Investment Decision Pack

NGET A7.03 Protection & Control Coordination

December 2019

As a part of the NGET Business Plan Submission

nationalgrid

Justification Paper Load Related – Protection & Control Coordination			
Primary Investment Driver	Lower inertia and fault-levels across the network due to increasing volumes of renewable energy		
Reference	NGET_A7.03 Protection and Control Coordination		
Location in Submission Narrative	Chapter 7 – *Enable the ongoing transition to the energy system of the future* Section 5.1 ii) *Invest in changes to protection and control required to maintain security of supply as the amount of renewable generation increases*		
Cost	£31.1m		
Delivery Year(s)	2021 – 2026		
Reporting Table	B series tables and totex cost matrix tables		
Outputs in RIIO-T2	Changes to protection settings and full scope of upgrades required (upgrades to be funded through a within period determination)		
Spend Apportionment	**T1**	**T2**	**T3**
	£0.3m	£31.1m (Baseline)	N/A
		£90.2m (Uncertainty)	

All costs are in 18/19 prices, unless otherwise stated.

Contents

Executive Summary

Power systems around the world are decarbonising and having to contend with the operability implications of increasing volumes of renewable generation connected to the network via power electronics. The Government's commitment to net-zero 2050 looks likely to accelerate this trend in the UK.

The reducing network short circuit level (SCL) and inertia level due to the increasing proportion of renewable generation and interconnectors is a major risk to the safe and reliable operation of transmission protection and control systems. Failure to address this risk could expose consumers to a combination of an inability to achieve net-zero 2050, increased system operation costs, as a result of needing to constrain on conventional plant and a higher likelihood of network disturbances arising from post fault instability, and the associated economic impacts.

We have been working closely with both domestic and international stakeholders in seeking to better understand and overcome the challenges. Work with the ESO and other TOs, through the System Operability Framework, indicates that this work must be undertaken in the T2 period to maintain confidence in a safe and reliable transmission network in England & Wales into the future. A study commissioned through independent experts, Quanta Technology, used available data to assess the impact of decreasing SCL and inertia on our network and made recommendations on the volume, scope and cost of approaches to mitigate likely impacts.

			preferred		
Quanta recommendations		**Option 1 (do nothing)**	**Option 2 (i + ii + UM)**	**Option 3 (i + ii + iii)**	**Option 4 (i + ii + iii)**
i.	Relay setting review and setting changes	0	25.78	25.78	0
ii.	Detailed modelling and coordination studies	0	5.37	5.37	5.37
iii.	Replacement of relays	0	0	90.20	0
iv.	Implementation of a PMU system for protection	0	0		396.00
	Baseline Plan Total	**0**	**31.1 (+UM)**	**121.4**	**401.4**

A number of options for how to implement Quanta's recommendations were considered. Option 2, involving (i) relay setting reviews and setting changes alongside (ii) detailed modelling and coordination studies at a cost of £31.1m is our preferred option. These costs are highly certain, having been derived primarily from Quanta Technology's independent assessment, checked against our procurement and commercial database, and utilising previous experience on project management and site delivery.

Quanta's work indicates relay replacements will also be required (at a cost of £90.2m), but we are proposing a within period determination for this work to manage uncertainty around the volume, scope and cost of this work. The outcome of the detailed modelling and coordination, as well as further engagement with stakeholders, will provide the necessary certainty.

Risks around pace of technological and best practice change, access to sufficiently robust models for protection relays and power electronic controllers, uncertainty over volumes of work and deliverability are highlighted. Robust mitigations, primarily around funding approach and extensive stakeholder engagement, are proposed to minimise likelihood and/or impact.

