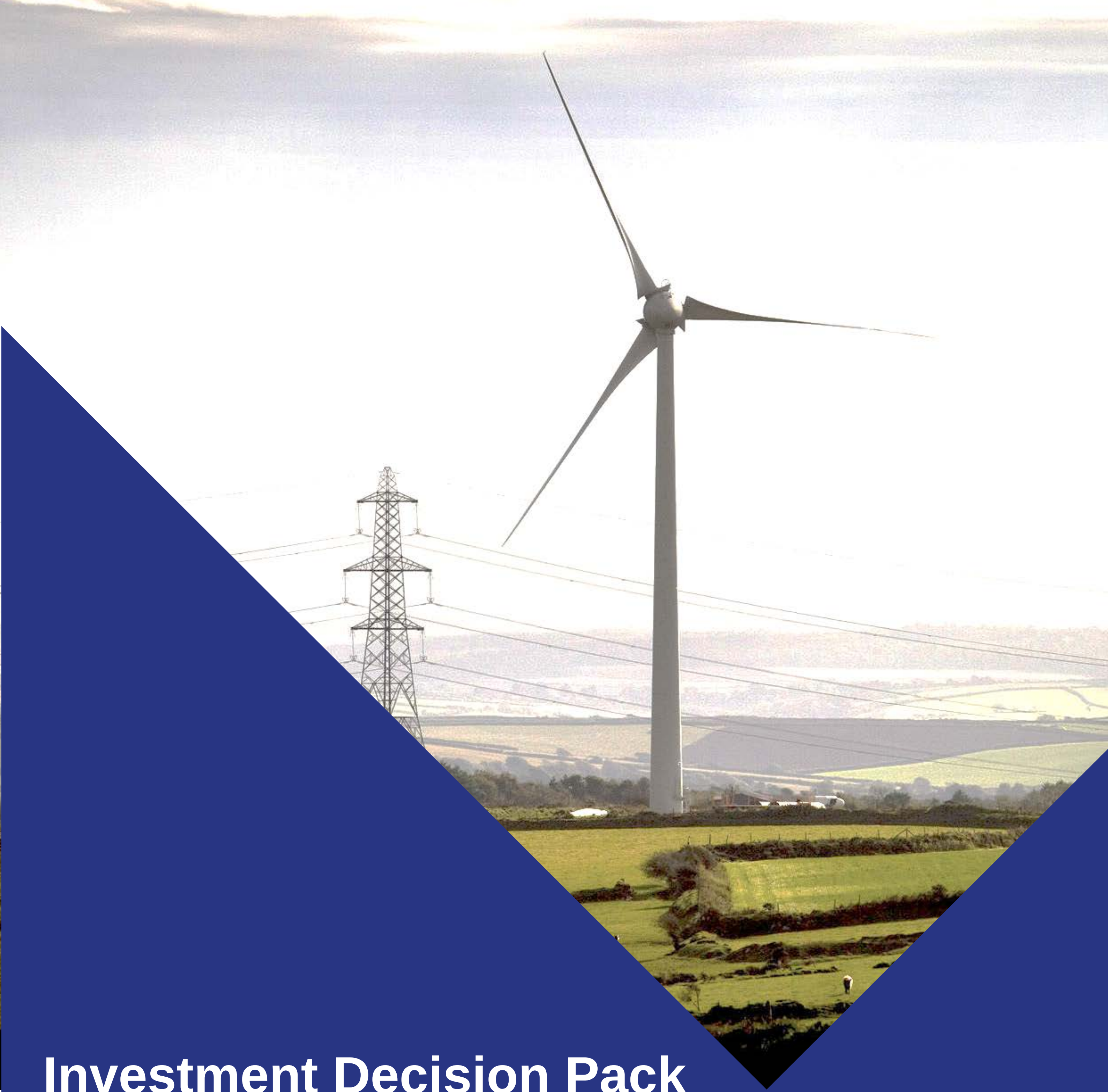

Investment Decision Pack

NGET_A9.21- Substation Auxiliary Systems

December 2019

As a part of the NGET Business Plan Submission

nationalgrid

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Engineering Justification Paper; Non-Load Related Substation Auxiliary Systems			
Asset Family	Substation Auxiliary Systems		
Primary Investment Driver	Asset Health (non-lead asset)		
Reference	A9.21		
Output Asset Types	- DC Battery Systems - LVAC Supply and Distribution Systems - Standby Diesel Generators		
Total Cost for RIIO-T2 Period	£75.05m		
Delivery Year(s)	RIIO ET2		
Reporting Table	C2.2A, C2.22		
Outputs included in RIIO T1 Business Plan	No - this category is not subject to the Network Replacement Outputs		
Spend Apportionment	**T1**	**T2**	**T3**
		£75.05m	

Table of Contents

1. EXECUTIVE SUMMARY

This paper provides justification for a total spend of £75.05m to replace or upgrade our substation auxiliary systems across a 5-year period in T2. These include:

- DC battery systems
- LVAC supply and distribution systems
- Standby diesel generators.

These systems enable the protection and automatic operation of substation equipment. They are essential for day to day telecoms and control of the network as well as in the fast restoration of transmission supplies following a system failure or 'black start' event. Spend associated with the reliability of these systems is included in this paper.

Extra resilience associated with an *enhanced* black start restoration standard is included in paper A10.08 'Black Start'. An industry-wide taskforce, led by Department of Business, Energy & Industrial Strategy is presently developing this. The costs associated with this are not included in this paper A9.21. Should the enhanced standard be adopted, the costs associated with it would impact [redacted] sites within this paper where more advanced battery technology would be deployed.

