project seeks to investigate how this could be achieved, with a focus on quantifying the potential economic benefits that could be realised using such an approach. This has the potential to lead to novel commercial arrangements in the future, once the underlying technical and economic drivers can be adequately assessed.

### Nominated Contact Email Address(es)

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## Problem Being Solved

Transformers could be aged more rapidly by loading them beyond normally accepted limits, therefore enabling the benefit of increased boundary power flows in the short term. In scenarios where the assets are likely to be replaced earlier in their life (i.e. their insulation system might not be life expired upon decommissioning), this could allow more value to be extracted from the assets and defer large investment in the network. This is of particular interest in the context of the very long asset lifetime in comparison to the significant uncertainty concerning changes to the way in which the transmission network will be used in the future. If the boundary flows on the transmission system need to increase significantly, perhaps as the result of new generation connections, then the alternative may be the delivery of very large capital schemes for additional equipment. As the requirements on the network begin to evolve much more quickly, these new assets could then become redundant before they reach the end of their life.

## Method(s)

The methodology developed starts from the well-known foundation of existing transformer thermal rating calculations, which are well established and are believed to give sufficiently reasonable indications of loss of life due to thermal stresses in an otherwise well maintained system.

The changing structure of sector, with a separation between the Transmission Owner and the System Operator, is the driving factor for the need to consider the overall value of rating enhancements versus additional capital build. Existing financial models will be sufficient to capture the cost of enhancing boundary flows through specific infrastructure investments, and can be extended to consider a mechanism for the valuation of rating enhancements as a result.

An initial review suggests that the use of game-theoretical models has considerable potential in terms of modelling optimal updated ratings, but also in developing appropriate pricing policies. This will also require the development of iterative/decomposition algorithms for computing equilibria in the different game settings. This has the potential to deliver a novel commercial arrangement which better links the cost of providing capacity with the benefits available from its existence.

The following analysis will be undertaken:

1. Determine the value of enhanced transformer ratings, in comparison to the incremental cost increases associated with more rapid consumption of insulation system lifetime (where the asset would potentially need to be depreciated over a shorter period).
2. Clarify physical limits associated with the extent of the uprating that could be achieved.
3. Examine the costs associated with delivering rating enhancements requested by National Grid ESO, and determine what level of enhancement presents an economically desirable balance between increasing boundary flows (to facilitate new generation connection) and preserving the long term health of the asset. This will also include consideration of the risk of failure of the asset and its consequences.
4. Assess the effect of future demand uncertainty on the desirable combination of transformer rating and transformer life expectancy. This will be informed by the use of the NGET risk model.
5. Develop an outline for a tool which will allow a range of scenarios to be evaluated in determining the most appropriate investment decision where boundary flows need to be increased, but are currently constrained by a transformer rating. The goal would be to minimise the whole life cost to NGET, considering the upfront capital costs, ongoing operating costs of additional infrastructure, versus the potential cost recovery in charges made to NGESO. Consideration would be given to the necessary inputs to the model, including those associated with regulatory requirements.

## Scope

This project is positioned as a detailed feasibility study. Although the methodology has not been used for this specific application, we believe that it will be possible to derive benefit from techniques which have become established in other industries. The key deliverables are as follows:

1. Development of mathematical/financial models which can quantify the value of being able to provide rating enhancements of a particular scale, also capable of choosing which assets should receive an updated rating so to keep a measure of the overall ageing of the infrastructure within a given threshold.
2. Development of mathematical/financial models capable of determining a pricing policy capable of delivering an overall ageing of the infrastructure within a given threshold.
3. Assessment of mechanisms to improve the short term overload ratings of transformers, including under reverse power flow (which can be a particularly limiting case). To include consideration of any tests which could be undertaken at Deeside as validation (testing itself not in the scope of this project).
4. Develop an outline for a tool to assess the potential cost (in terms of increased maintenance and additional life lost) from the deployment of rating enhancements, including assessment of high impact low probability failure events. This is of particular relevance for contingency scenarios where N-2 (redundancy level allowing for failure of two components without loss of load) capability is being utilised.
5. Conduct studies on how the methodology in item 4 could be implemented within NGET, including the possible impact upon network reinforcement scenarios identified through a series of case studies.

## Objective(s)

The objective of the EAT project is to determine if there are scenarios in which the use of higher transformer ratings, at the expense of the longevity of the asset, could be economically beneficial to the operation of the electricity transmission system. The project would seek to design a methodology which would allow the financial impact of different options to be assessed, with due consideration of the uncertainty surrounding actual asset utilisation. This would allow greater understanding of the economic case for providing enhanced ratings.

## Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

### Success Criteria

This project will be judged to be successful if:

- A method is developed which can provide a robust analysis of the likely costs of delivering enhanced ratings for transformers in comparison to the value which is unlocked as a result of their availability.
- It is possible to conclusively identify whether novel commercial arrangements exist which would enable new generation to be connected adjacent to boundaries where power flows are constrained by transformer capability.

### Project Partners and External Funding

None

### Potential for New Learning

At the present time, no method exists for explicitly evaluating the cost of delivering, or the value of offering, transformer rating enhancements beyond the conventional short term ratings calculated under existing policies. The same applies for methods capable of determining a suitable pricing policy. The use of the developing mathematical area of game theory is also particularly novel in this context.