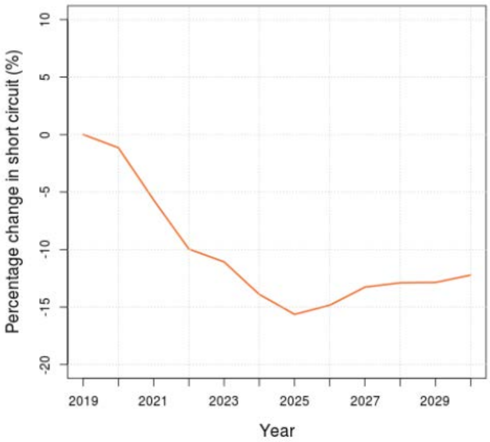
1. Context and need case

The electricity system has made considerable progress towards decarbonisation and the Government's commitment to achieving net-zero by 2050. Adopting the Climate Change Committee's (CCC) recommendations into legislation is likely to accelerate progress across all sectors of the economy. This trend has significant implications for the electricity transmission network. Further understanding and intervention are necessary to ensure continued safe and reliable operation.

The electricity system is undergoing a period of transformation, from historically having been supplied mainly by conventional synchronous generation to a future supplied predominantly by renewable generation and interconnectors connected to the system via power electronic technology. The CCC indicates that a further 50GW of renewable generation could be required to meet targets; a more than doubling of capacity in 2019 and the ESO's Network Options Assessment of optimal future interconnection capacity indicates an increase to between 18.4GW and 21.4GW from the 5GW of capacity connected in 2019.

This proliferation of power-electronic-based sources of supply will impact key power system characteristics, such as a decline in the short circuit level (SCL - described in Appendix A) and inertia. Figure 1 shows the *average* rate at which SCL is set to decline across the four Future Energy Scenarios (FES), as calculated by the ESO. A steady decline is expected out to 2025 where, in some scenarios, there is an increase in new synchronous generation connecting. This increase is much less likely to occur in scenarios consistent with achieving net-zero.

Figure 1 – Average % change in national short circuit level across FES scenarios



A declining SCL has operability implications related to protection, voltage and stability. The impact of low SCL on the function and performance of protection and control systems is one of the most direct impacts of this trend.

Understanding the impact is complex as it varies by region and is influenced by the behaviour of power-electronic-based generation under power system faults. This behaviour differs considerably from that of conventional rotating-machine-based generation, due to the vendor-specific design of electronic control schemes, as well as inherent fast-response (inertia-less) characteristics.

The accurate and dependable operation of protection and control (P&C) systems is critical to the reliable and safe operation of the electricity transmission network. P&C systems (also known as secondary equipment) are designed to automatically detect and isolate a fault from the network to prevent excessive damage to plant, injury to people and to minimise any impact on the operational integrity of the electricity transmission network. The risks associated with protection mal-operation include disconnection of healthy circuits, slow fault clearance, failure to disconnect the faulted equipment, cascade tripping, system stability problems and the possible disconnection of demand and generators, and associated significant economic consequences for consumers.

As a Transmission Owner in England & Wales we have a licence obligation to provide a network that can be operated efficiently and securely across conditions that could reasonably be expected to occur across the year. To achieve the required security standard (as required by our licence and associated industry codes), protection systems usually consist of two main and one backup protection. Most protection approaches, such as unit, distance and over-current fundamentally need a high SCL, which results in a large fault current, to operate in a coordinated manner so that a fault can be correctly detected and cleared within the required *critical clearance time* (CCT). The CCT is crucial to maintaining power system stability and is closely related to the system inertia.

We need to understand the implications of changes in inertia and SCL on our protection systems, as summarised in Table 1. This requires a comprehensive investigation of protection and control device performance against various background conditions to allow for mitigations to be defined that ensure continued effective and efficient operation.

Table 1 – Overview of impact of low SCL on protection

Protection Approach	Operating Principle	Impact of Low SCL
Unit protection	Compares the current input and output from network equipment; if the difference between the two is greater than a pre-set value, the relay is set to trip. The pre-set value has to be more than a minimum level (pickup) which is calculated based on SCL.	With reduced SCL, the unit protection settings need to be reviewed and changed as appropriate to avoid mal-operation and this risks delayed fault clearance.
Distance protection	Calculates the impedance at the relay point and compares it with the reach impedance; if the measured impedance is lower than the reach impedance, the relay is set to trip. The relay performance will be affected by high Source Impedance Ratio (SIR), should be used if SIR > 30.	Not affected if the ratio of voltage to current decreases following the short circuit. However, this ratio is affected by the significantly different volumes of synchronous generation at peak and minimum demand.
Over-current protection	The operating time of the relay is inversely proportional to the magnitude of the short circuit current.	This type of protection is the most likely to be affected by low short circuit levels. These schemes are mainly used for back-up protection and the likelihood of maloperation is therefore less, provided main protection schemes are not compromised.