In T1 we forecast to spend more than the allowance for substation auxiliary systems. This increase is mainly due to greater spend on DC battery systems and associated work to improve their safety. As the majority of the auxiliary infrastructure has not been upgraded since installation 40-50 years ago, it has led to an increase in the scope of the works required.

Proposals

In T2 the following specific investment is proposed, which is further detailed in this paper;

1. DC batteries

These provide a power supply to the telecoms, protection and control of a substation under normal operating conditions as well as during a loss of site supplies until they become discharged. There are [redacted] units on our network. Depending on the battery type, they either have a service life of 8 years (VRLA – [redacted] units)) or 25 years (Planté – [redacted] units, Ni-Cd – [redacted] units). We will need to replace [redacted] units in T2 at a cost of £26.95m.

2. LVAC systems

These provide power to essential equipment in a substation such as transformer tap changers, air compressors, switchgear drive motor circuits and battery chargers. There is a total of [redacted] LVAC distribution boards installed at [redacted] sites. There are [redacted] LVAC systems that require full replacement (£21.15m) in T2, with an additional [redacted] that require minor intervention (£4.25m).

3. Diesel generators

These provide power to the LVAC systems during a system failure. There is a total of [redacted] diesel generators installed at [redacted] sites. There are [redacted] such generators at [redacted] sites that require replacement (£17.70m), and an additional [redacted] generators require minor intervention (£5m).

T2 intervention volumes are consistent with expectations given the population and expected asset life.

Cost benefit analysis

Several options were considered to maintain our substation auxiliary systems. These were based on:

i) do minimum (no investment, just maintain asset)
ii) targeted component replacement (replace unhealthy components)

iii) full replacement (of whole asset).

We carried out analysis using case studies to illustrate the consequences of substation auxiliary failures, including the Value of Lost Load (VOLL), where this is taken to be £[redacted]k per MWh (Special Licence Condition 3C - £[redacted]k in 18/19 prices). We have used the results as a guide to set the T2 forecast volume and spend.

2. INTRODUCTION

Substation auxiliary systems underpin the core functions of a substation. The protection and control aspects, including the automatic operation of switchgear and voltage control equipment, would not be possible without these systems. As well as providing power to equipment that is integral to the normal operation of the transmission network, the function is crucial to the recovery phase following a system failure or 'Black Start'.

Equipment that constitutes substation auxiliary systems:

1. DC battery systems - substations require DC supplies for powering telecommunications and other light current equipment. These supplies are derived from a battery system which comprises of batteries, battery chargers and a DC distribution system. Different types of battery technology are used for different applications including lead acid (Planté or Valve Regulated Lead Acid (VRLA)) and nickel-cadmium (Ni-Cd). There are [redacted] recorded battery systems on the network.

	Planté	**VRLA**	**Ni-Cd**
Population	[redacted] ([redacted]%)	[redacted] ([redacted]%)	[redacted] ([redacted]%)

2. LVAC distribution systems - substation Low Voltage Alternating Current (LVAC) systems play a critical role in normal transmission operation and in the recovery phase following a system failure. LVAC systems provide substation auxiliary power for essential equipment such as transformer tap changers and cooling, air compressors, switchgear drive motor circuits and site battery chargers. There are [redacted] recorded LVAC boards at [redacted] sites on the network (includes non-substation locations such as cable sealing end compounds and tunnel head houses). LVAC distribution boards have an expected asset life of 40 years.

3. Standby diesel generators - substation diesel generators are crucial in maintaining LVAC auxiliary power during a supply failure. Within minutes, an auto-changeover facility will connect the standby generator to limit the disruption until such time that the supply is restored. Modern containerised generator solutions contain an integral fuel tank and fire suppression system. There are [redacted] recorded diesel generators at [redacted] sites on the network. Diesel generators have an expected life of 40 years.

The appendix (section 9) details how these assets are maintained (inspection and testing) and the scoping of end-of-life interventions.

[redacted]

The health of substation auxiliary systems underpins overall resilience to Black Start events. They provide power to enable indications and control of the substation for swift switching and restoration of the transmission network. Conversely, failure of these systems to provide power to the substation protection exposes the network to greater damage, safety and system stability risks for the next fault.

3. BACKGROUND INFORMATION

During T1 we forecast to spend more than our T1 allowance for substation auxiliary systems. This increase in spend is driven by unit cost, mostly in DC systems but driven by the safety of the rooms in which they are housed, where the planned spend has more than doubled.

Asset Type	Allowance (£m)	T1 Forecast (£m)	Difference (£m)
DC batteries	12.3	25.8	+13.5
LVAC / Diesels	23.2	29.7	+6.5
Total	35.5	55.5	+20

1. DC battery systems - the increase in cost is attributed to an increase in volume of battery systems and work required on lighting, heating, ventilation and fire safety of battery rooms which was not planned as part of our T1 allowance. During T1, there has been a transition in our approach to battery systems from a reactive approach to a pre-emptive one which is based on predicted asset life and output from surveys to prioritise replacements. Work on the battery rooms ensures they meet the standard of BS EN 50282-2, *Safety Requirements for Secondary Batteries and Battery Installations*.

   [redacted] DC batteries have been replaced up to February 2018 totalling £9.6m, which gives a cost per unit of £[redacted]. A further [redacted] batteries are expected to be replaced in the final years of T1. Additional work required on battery rooms (i.e. to meet BS EN 50282-2) is expected to increase this cost per unit (over the remaining [redacted]) to £[redacted]. This is the unit cost that is used for T2 forecasting as battery rooms have been added to the scope of these replacement works. This higher unit cost is not enduring and is expected to reduce by the end of T2 as we complete a cycle of the VRLA-type battery replacements and associated room works.