Although this project is initially focused on the transmission system, if the methodology is shown to be successful then it will be a valuable tool for use on the distribution networks. This is because distribution network operators are routinely faced with requests to connect renewable generation to their networks, and may be more likely to experience reverse power flow issues. On this basis, the methodology could have benefits on all networks at 33kV and above.

### Scale of Project

This project is positioned as a detailed feasibility study, although elements of it require significant research to be undertaken on new modelling methodologies for the valuation of enhanced ratings and their impact on the network utilisation by the NGENSO, which is necessary to estimate the actual increase in usage of an asset made possible by the updated ratings. Although this does present some risk, there are excellent opportunities to translate learning from other industries. The project will require approximately 40 person-months of effort, delivered over an 18 month project duration. Although the underlying technical methodologies could be developed within one year, time is expressly added to enable case studies to be developed based on existing or previous known transformer-related boundary flow constraints. This is considered to be critical to the success of the project, as it will facilitate not just the creation of a new methodology, but also the evaluation of how the technology could have impacted upon business decisions in the past (had it been available). By doing this, it will be possible to assess whether the modelling techniques developed can be more readily implemented into Business-as-Usual processes once the necessary modelling tools are designed and built based on the successful outputs of this project.

### Technology Readiness at Start

TRL3 Proof of Concept

### Technology Readiness at End

TRL5 Pilot Scale

### Geographical Area

This is a desk based study.

### Revenue Allowed for the RIIO Settlement

None

### Indicative Total NIA Project Expenditure

£544,000



## 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:

n/a

#### 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)

There has been little estimation to date of the economics of the provision of transformer rating enhancements. This project will identify a modelling approach that will evaluate and attempt to identify the level of enhancement that provides the most economic benefit on a case by case basis taking into account the known factors.

A study undertaken within NGET has identified five investment schemes which could be influenced by the use of EAT, along with other projects. This study identified that a modest reduction in the system level constraints could save consumers £40m though deferred investment and through the reduction of constraint payments.

#### Please provide a calculation of the expected benefits the Solution

An example CBA is alleviation of thermal constraints imposed by a transformer. Using the Unit Cost Allowances (UCA) for transmission investment and specific instances of thermal constraints from the Energy Ten Year Statement (ETYS), a 10% increase in the maximum rating of an example transformer would result in a cost saving of £6m for consumers per site. A number of potential sites across the country where this could be applied have been identified.

The longer term aim of EAT will be a tool to identify the cost benefit of enhancements on a case by case basis, this will require further work based on the successful outputs of this project i.e. a modelling approach that can be used to produce a modelling tool. The final report from EAT will give example scenarios and the potential benefits in each case. This will feed into the benefits case for any future work in this area

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

If the project is successful in developing a methodology which can then be incorporated into a modelling tool (which would require a follow-on project) the roll-out would be relatively straightforward as long as the inputs are available. Any instance where a transformer thermal constraint exists, whether this is a short term situation or in support of a new connection, could potentially be evaluated using this methodology. The methodology would have to be supported by policy documentation.

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

The development of relevant policy documentation to support the use of the methodology would cost around £50,000. This standard could then be rolled out across the GB network, at a further cost of around £25,000 per licensee in order to adopt this new type of

technology/service.

### 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 learning generated by this project will be readily usable within NGET in determining how to respond to requests to connect new generation, which would otherwise have resulted in the requirement for new infrastructure to be constructed. It is also likely to have benefits for distribution network operators.

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

Service Delivery - Developing new service-based propositions and business models

- Has the Potential to Develop Learning That Can be Applied by all Relevant Network Licensees

#### 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.

These concepts have never been investigated before in this way; the mathematical tools in particular are highly novel.

#### 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

Conventional rating methods for transformers are almost entirely focused on the provision of a long service life for the equipment; in traditional network operation, this has been highly desirable. As the functional requirements for the transmission network begin to evolve more quickly, it may be beneficial to consider allowing the life of some assets to be shortened in return for the system wide benefits realized as a result of being able to connect generation more quickly. This is a very different take on the problem, and has not been investigated previously.

### Relevant Foreground IPR

n/a

### Data Access Details

n/a

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

This project will explore a number of concepts, which have yet to be tested fully. We do not currently know the performance required and the cost of these concepts. As the outputs of this project cannot be directly related to benefits for consumers in the short term, there is significant risk in attempting to develop novel investment methods using business funds.

### 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 project can only be funded through the NIA as there are significant risks which warrant further investigation and development of this innovation topic, prior to its use within the business. The main risks are:

- No proven business case – While a value case has been defined for this project, it is contingent on obtaining an as yet unknown level of technical knowledge. No matter the outcomes of this project, they will be of value to consumers, potentially in a more qualitative manner. At this stage, the foreseen benefits are insufficient for the business to justify the project's budget.
- Regulatory challenges – As this research is investigates the fundamental behaviour of untested network investment concepts and may require a different arrangement between the TO and SO for releasing capacity from transformers potentially reducing the life of an asset, there may need to be an alternate mechanism of funding the scenarios in the best interest of the consumer. However, these can only be identified through research and attempting to evaluate the potential scenarios. This results in further research being required to technically understand Economic Ageing of Transformers in sufficient detail to extract clear value. These risks make it hard to justify when the business would obtain returns for consumers. Without the NIA funding these risks would never be mitigated, and the business would justifiably not research this area; resulting in the potential benefits never being obtained or investigated.

### This project has been approved by a senior member of staff

Yes