The challenges associated with the reduced SCL and inertia is a concern that is being discussed globally. Working groups have been initiated by the international technical bodies such as ENTSO-e (PE sub-Group), CIGRE (JWG B5C4-61) and IEEE/NERC (Task Force), to investigate how these changes will influence protection and control schemes.

Some countries have already introduced regulations for network wide protection co-ordination studies. The North American Electric Reliability Corporation (NERC) requires such a co-ordination study (NERC standard PRC-027) every 6 years or whenever the SCL changes more than 15%. The studies we propose undertaking will take several years to complete, and the pace of renewable deployment is increasing, so addressing the issue in T2 is important.

Stakeholder engagement with international bodies, the ESO and other network owners indicates that we need to ensure that any mitigations proposed are complimentary and efficient from a whole systems perspective. Both the recent Government commitment to net-zero by 2050 and the ESO's stated ambition to achieve the ability for zero-carbon operation 2025 directly influence the need to undertake this work in the T2 period.

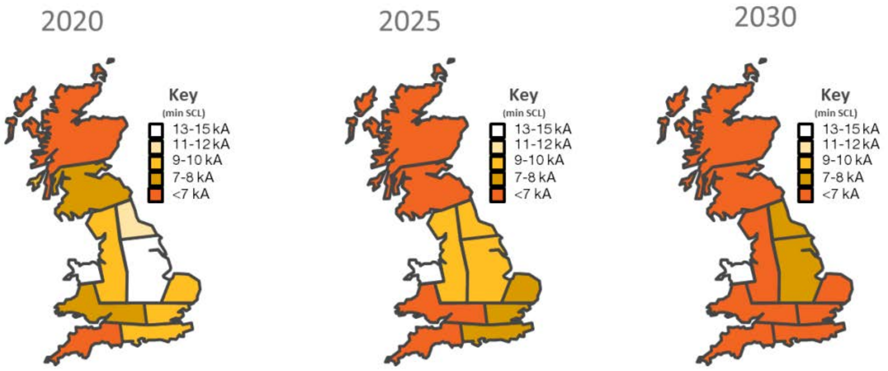
2. T1 experience and lessons learned

Over the course of the T1 period we have worked closely with domestic and international stakeholders to monitor developments, better understand the emerging challenges and contribute to the development of guidelines and best practice on how to address them.

A key stakeholder on this topic is the ESO. As the organisation with the accountability for operating the system, they have been leading the domestic debate on the impact of reducing SCL as one of the topics monitored and explored through their System Operability Framework (SOF). We have engaged extensively in this process by participating in regular events and periodic publications since 2014, as well as topic specific collaboration.

In 2019, as part of their Operability Strategy, the ESO published a document outlining the impact of declining SCL, which includes an update from collaborative work between the ESO and Transmission Owners to understand the impact of SCL on declining network protection. As part of this, each TO selected several case studies to analyse in detail based on the times and regions with the lowest SCL as identified through the ESO's year-round analysis out to 2030. This work showed that several circuits are at risk due to declining SCLs and that the number of systems affected by declining SCL varies around the country depending on how common they are, how low SCL is and how much SCL has declined. Initial results, as shown in Figure 2 – *Regional SCL over the coming decade*, show that Scotland and the South West of England are the first to see the impact, but that the effect is pervasive by the T3 period across Great Britain.

Figure 2 – Regional SCL over the coming decade



To manage the risks of declining SCL identified in the report, the ESO launched a stability pathfinder for Scotland and the South West on the 22nd of October 2019. The focus of the pathfinder is to find the right balance of operational, physical and commercial solutions to meet their requirements, but will not resolve the transmission protection issue.