2. LVAC distribution systems / diesel generators - the increase in cost is attributed to additional work required following an increase in understanding of the LVAC system condition. There is also other work included which was not anticipated at the time of our T1 submission. These complexities included; asbestos removal, additional civils work such as a requirement for room extensions and lifting equipment. The spend on the sites discussed below totals £26.7m which gives an average cost per site of £[redacted] compared to an average allowance of £[redacted] per site.

   [redacted] sites were planned for T1 under two separate investments (Phase 4 and Phase 5 – [redacted] sites in each). [redacted] sites are now planned to be completed in Phase 4. Phase 5 has been delayed until T2 and 6 (Phase 3) have been delayed from TPCR4 into T1 because of the additional complexities noted above. A further 9 substation sites (denoted “site specific scheme' below) have had major works completed during T1, separately to Phase 4 because of their condition.

   The following [redacted] sites are now planned (or have been delivered) in T1.

[redacted]

In addition to the £26.7m spend on the above sites, there is an additional £3m spend on minor capex interventions in T1 which have addressed [redacted] *issues at* [redacted] *sites ranging from diesel fuel delivery systems to mobile connection points.*

<u>T2 Volumes</u>

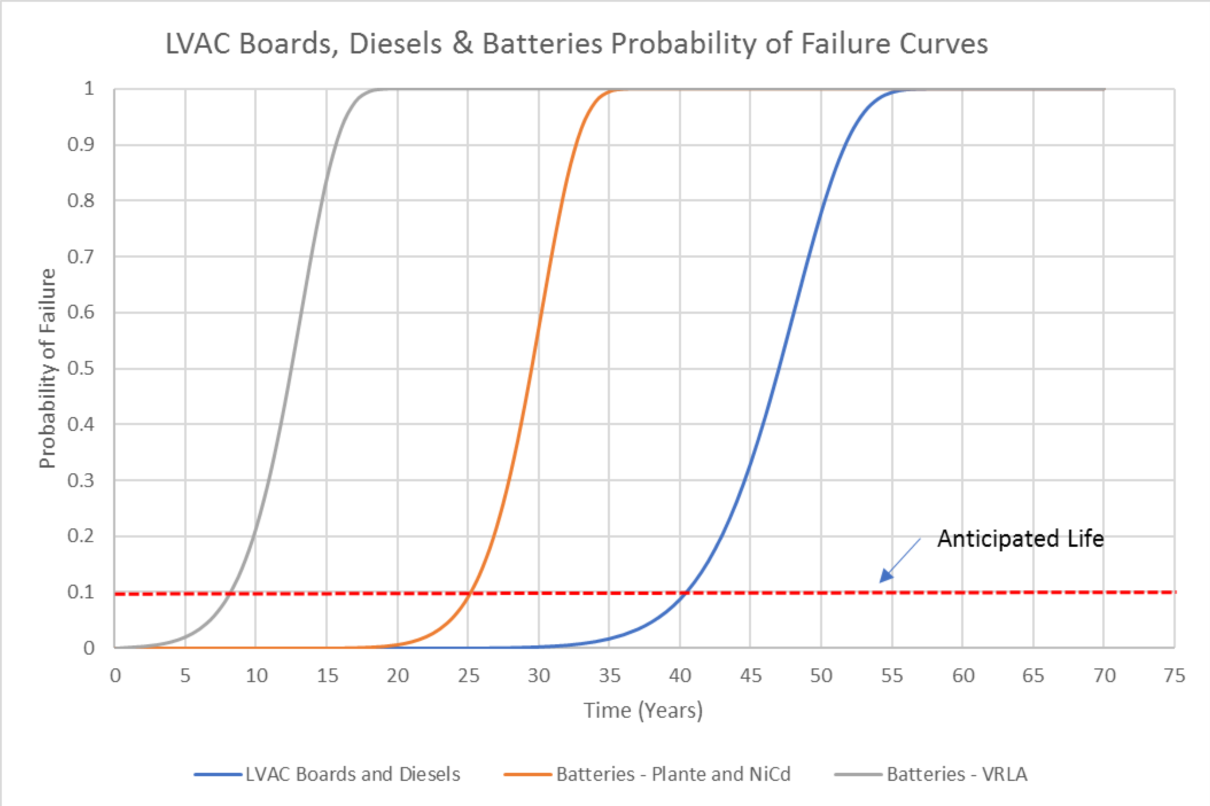
Our stakeholders have told us that a safe and reliable network is one of their priorities. In order to maintain today's levels of reliability for non-lead assets we have used our established asset policies and guidance to identify assets requiring intervention during T2. These policies have not changed during T1 and it is therefore appropriate to use them to determine T2 interventions. These policies include anticipated asset lives (based on our understanding of asset deterioration), asset condition, obsolescence and known family issues.

The key drivers for intervention on substation auxiliary systems in T2 are age, obsolescence, maintainability, condition and performance.

The below chart depicts the probability of failure curves for:

- LVAC Boards and Diesels (anticipated life of 40 years)
- Planté and Ni-Cd Batteries (anticipated life of 25 years)
- VRLA Batteries (anticipated life of 8 years)

This rise in probability of failure is used in the CBA analysis section. The anticipated life of an asset is when its probability of failure reaches approximately 10%. At this point, the subsequent rise in probability of failure then averages to approximately 20% within a 5 year period (1 in 5 chance of failure).



1. DC batteries - interventions are identified by:
    a. Anticipated Life, primarily based on cell technology type
    b. Maintenance and inspection testing comprising of two-monthly routines, annual 'basic' and 6 yearly 'major' maintenances. The condition data captured on these activities from visual inspection to conductance testing, prioritises those assets that are found to be in poor health.