In parallel with this work, we commissioned in 2015 a Network Innovation Allowance (NIA) project NGET 0182 "Feasibility study on the suitability of protection policy for future energy scenarios. The purpose was to provide an assessment of protection functionality and performance with respect to declining system short circuit levels and inertia" with academia and independent international experts, Quanta Technology. This project quantified the nature and scale of the challenge on our network, using available data, and proposed mitigations and further analysis that should be undertaken. The basis of this work was the generation mix and system data from the 2017 Electricity Ten Year Statement.

A summary of the conclusions and recommendations of Quanta study are set out in Table 2.

Table 2 – Summary of Quanta conclusions and recommendations

Conclusions	Recommendation		Detailed Implications
Thermal limitations of inverters, are ***reducing SCL*** (short circuit levels). ***Power system inertia is declining*** as todays inverters do not have the inertia to support high current for long intervals.	i.	Relay setting review, and setting changes	• Low SCL will cause issues for unit, non-unit (distance) as well as over current protection approaches, where they may either mal-operate or fail to operate. Relay setting adjustments are required to mitigate this. • Low inertia means faster critical clearing times for faults may be required in future, alongside potential mitigations based on energy storage and synthetic inertia, to guarantee system stability in future. • Distance protection relays may require the use of power swing blocking functions to avoid operating on power swing events.
SCL changes require detailed analysis of the consequences whenever fault levels change by more than 10% to 15%.	ii.	Detailed modelling and coordination studies	• Comprehensive computer software and analysis is necessary to perform "system wide" protection coordination studies, which cover the whole transmission network. Specifically, this involves modelling the detail of all secondary systems and verifying the dynamic response of generation and system controllers.
Limits of existing relays and increase in SIR *(source-impedance-to-system-impedance-ratio)* will require replacement of some relays.	iii.	Replacement of relays	• Replacement of overcurrent protection replays is required when existing relays cannot securely be set to differentiate between fault and load current. • A SIR above 30 leads to decreasing measurement accuracy and incorrect operation of distance protection, requiring replacement with unit protection.
The implementation of a new approach involving ***adaptive or predictive protection devices*** may be warranted	iv.	Consider implementation of an alternative method for protection	• Whilst the use of relays set to make trip decisions based on real-time synchro-phasor measurement technology in wide area protection schemes is currently limited, this is a promising area of development.

We have used the outcome of engagement with the ESO and other TOs as part of the SOF, and the work commissioned with Quanta Technology, to inform our proposals for the T2 period.

3. T2 proposals

The commitment to net-zero 2050, zero carbon operation by 2025 and our learning from the engagement and independent analysis commissioned in T1, demonstrates the need to act in the T2 period to further our understanding and begin to put in place effective and efficient mitigations on our network, to compliment those being developed and implemented elsewhere.

Optioneering

We have considered a number of options for addressing the various recommendations in Quanta's report. Table 3 shows the costs of each recommendation, predominately drawn from Quanta as part of the study. Each option is described in turn, below. Option 2 is our preferred option and has been included in our plan for the T2 period. All options require continued engagement with key stakeholders.

Table 3 – Cost of Quanta recommendations

Recommendation		NGET Cost (£m)
i.	Detailed modelling and coordination studies	5.37
ii.	Relay setting review and setting changes	25.78
iii.	Replacement of relays (estimate)	90.19
iv.	Implementation of a PMU system for protection (estimate / option)	396.00

Option 1 - Do nothing **[£0m]** **-** It is evident from the initial research and direction of travel in the energy industry that there is an issue that needs to be addressed. We believe it would not be prudent for us, given our responsibilities as a Transmission Owner, not to take any action. Failure to fully understand the issues and begin to put in place mitigations in the T2 period will have negative implications on consumers through a combination of (a) an inability to deliver net-zero targets, (b) massive increases in constraint costs as the ESO pays conventional generators to run in lieu of renewables, and (c) an increased risk of major system disturbances as post fault instability becomes more likely.

Option 2 (preferred) - Deliver recommendations (i) + (ii) in our baseline plan **[£31.1m]** - As a responsible licence operator we believe it is necessary to fully evaluate the risk through building a suitable model and performing protection coordination studies using actual generation and system data (rather than forecasted) and explore new protection solutions at a cost of £5.37m; and undertake a review of settings and deliver the required setting changes at a cost of £25.78m. Upon completion of the full detailed protection coordination studies and exploration of new solutions (e.g. adaptive relays), a better estimated cost for the replacement of relays (estimated by Quanta at £90.2m) will be available. To protect consumers from this uncertainty, we propose a within period determination uncertainty mechanism that would provide allowances when scope and cost of work is known.

Option 3 - Deliver recommendations (i) + (ii) + (iii) in our baseline plan **[£121.4m]** - This option has the same scope as option 2, but instead of waiting for the outcome of the protection coordination studies to provide a better cost estimate for the replacement of relays it would provide the full cost as an ex-ante allowance from the start of the T2 period. We do not believe that there is sufficient cost or scope certainty to proceed with this option. In addition to cost uncertainty, replacements would also have a greater requirement for system access, which would pose significant deliverability challenges alongside the remainder of our T2 plans without further scoping and planning work.

Option 4 - Deliver recommendations (i) + (iv) in our baseline plan **[£401.4m]** - Common to options 2 and 3, this option would build a suitable model and performing protection coordination studies using actual generation and system data at a cost of £5.37m as well as implement PMU systems in each region of England and Wales (consisting of [redacted] busbars per region) at a cost of £44m per region; £396m in total. We do not believe that it is prudent to pursue this approach, as even the Quanta report highlights that the use of PMU systems in wide area protection applications is in its nascent stages (introducing risks), current indications are that modern relays could be sufficiently robust (studies are required to conclude this) and that the cost of this solution cannot be justified until other potential whole system solutions are explored fully.

Further detail on the preferred option

The proposed approach is comprised of 2 work streams with high levels of cost certainty: (i) detailed modelling, coordination studies and new protection solution development; and (ii) relay setting review and setting changes.

Costs for each of the work streams have been derived primarily from Quanta Technology's independent assessment, checked against our procurement and commercial database and utilising previous experience on project management and site delivery.

Detailed modelling, coordination studies and new protection solution development

Historically, protection settings have been calculated by considering the worse-case in-feeds and fault levels anticipated as the network grows. This philosophy however is no longer appropriate with the move towards inverter dominated grids. The scale of analysis necessary to regularly review protection performance is considerable. It is a major exercise to develop all the models; gather and prepare input data; and validate and analyse a system with over 2500 protection functions.

To understand whether the protection will perform in a reliable and coordinated manner, it is necessary to accurately model the whole network, including all the primary plant, secondary equipment, generators (particularly renewable ones), as well as develop effective tools and methods for the numerical simulation and analyses. This will also need to be automated due to the large volume of protection functions, scenarios to consider and the performance of each specific type of protection.

The analysis will consider the change of SCL against updated generation data and system information and assess its impact on different protection and control functions to determine the risk and appropriate remedial actions.

The feasibility work identified that the modelling tools, software and automation, shown in Table 4, as essential for the protection co-ordination study as part of this RIIO-T2 investment plan:

Table 4 – Detailed cost breakdown of modelling and coordination

Protection Modelling and Coordination	Cost (£m)
Overall Modelling & Programme	1.50
Busbar Protection (BBP) Assessment	0.06
Over-Current (O/C) Protection assessment	0.10
Non-unit Protection/(SIR) Assessment	0.06
New protection solution development	3.65
Total	**5.37**

The costs include the resource for developing and configuring the overall model and software to automatically asses the SCL and determine the protection coordination issues. The costs are based on Quanta's world-wide experience in this field. NGET has a maintained power system model and a short circuit program that should facilitate the automation of short circuit simulations via an interface. Given the changing state of the system, it is likely that we will need to review the SCL annually to ensure that the settings of protection functions meet the reliability requirements.

New Protection Solution Development

While it may be possible to revise settings, or replace some units with established and known alternatives, there remains the risk that these may not be sufficient, and new techniques to detect faults and trigger protection schemes are required. NGET will evaluate the feasibility of alternative protection methodologies such as travelling wave and PMU based solutions, as preparation for the future replacements for non-unit solutions and overcurrent protections. This will consider the reliability, dependability and suitability of these solutions for different types of configurations (lines, cables, multi-ended circuit transitions, transformers and combinations thereof). The estimated costs include £650k for development and testing, plus 6 field trials to assess each of the types of configurations (above) costing £500k each. These costs are informed by the Quanta work and based on current replacement costs, accounting for novel technology and implementation uncertainty.