The relatively short life of DC batteries, the volume of batteries and their criticality to substation supplies means that this is an appropriate driver for investment. However, condition is used to prioritise the timing of interventions in the short term.

For DC batteries, the opportunity is normally taken to replace both battery systems (system 1 and 2) which are of similar age and condition. For the avoidance of doubt, these are classed as separate interventions in this paper (each battery unit is counted as one intervention). Batteries have a service life of typically 8 years (VRLA) or 25 years (Planté, Ni-Cd). The replacement of battery chargers and now upgrades to rooms to bring them to standard BS EN 50272-2 is carried out in conjunction with the battery replacement to reduce system access requirements over the lifetime of the asset.

There are [redacted] units which require intervention during T2. The volumes requiring intervention in both T1 and T2 are greater ([redacted]) than the recorded population of DC batteries ([redacted]). This is because VRLA DC batteries have a life (8 years) that is shorter than the 13-year timespan of T1 and T2.

	Planté	VRLA	Ni-Cd
Population	[redacted]	[redacted]	[redacted]
T2 interventions (1 intervention = 1 battery replacement)	[redacted]	[redacted]	[redacted]
% of population	[redacted]	[redacted]	[redacted]

DC batteries spend underpins black start resilience by providing a reliable DC power supply to the telecoms, protection and control elements of a substation that will enable the timely restoration of power flow in the event of a system supply disruption.

2. LVAC systems

In line with our policies and technical guidance, an Asset Health (AH) scoring system has been used for LVAC distribution boards and diesel generators. We have applied weightings to the factors so that the score places less emphasis on anticipated life (max score of 50 based on anticipated life alone) and higher scores are driven by condition and performance.

$$AH\ Score = \left(1 - \left(1 - 0.5 * \frac{Anticipated\ Life}{100}\right)\left(1 - 0.9 * \frac{Condition \,\&\, Performance}{100}\right)\left(1 - 0.5 * \frac{Family\ History}{100}\right)\left(1 - 0.5 * \frac{Obsolesence}{100}\right)\right) * 100$$

The inputs used to identify the LVAC system and diesel generator assets requiring intervention during T2 are outlined below.

Asset Health Input	Description	Scoring Criteria
Anticipated Life Score	Only included if asset is beyond its 'Latest Onset of Significant Unreliability' as per Policy	Only assets greater than 50 years old (1968) are assigned a max Anticipated Life score of [redacted]. Otherwise this factor scores [redacted]
Condition & Performance Score	Cost and number of defects and any specific concerns for reliability reported. Increasing defect count and severity is a trigger for further investigation that could lead to minor or major investment.	More than [redacted] defects in the last ten years averaging more than £[redacted]. Condition concerns reported for short term reliability (0-5 years) – [redacted] [redacted] defects in the last 10 years averaging £[redacted]. Condition concerns reported for medium term reliability (5-10 years) – [redacted] Otherwise this factor scores [redacted]
Family History	Based on the proportion of family with high condition scores	[redacted] or more of the family the asset belongs to has a performance and condition score of 50 or more – [redacted] Otherwise this factor scores [redacted]
Obsolete/Unsupported	Spares availability	No spares available – [redacted] Routine spares provision is limited to grey spares only – [redacted] Otherwise this factor scores [redacted]

Our asset health review in 2018/19 identified [redacted] boards at [redacted] sites which require a full intervention within the next 10 years. [redacted] of these [redacted] LVAC systems ([redacted]%) have a driver based on anticipated life. Most of these assets were installed in the 1960s and their age impacts sourcing of spares. These installations are also likely to not meet modern wiring regulations.

[redacted]

The above chart shows the population of boards at different Asset Health Score bands with their equivalent Asset Health Index; AHI1 – 'unacceptable condition in a relatively short period of time (less than 5 years)', AHI2 – 'uncertainty regarding medium to long term health. Expected to deteriorate to AHI 1 within 5 to 10 years', AHI3 – 'low level of faults or defects across the family – some with the potential to cause failure', AHI4 – 'good condition – no known specific or general problems within the family'.

There are [redacted] LVAC systems at [redacted] sites that require a full intervention during T2. A list of these assets and their Asset Health Index can be found in the appendix. Together with the Phase 4 Scheme which is still ongoing in T1 (*12 sites outstanding*), these volumes provide coverage of a total of [redacted] *sites* ([redacted]), or [redacted]% of the drivers within the next 10 years. All AHI1 assets are addressed before the end of T2. The remaining [redacted]% are expected to be delivered in the T3 period. It is anticipated that an additional [redacted] LVAC systems require a minor capex intervention during T2 to manage the reliability of the full system.

LVAC systems spend underpins black start resilience by providing a reliable distribution of backup AC power when normal incoming supplies fail. This AC power is required to charge the batteries that provide DC power supply to the telecoms, protection and control equipment and to the AC motors that drive disconnector switches automatically. These will enable the timely restoration of power flow in the event of a system supply disruption.

3. Diesel generators

Our asset health review in 2018/19 identified [redacted] diesel generators at [redacted] sites which require intervention within the next 10 years. Approximately [redacted]% of the drivers for intervention are based on anticipated life alone. There are known obsolescence (linked to age) or defect issues associated with the remaining drivers.

[redacted]

The above chart shows the population of boards at different Asset Health Score bands with their equivalent Asset Health Index; AHI1 – 'unacceptable condition in a relatively short period of time (less than 5 years)', AHI2 – 'uncertainty regarding medium to long term health. Expected to deteriorate to AHI 1 within 5 to 10 years', AHI3 – 'low level of faults or defects across the family – some with the potential to cause failure', AHI4 – 'good condition – no known specific or general problems within the family'.