Relay setting review and setting changes

The protection coordination will establish whether the functions work and the effectiveness of the strategy. This is a device specific and manual process which will perform a dedicated calculation and settings review for the 'at risk' relays identified above and Quanta's scoping work.

This work includes the following protection setting activities, set out in Table 5, have been identified for this RIIO-T2 plan. The estimated unit costs include both the study for the protection setting revision and site delivery of the work. This is not routine maintenance work and requires experienced engineers to calculate the new settings, configure the changes and robustly test the relay to make sure the modifications do not compromise other functions.

Table 5 – Detailed cost breakdown of relay settings review and settings changes

Activity	Units	Unit Cost (£m)	Total cost (£m)
Busbar Protection (BBP) Settings Revision and Changes	[redacted]	[redacted]	1.32
Overcurrent (O/C) Protection Coordination Study and Settings Changes	[redacted]	[redacted]	19.93
Supergrid Transformer (SGT) O/C backup protection settings review and changes	[redacted]	[redacted]	0.70
Revision on Power Swing Blocking	[redacted]	[redacted]	0.37
Revision of Synchronizing Devices	[redacted]	[redacted]	3.46
		Total	**25.78**

Busbar Protection (BBP) Setting Revision and Changes

A review of the busbar protection setting calculation is required whenever the fault current level at a busbar changes more than 15%. The busbar protection is affected by declining SCL levels and will need to be adjusted to the new system conditions. The Quanta analysis estimated that, based on the generation and system parameter changes between 2017 - 2025, 220 busbar protection schemes have been identified for setting review or upgrading by the end of RIIO-T2.

Furthermore, during the detailed protection co-ordination study, using the summer minimum SCL, if the fault current levels fall below 50% of the CT secondary nominal current, the relays will need to be replaced in line with NGET settings policy PS(T) 10.

Overcurrent (O/C) Protection Coordination Study and Setting Changes

Reduced SCL will affect settings of overcurrent protections. This is the most common protection method featuring in most back-up and transformer protection functions. The available data from 2017 - 2025 shows that we will, on average, have to perform a coordination review on [redacted] busbars each year. Each busbar has at least 2 overcurrent protection relays, totalling [redacted] overcurrent protections which will need to be assessed and any setting revision/change work completed by 2025.

The unit cost is roughly double of other protection types, since there are two over-current functions per device, that will require investigation, necessitating twice the resource.

SGT O/C backup protection setting review and changes

All the overcurrent backup protections for Supergrid Transformers should have the settings reviewed and modified wherever the minimum or maximum fault current changes more than 10%. A total of [redacted] SGT overcurrent protections were identified to have the need for the setting revision and change work during the RIIO-T2.

Revision on Power Swing Blocking

The use of the power swing blocking function in non-unit protection relays will be required when the system inertia decreases significantly to marginal values (2-3s or below), especially for long transmission lines. We will need to review [redacted] non-unit protection schemes ([redacted] at 400kV, [redacted] at 275kV) based on the declining system inertia.

Revision of Synchronizing Devices

Circuit breaker closing is supervised by a synchronising device, the settings for the synchronization such as the frequency slip and phase angle need to be reviewed and adjusted to reflect the changing system inertia. We will need to review these settings at least once during the RIIO T2 period on a total of [redacted] circuits ([redacted] at 400kV & [redacted] at 275kV), which may require a settings revision and adjustment. The Quanta analysis only identified [redacted] circuits for review, as this was limited to overhead line circuits only. As cable circuits will also have to be reviewed, we have increased the total volume by [redacted] to [redacted] to account for this.

The risk of not performing the review and adjustments of these settings is that circuit breakers may not reclose automatically or increase the delay after the fault clearing. This may result a weaker system for the duration of the circuit outage and may increase the likelihood of stability problems.