There are [redacted] diesel generators at [redacted] sites which require a full intervention during T2. A list of these assets and their Asset Health Index can be found in the appendix. Together with the Phase 4 Scheme which is still ongoing in T1 ([redacted] *sites with replacement diesels outstanding*), these volumes provide coverage of a total of [redacted] *sites* ([redacted]), or [redacted]% of the drivers within the next 10 years. All AHI1 assets are addressed before the end of T2. The remaining [redacted]% are expected to be delivered in the T3 period. It is anticipated that there are an additional [redacted] diesel generators that require a minor capex intervention during T2 to manage the reliability of the rest of the population (e.g. control panels, fuel pumps etc).

4. OPTIONEERING

To maintain the reliability of the substation auxiliary systems and address the drivers for intervention arising from the 2018/19 asset health review, three approaches to intervention are considered:

1. *Do minimum* - this option assumes that no capital investment is made. The current maintenance (opex) regime continues. Any obsolescence issues that may arise in the completion of maintenance are not factored into the cost assessment. Instead these are drawn out qualitatively in the option selection that takes place once a quantified Cost Benefit Analysis (CBA) has been completed.
2. *Targeted component replacement* - unhealthy components are swapped out for new. As the systems rely on distinct components that need to work in sequences, the overall health of the system is only as good as the poorest health component within it (i.e. weakest link in chain). However, if sufficient overall life is remaining in the asset, targeted replacement of components may be the best option.
3. *Full replacement* - the whole asset is replaced.

The replacement scope of LVAC systems and diesel generators varies given the site context:

a. Substation LVAC ownership arrangements are not identical at all sites (for example some are partially owned by DNOs or generators) and this has an influence on the scope and cost of the works.

b. Replacement of LVAC distribution boards is biased towards full replacement for aged systems. The criticality of LVAC distribution systems and their design, make the gathering of internal condition data challenging, as outages associated with critical loads are difficult to manage. Many of the distribution boards were installed as part of the original substation build, and therefore are obsolete with the manufacturers offering no spares support. If component failure occurs (such as circuit breaker/isolator) the only short-term option is to replace with a modern equivalent, which is often difficult to fit to the existing bus-bars, and usually requires considerable site engineering/ modification. Many of the LVAC distribution systems use fuse carriers and circuit breaker arc chutes which contain asbestos for heat resistant shielding. Under replacement activity, this equipment will require management as a hazardous waste.

c. Diesel generators are replaced based on age, condition and availability of spares support. This work also includes the installation of a standby generator connection point. This facilitates the connection of an additional fully rated standby generator in the event of installed standby generator failure or during maintenance.

At the May 2019 reliability workshop, stakeholders stated that they expect a greater emphasis on condition assessment in our T2 plan. The option selection needs to consider the spectrum of ‘do minimum’, partial replacement/ refurbishment and full replacement choices by utilising a condition and load survey of every site in the scope of this paper. An example of this can be seen in the case study of Pembroke (included in the CBA and in more detail in the appendix). We have determined that full board replacement is likely to be chosen at all sites in the T2 plan to enable future maintenance, inspection and testing. Obsolescence and maintainability are consistent issues reported by National Grid Electricity Transmission Operations teams. The criticality of these assets to black start also makes their inspection and testing (the ongoing verification of condition) an important part of delivering reliability and resilience. Funding for the minor capex interventions will replace components like programmable logic controllers (PLCs), switchgear and wiring in the population without the need for full replacement of the LVAC Board.

5. DETAILED ANALYSIS AND CBA

In this section, examples are used to illustrate the consequences of substation auxiliary system failures when a loss of normal substation site supplies occurs. As these systems are critical to the restoration of normal power flow, the impact of a loss of transmission supplies is analysed. The 'Value of Lost Load' (VOLL) is employed using the Special Licence Condition 3C value of £[redacted] converted to 18/19 prices ([redacted]). Demand in MW is available from the Common Energy Scenario (one of the Future Energy Scenarios) to understand the consequence of a loss of transmission supply.

The black start resilience of wider society cannot be assumed to be the equal of or better than National Grid Electricity Transmission's own resilience. In the rare event that transmission supply is interrupted, time lost to restoration has a worsening impact on the recovery of normal service to the consumer. If the restoration of transmission power is protracted, the backup supplies of customers may be exhausted, further delaying the overall recovery of normal service. The substation auxiliary system investments outlined in this paper seek to support this timely restoration process.

Failure of LVAC systems in a black start scenario constitutes a 'high impact, low probability' event. It is possible that the lowest cost CBA option is 'Do Minimum'. Sensitivity analysis is required to test the favourability of the options and is evident in the examples below.

Unit costs used in the CBA are based on historic spend in T1 for minor capex and full replacement.

Asset Type	Unit Cost (£m)	Description
Batteries (Full replacement of batteries, chargers and upgrade of rooms)	[redacted]	Average unit price of RIIO T1 battery replacements planned to be delivered in the final years of RIIO T1, including the work required on Battery rooms. Level of work on battery rooms expected in T2, but not on an enduring basis beyond.
LVAC Boards and Distribution (Full Replacement)	[redacted]	Single board replacement
LVAC Boards and Distribution (Minor Capex)	[redacted]	Average unit price of minor capex in RIIO-T1. These represent a blend of options delivered in RIIO T1 from repair, refurb to replacement.
Diesel Generators (Full Replacement)	[redacted]	Single diesel generator replacement
Diesel Generators (Minor Capex)	[redacted]	Average unit price of minor capex in RIIO T1. These represent a blend of options delivered in RIIO-T1 from repair, refurb to replacement.

We have included a set of case studies to demonstrate the approach taken to determine intervention.