<u>Protection Replacement (within period determination)</u>

Following the protection coordination and settings review, in some instances, the setting changes may not be able to mitigate the impact of the reduced SCL on the existing protection and control equipment. In these cases, the equipment has to be replaced with a different type of protection and control function. This will include:

- The replacement of non-unit protection by a unit protection is required on the circuits where the SIR ratio will increase above 30, as defined in the NGET's Protection Settings Policy document PS(T) 010.
- The replacement of overcurrent protection relays with voltage-restrained or voltage-controlled overcurrent relays is required when existing relays cannot securely be set to differentiate between fault and load current.

Quanta's analysis identified the following volume of candidates likely to require replacement, detailed in Table 6.

Table 6 – Cost breakdown of relay monitoring, setting review and setting changes

Activity	Units	Cost/Unit (£m)	Total Cost (£m)
Non-Unit Protection replacement	[redacted]	[redacted]	21.93
Overcurrent replacement	[redacted]	[redacted]	68.26
		Total	**90.19**

The exact number of the units will need to be confirmed through the detailed co-ordination study and stakeholder engagement. This volume of work will have implications on costs, deliverability and site access, possibly extending into RIIO-T3 due to system access issues. The estimated unit costs include the cost for the hardware, engineering, installation and commissioning.

4. Risks

Pace of technological change and best practice

The impact of the reduced fault-level and inertia on protection and control is an issue common to the global power industry as renewable penetration increases. As other companies work to overcome this challenge the pace of technological development and evolution of best practice is accelerating. To mitigate this risk, we have been engaging with other utilities such as REE, TenneT, and National Grid US through different collaboration opportunities such as the ENTSO-e, CIGRE and IEEE to exchange ideas and seek best practice. Our plan allows for new protection solution development and this will involve continuous, extensive engagement into T2 and beyond.

Access to sufficiently robust power electronic controller models

The effective mitigation of reduced network SCL and inertia relies upon the successful delivery of the protection co-ordination study. One specific risk associated with the study is to obtain all the required data and models of the protection and control equipment, which can be vendor-specific and protected by the Intellectual Property Right (IPR). While we recognise this dependency, given the long-standing relationships we have with equipment manufacturers, we believe this will be overcome by continued close working and exploring options such as developing validated equivalent models.

Uncertainty over volume of work

Despite Quanta's analysis and estimation of the number of relays to be replaced, we have judged that this element of cost is insufficiently certain to include in our baseline plans. Upon completion of the detailed coordination study we will have much greater certainty over which relays require replacing. As such, to protect consumers and mitigate the risk of uncertainty, we are proposing a within period determination to fund replacement work.

Deliverability

The detailed modelling and coordination studies as well as relay settings review and setting changes have relatively low system access requirements and, as such, confidence in deliverability is very high. Site and system access requirements for the replacement work are much more considerable and there is a risk that any programme of work identified is being required is not deliverable, leading to delays and to increased system operation costs to maintain a safe and reliable system. To mitigate this risk, we will ensure that we continue to engage closely with the ESO and other TOs and that the programme of work we bring forward through the within period determination has factored in the latest view from engagement and associated access requirements.

5. Approach to uncertainty

Baseline proposed costs are highly certain, having been derived primarily from Quanta Technology's independent assessment, checked against our procurement and commercial database and utilising previous experience on project management and site delivery.

A key aspect of our proposal is that, upon completion of the full detailed protection coordination studies, a better cost estimate for the replacement of relays (estimated by Quanta at £90.2m) will be available. To protect consumers from this uncertainty, we propose a 'within period' determination uncertainty mechanism that would provide allowances when scope and cost of work is known. This is summarised in Table 7, below, and further details can be found NGET_ET.12 Uncertainty Mechanism Annex.

Table 7 – Proposed within period determination for protection replacement costs

Protection and Control – within period determination		
Uncertainty characteristics	**T1 experience and learning**	**T2 proposals**
i) Risk and ownership • System need and the specific mitigating investment required uncertain • Requirements driven by detailed study of system requirements, from modelling activity included in baseline plan • Cost and volume risk too high to set ex-ante allowances in order to protect consumers **ii) Materiality** • A total uncertainty of £90.2m is estimated based on independent review by Quanta Technology **iii) Frequency and probability** • Low frequency – upon outcome of coordination study • 100% probability of coordination studies identifying some additional future requirements	**i) T1 experience** • ESO & international studies consistently forecast a significant reduction of system inertia and short circuit level as capacity of synchronous generation reduces • We employed an independent party (Quanta Technology) to estimate the scale and scope of the challenges and lay out a plan for further development to ensure effective operation and coordination of our protection and control systems • We continue to engage extensively with experts and other network companies **ii) Learnings for T2** • To identify the details of protection and control issues and most efficient mitigating actions, it is necessary to develop comprehensive models and perform "wide area" protection coordination studies across the transmission network • Changes to settings are also required and included in our plans, but subsequent investments will be required to enhance system operability and maintain security of supply	**i) Proposed mechanism and benefits** • Baseline allowance proposed in T2 period to deliver the coordination study and consequential changes to protection settings • Subject to the outcome of the co-ordination study, further investment estimated at £90m for protection equipment replacement or other equipment installation may also be necessary to maintain protection performance within T2 period and beyond • We propose the cost of protection upgrades would be subject to a targeted in period determination upon sufficient progress of the coordination studies **ii) Drawbacks and mitigations** • A within period determination with a fixed date or window could delay funding to undertake the work required to operate a net-zero system by 2025 and mitigate the issues highlighted by the ESO in the System Operability Framework • We propose that the determination could take place at any point during the T2 period when coordination studies have provided sufficient clarity on scope

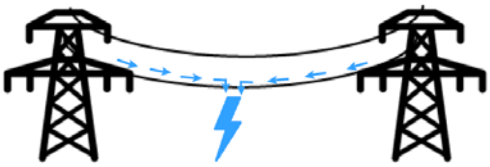
Appendix A – A description of short circuit level (SCL)

SOURCE: ESO SOF 18

What is SCL?

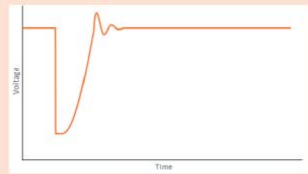
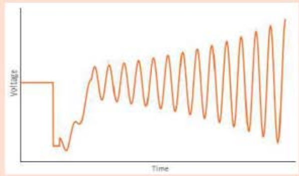
Short circuit level is the amount of current that will flow on the system during a fault. These faults can be caused by a tree hitting an overhead line, an equipment failure or something else. During the fault, the system sees a direct connect to earth and current flows from all sources into it, as shown in Figure A1, below.

Figure A1 – Short circuit flow to a fault



SCL is also used as a description of the strength of the system. When SCL is high we say 'the system is strong' and when the SCL is low (as is the case in a system with a high penetration of renewable energy) we say 'the system is weak'. The strength of the system is a key factor in how stable the system is when it experiences a fault. Table A1 shows how system stability is affected by different levels of SCL.

Table A1 – Effect of SCL on system stability

SCL	Effect on the system
High SCL In a high SCL system during a fault voltage will fall, but it will quickly recover once the fault is fixed. The voltage will settle down to normal condition quickly with only small oscillations.	
Low SCL In a low SCL system the voltage will still fall during a fault, however it will experience oscillations as it starts to recover. The voltage will settle down to normal conditions but this will happen slowly and voltage will fluctuate during this period.	
Very low SCL In a very low SCL system, the voltage behaves in a similar manner to the low SCL system, however instead of recovering to normal conditions the oscillation will continue or increase.	

Declining SCL can impact the safe and reliable operation of the system is a number of ways, as set out below. These impacts impact the ESO, network owners and users of the network (our customers).

Protection

Lower SCL means protection sees smaller (or different) currents than it was expecting and may not work

Voltage

Lower SCL means that voltage moves faster and to a greater extent when there is a disturbance on the system

Stability

The lower system strength means that the system may not be able to return to normal operation after a disturbance

Converters

The faster moving voltage caused by low SCL can mean that converters may not know what the system is doing and how to respond