Using these case studies as a guide, the T2 forecast volume and spend for substation auxiliary systems is as follows:

Asset Type	**Unit Cost (£m)**	**Total Volume (units)**	**Annual Volume (units)**	**Total Cost (£m)**
Batteries (Full replacement of batteries, chargers and upgrade of rooms in line with unit cost planned in the remainder of T1)	[redacted]	[redacted]	[redacted]	26.95
LVAC Boards and Distribution (Full Replacement)	[redacted]	[redacted]	[redacted]	21.15
LVAC Boards and Distribution (Minor Capex)	[redacted]	[redacted]	[redacted]	4.25
Diesel Generators (Full Replacement)	[redacted]	[redacted]	[redacted]	17.70
Diesel Generators (Minor Capex)	[redacted]	[redacted]	[redacted]	5.00
Total	[redacted]	[redacted]	[redacted]	***75.05***

The unit costs are generated from the National Grid 'Cost Book' which is based on actual spend in these activity areas.

Case Study 1 'Do Minimum' versus Minor versus Major Works on LVAC Board. [redacted]. Justification for a Full Board Replacement

[redacted]

[redacted]

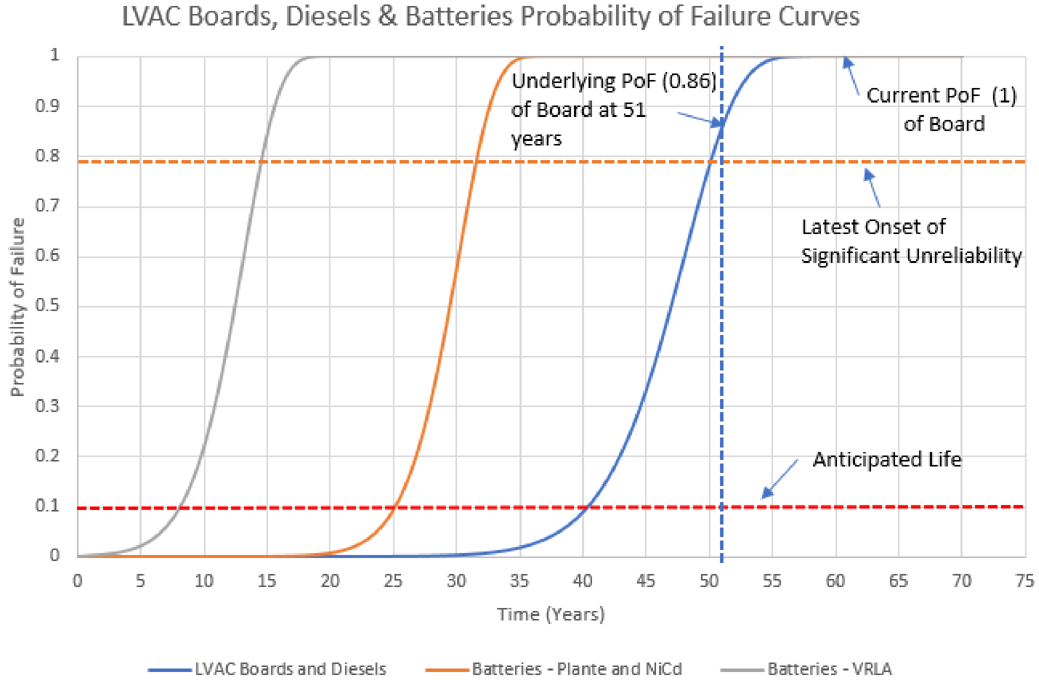
See appendix for more detail.

Two of the options discussed in Section 9 are; minor replacement of sub-components and replacement of the complete LVAC board at the 400kV.

1. How much remaining life is required on an LVAC board to make minor investment favourable?
2. How does this compare to the 'Do Minimum' option?

Probability of Failure (PoF)

LVAC Board



The following assumptions are made about the probability of failure now and the rise in probability of failure over time.

- Assume an LVAC board is in a state requiring replacement (its 'anticipated life') by 40 years of age (Probability of Failure = 0.09)
- Assume the 'latest onset of significant reliability' is reached by 50 years (PoF = 0.78).

- Assume PoF = 1 occurs at 58 years of age as per the above profile
- The LVAC Board was installed in 1968 (51 years ago) so its underlying PoF is 0.86
    - However, the Current PoF is 1, driven by the circuit breaker and auto-changeover issues.
    - This can be reduced to the underlying PoF by either a minor capex (0.86 in the first year) or a full replacement (0) intervention.

[redacted]

- Current Risk of Failure [redacted]
  - o PoF * CoF
  - [redacted]

Options

Baseline - Do Minimum, continue with existing arrangement, manage failures when they arise, live with existing probability that site LV supplies will be interrupted following failure of either the ACBs and/or auto changeover scheme. Rely on manual instead of automatic switching where safe to do so and possible.

1. Replace existing ACBs in 400kV LVAC board, New auto changeover scheme to overcome PLC issues, retain existing running arrangement. Install a connection point for a mobile diesel generator using spare ACB panels in the existing LVAC board.
2. At the 400kV, install new board in the diesel generator room, no transitional board; offline build and transfer of circuits from old to new board in stages Install mobile diesel generator connection point on the new 400kV LVAC board.

Intervention Costs

- Baseline – Assume 0. No PoF reduction achieved
- Option 1 - £[redacted] for minor capex. Small PoF reduction achieved, returning to PoF = 1 in 7 years
- Option 2 - £[redacted] for single full board replacement. Maximum PoF reduction achieved.

Option Analysis

In this analysis we are looking for the lowest impact Total NPV. As these are costs, they appear as negative numbers.

Option	Total NPV (£m)
Baseline - Do Minimum – maintain existing arrangement until full board replacement in the 8th year	-£0.13
1. Minor LVAC Capex followed by Full Board Replacement in the 8th year	-£0.17
2. Full board replacement in the first year	-£0.11
3. Minor LVAC Capex followed by Full Board Replacement in the 21st year	-£0.11

The favourable option is to replace the full board in the first year. The minor capex intervention does not address the fundamental end of life probability of failure associated with the board.

How long would the board have to last to make minor capex favourable?

There would need to be 21 years of life remaining (or the equivalent PoF) in the board to make minor capex favourable NPV to Option 2.

[redacted]

[redacted]

Intervention Cost

- Cost of a new Diesel = £[redacted]
- Assumption on the benefit of a new Diesel: loss of supply recovery is 90% faster (£[redacted] reduction in the consequence cost)

Option Analysis

In this analysis we are looking for the lowest impact Total NPV. As these are costs, they appear as negative numbers.

Option	Total NPV (£m)
Baseline - Do Minimum – maintain existing arrangement	-£0.02
1. Install an NG-owned Diesel Generator	-£0.23
[redacted] Do Minimum – test sensitivity of answer by increasing the assumed duration of a loss of supply to [redacted] hours (Here, a demand value of [redacted]	-£0.26

Option 1 provides direct control of the reliability of the backup supplies and reduces the probability of prolonged loss of supply incidents by enabling remote switching of the substation. However, it would take a loss of supply event of [redacted] hours or more to make option [redacted] favourable. It is unlikely that this duration would occur as manual switchers would be mobilised to site to recover the situation before this time elapsed. Here, the baseline option is favourable.

If the diesel generator had a PoF = 1, the sensitivity analysis would show a break-even point with option 1 at [redacted] hours loss of supply. It is still more likely that National Grid switchers would be available and on site to recover the situation before this time elapsed. When taking the winter peak of [redacted] MW, this reduces further to around [redacted] hours. The baseline option in this case is still marginally favourable as its likely that restoration could be made in a similar time to the [redacted]

Probability of Failure (PoF)

The following assumptions are made about the probability of failure now and the rise in probability of failure over time.

- Current PoF
  - Diesel Pump PoF = 1
  - Rest of the Diesel = 6E-07 (15 years old) based on the probability of failure plot in Case Study Scenario 1)
- How does PoF change over time?
  - assume the remaining life of the board is aligned with its anticipated life curve

Consequence of Failure (CoF)

Here, the consequence of failure is not considered. The diesel generator cannot perform its function (standby power supply) without a fuel pump. This function is required by the substation site, not having a standby supply isn't an option.

Options

Baseline - Replace Fuel Pump Only and Diesel Generator in 25 years

1. Full replacement of diesel generator and fuel pump

Intervention Cost

- Cost of diesel fuel pump work = £[redacted]k
  - PoF reduced to underlying diesel generator life curve
- Cost of diesel generator replacement = £[redacted]k
  - PoF of diesel generator and fuel pump reduced to 0 with a new life of 40 years

Option Analysis

In this analysis we are looking for the lowest impact Total NPV. As these are costs, they appear as negative numbers.

Option	Total NPV (£m)
Baseline - Replace fuel pump only and diesel generator in the future	-£0.11
1. Replace diesel generator and fuel pump	-£0.23

The favourable option is to replace the fuel pump given the expected life remaining on the diesel generator. The output ensures reliable AC supplies to charge batteries and provide power to motors in disconnectors and tap changers. This standby supply ensures the substation retains its protection and control functionality for the next fault, providing system stability and safety from the dangerous overloading of assets.

6. KEY ASSUMPTIONS, RISK AND CONTINGENCY

1. Volumes
    a. Volumes in this paper are not catered for by a Load related or 'Separation of Site Services' scheme
    b. Extra resilience associated with an *enhanced* black start restoration standard is included in paper A10.08 'Black Start'. An industry-wide taskforce, led by Department of Business, Energy & Industrial Strategy is presently developing this. The costs associated with this are not included in this paper A9.21. Should the enhanced standard be adopted, the costs associated with it would impact 60 sites within this paper where more advanced battery technology would be deployed
2. Costs
    a. The estimating methodology for capital projects is based around a standard and consistent approach. This is controlled by an in-house, central estimating team (e-Hub) within Capital Delivery Project Controls. The detail of this methodology can be found in NGET_A14.09_Internal Benchmarking of Capex unit costs.
    b. Value of Lost Load (VOLL) is £[redacted]k per MWh (Special Licence Condition 3C £[redacted]k in 18/19 prices). Changes in this may affect the outcomes of cost benefit analysis carried out on these investments.
    c. The level of contingency has been concluded by identifying, assessing and analysing the historical cost-risk drivers, both probabilistic and deterministic, to understand and quantify the relationship between cost and the key technical and/or operations risks realised.
3. Deliverability
    a. Due to the complexity of substation auxiliary systems, considerable outage planning will be required, to enable auxiliary systems to be taken out of service. Constraints may result in the planning of several outages (sub-systems) rather than larger, or complete systems, as the loss of some essential site supplies may be unacceptable.
    b. These interventions will be delivered using internal (SAP and Commissioning Engineer) and external sourcing. Specialist engineering services will be required.
    c. Volumes are deliverable but require a step change from T1.

7. CONCLUSION

The reliability and safe operation of the primary equipment that underpins the transmission network is dependent on the resilience of critical substation auxiliary systems to ensure the timely operation of protection, control and telecommunication functions.

Correct disconnection of faulty primary equipment from the network is of vital importance to prevent or minimise damage to plant and people and to minimise any impact on the operational integrity of the electricity transmission network. Reliable back-up supplies and distribution systems enable the fast restoration of power flow in the event that normal system supplies are lost in a 'Black Start' event.

To ensure the network risk and system reliability levels are maintained in line with policy, cost-effective interventions for £75.05m is required in T2 to deliver the works.

8. OUTPUTS INCLUDED IN RIIO-T1 PLANS

None

Appendix 1: Maintenance - Inspection and Testing

An interval-based maintenance policy is carried out on diesel and battery assets where condition is identified to prompt further investigation where required. Planned maintenance is delivered using both internal and external resources. For example, specialist contracted engineering services are employed on standby diesel generator assets for major and minor maintenance activities. This is supplemented by a routine diesel operational test run (including auto-changeover systems where possible) at 3 and 6 monthly intervals (off and on-load) using internal resources.

However, access to LVAC boards and wiring for intrusive inspection and maintenance is incredibly challenging because of the lack of redundancy in LVAC boards and the system outages required to complete this activity. Additionally, there is a lack of experience and technical knowledge with older equipment amongst maintenance staff and contractors

Periodic inspection and testing of LVAC substation *wiring or 'multicore cabling'* is necessary to prevent, so far as reasonably practicable, danger due to damage and wear that may occur during service life. Compliance with the requirements of BS7671 through a regime of continuous monitoring and maintenance is necessary to provide electrical safety. If wiring is found to be in a state requiring replacement, funding for this activity will be prioritised within the LVAC and wider non-load related allowances. It is likely during T2 that some wiring will be found in a condition requiring replacement and this is one of the uncertainties affecting this part of the business plan. Any investment option selection shall consider the remaining life of the rest of the substation system. This is particularly important if extensive replacement of multicore cabling is required at a site due to its complexity and cost.

In T1, LVAC boards and diesel generators have been surveyed to review their health. The following issues with maintenance, obsolescence and/or defects were found. Further site surveys are planned to be undertaken on boards in T1, with intrusive maintenance and inspection of LV circuit breakers occurring in conjunction with protection interventions. This will involve the creation of new asset inventory data to record the types of circuit breaker in use.

Maintenance	Obsolescence	Defects
Asbestos Lack of isolation Lack of any maintenance in recent history (boards) No ability to connect diesel generator to external load bank Rare use of diesel generators mean that they have problems when they are exercised on test	No spares readily available for the following items as the original equipment manufacturer does not exist or does not support: Control boards Relays Switchgear Diesel generator Battery charger Governor	Alternator Battery Battery charger Control Cooling Enclosure Fire protection Fuel system Programmable Logic Controller (PLC) - this is part of the 'auto changeover' scheme when the incoming supply fails and the diesel generator is required to be switched in.

Scoping End-of-Life Interventions - Uncertainty

There is uncertainty in the forecast for LVAC distribution boards and diesels because the identification of the exact scope of works required at each site is yet to be completed. The unit costs utilised for RIIO T2 reflect the ‘Cost Book’ prices per board and diesel generator. When interventions are made on all or some aspects of these systems, uncertainty is driven by the following:

Driver	Description	Issues Impacting Scope
Condition and Performance of LVAC Boards and Diesels highlighted by the Asset Health Review	Either parts can be retained as is or all aspects require replacement.	***Obsolescence*** – can modern components (e.g. circuit breakers) be fitted to the existing board? ***Load Survey*** – is the existing diesel and board sized correctly for the current and future load requirements? ***Maintainability*** – can the current board be isolated and earthed in appropriate sections for inspection and testing?
National Grid Policy on ‘back-up’ or ‘standby’ supplies	To provide for essential load: 1. Permanent Supply 2. Automatic Standby Supply 3. Mobile Standby Supply Connection Point	Some sites do not have an automatic starting standby generator system, fully-rated standby diesel, or an emergency diesel connection point. This impacts on the Black Start resilience of the substation site, in the event the normal incoming supply fails.
Condition and Performance of Wiring	Compliance with the requirements of BS7671 through a regime of continuous monitoring and maintenance is necessary to provide electrical safety.	If wiring is found to be in a state requiring replacement, it can be extensive and complex to do so.
Location of LVAC Distribution Board	The volume of space that the current board/ set of boards is housed in. Contains entry/exit points and pathways for a large quantity of wiring.	There may not be enough space to locate a new board whilst the existing one is in service. New accommodation may need to be adapted in another building or a new building may require construction.
Existing Flood Defence Scheme	Cable ducts and troughs grouted and sealed to provide flood protection.	More labour intensive to replace cabling and reinstate flood defence measures.
[redacted]		

[redacted]

[redacted]

Appendix Sites with LVAC Board and Diesel Drivers

Substation auxiliary T2 interventions

LVAC Distribution Boards	AHI1	AHI2	AHI3	AHI4
400kV Sites	[redacted]			
275kV Sites				
132kV Sites				
<132kV Sites				

Diesel Generators	AHI1	AHI2	AHI3	AHI4
400kV Sites	[redacted]			
275kV Sites				
132kV Sites				
<132kV Sites				

LVAC Distribution Boards

This list has been redacted

Diesel Generators

This list has been redacted

Appendix Sites versus Battery Type

Battery Systems	VRLA	Ni-CD	Plante	Total
400kV Sites	[redacted]	[redacted]	[redacted]	[redacted]
275kV Sites	[redacted]	[redacted]	[redacted]	[redacted]
132kV Sites	[redacted]	[redacted]	[redacted]	[redacted]
<132kV Sites	[redacted]	[redacted]	[redacted]	[redacted]
Total Population	[redacted]	[redacted]	[redacted]	[redacted]
Total T2 Interventions	[redacted]	[redacted]	[redacted]	[redacted]
% of Population	[redacted]	[redacted]	[redacted]	[redacted]