Investment Decision Pack

A9.08 – Dinorwig-Pentir Cables

December 2019

As a part of the NGET Business Plan Submission

nationalgrid

Engineering Justification Paper; Non-Load Related Dinorwig-Pentir Cables			
Asset Family	Underground Cables		
Primary Investment Driver	Monetised Risk (Lead assets)		
Reference	A9.08		
Output Asset Types	**Equipment Type**		**Volume (on)**
	400kV XLPE Cable		[redacted] km
	GIS Bays (circuit breakers, earth switches, disconnectors, cable sealing ends and busbar systems)		[redacted] bays
	AIS Bay (circuit breaker, earth switch, disconnector, busbar system and cable sealing ends)		[redacted] bay
Cost (T2 schemes proposal)	£[redacted]m		
Delivery Year(s)	2021 – 2026		
Reporting Table	C2.2A		
Outputs included in RIIO T1 Business Plan	None		
Spend Apportionment	**T1**	**T2**	**T3**
	£[redacted]m	£[redacted]m	£[redacted]m

Contents

1. EXECUTIVE SUMMARY

This report justifies the RIIO-T2 expenditure of £[redacted] to deliver the replacement of the Dinorwig – Pentir cables and the associated substation works at Dinorwig and Pentir over the period 2021-2026. [redacted] km of [redacted] oil filled cable will be replaced with [redacted] km of XLPE cable.

The Dinorwig-Pentir circuits connect the Dinorwig power station to the transmission network. Dinorwig power station is the only pumped hydro power station in England and Wales, and provides system critical response and reserve services to the network. As these are the only circuits connecting Dinorwig to the transmission system, outages of these circuits result in high constraint costs. If no action is taken to replace the cables with their modern equivalent then the cables are at [redacted] leading to systems outages and availability (and increased energy not supplied), safety incidents and increased maintenance costs.

The risk impact of the Dinowig-Pentir circuits in the RIIO-T2 plan, contributes to a [redacted] reduction than the uncontrained increase in monetise risk. This is in part due to bringing forward the replacement date of the second circuit into RIIO-T2 (rather than the later date of 2031).

The result of optioneering proposes a three-circuit offline cable solution and full substation replacement delivered by 2026. The options analysis considered the balance of capital costs against operational costs over the construction period and the whole life of the asset to ensure delivery of the most value to consumers.

This report justifies the scope and cost for the replacement of these cables, and represents value for money for consumers and customers and ensures the least disruption for local businesses and communities.

2. INTRODUCTION

This report is an addition to the Underground Cable justification report (A9.07) and is specifically relevant to the Dinorwig-Pentir underground cables replacement strategy.

Underground cabling is one of two main options for connecting electricity infrastructure including power stations, High Voltage (HV) substations, and demand centres. The other option being Overhead Lines (OHL).

Although, underground cabling is on average more expensive than OHL per kilometre, they have the advantage of reduced visual impact for areas where OHLs are not appropriate or cannot get access (e.g. urban areas, river crossings and subsea applications). This makes underground cabling the best solution for conservation areas, green spaces, and densely populated areas such as central London, where space is at a premium.

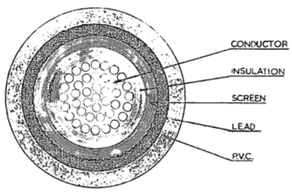
Underground cables can be broadly divided into two categories, Transmission (or Lead Cables) and Substation (or Non-Lead Cables). National Grid owns and operate around [redacted] km of High Voltage Alternating Current (HVAC) cables at voltages from 3.3kV to 400kV. We have [redacted] km of underground cables on the network with an average age of 30.4 years.

Substation cables typically operate at voltages of 132kV or lower and provide links within substations where busbars or OHLs are not suitable. These cable systems are typically shorter than 1km in length.

High Voltage Cable Types

High Voltage cables consist of three major components: conductor, insulation and protective jacket. Cables are mainly distinguished by their insulation type with 3 main technologies types being the subject of this report (Table 1):

Table 1: Overview of cable technology type

Type	Description	Diagram
Mass Impregnated Non-Draining (MIND)	• Paper insulation wrapped around a central conductor, impregnated with viscous resin-based compounds • Largely obsolete technology • Utilised by NGET up to 66kV • Installed 1952-1992	
Fluid Filled Cable (FFC)	• Paper insulation saturated with low viscosity oil fed from pressurised tanks via an oil duct • Mature technology used at all voltages • Support reducing worldwide as market moves towards XLPE • Installed 1952-2006	
Cross-Linked Polyethylene (XLPE)	• Extruded polyethylene (plastic) insulation surrounding a conductor (aluminium or copper) • Mature technology and used at all NGET transmission voltages • Installed 1990-present	

Many of National Grid’s existing underground cable routes were installed over 50 years ago, when the main cable technology were MIND and fluid filled cable. Over time the outer sheath can degrade, leading to a risk of oil-filled cables leaking oil into cable ducts and the surrounding soil.

Modern cables are typically XLPE technology except for where specific technical or installation requirements require a different technology (e.g. HVDC connections or fault repairs).

3. RIIO-T1 VOLUMES AND PERFORMANCE

During RIIO-T1, no work was initially planned for the Dinorwig-Pentir cable circuits, however, due to the increased rate of deterioration of the cables as evidenced by the joint bay failures and increase in maintenance costs, this work has been accelerated.

Initially, additional monitoring equipment was installed to better understand their condition, which identified that the recent changes in power station loading cycles have been subjecting the cables to increased thermo-mechanical forces than previously experienced. This change has affected the natural settled dynamics of the cable.

Following continued concerns over the cable conditions a replacement strategy and development works (cost totalling £[redacted]) were commenced in RIIO-T1 and replacement planned in RIIO-T2.

4. INVESTMENT NEED

4.1 Investment Drivers

Feedback from our programme of stakeholder engagement indicates that consumers and customers want us to maintain network risk at the current level. If we do not intervene on assets during RIIO-T2 and beyond, network (or asset) risk will rise, which will increase energy not supplied to our customers. The rate at which this risk rises, informs the volumes required to be replaced in any given period. This rate is informed by the probability of failure (PoF) and the consequences of failure (CoF), as set out in Ofgem's NARMs methodology.

The section below sets out the need for undertaking this intervention strategy for Dinorwig-Pentir to continue to maintain network risks at our current levels for consumers.

4.1.1 Cable Circuits

The Dinorwig–Pentir cable circuits are the only connection between Dinorwig Power Station, a [redacted] MW pumped storage facility, and the transmission network. Dinorwig Power Station is an important generator for the Electricity System Operator (ESO) as it fosters liquidity of the electricity market and provides fast generation response to the GB transmission system to mitigate instances of low frequency. When Dinorwig Power Station is unavailable there is less competition within the electricity market for certain services. Anticipated changes in the GB Electricity Market, due to increased demand from electrification of transport and heat mean these costs are likely to increase in the future.

Whilst pumping, Dinorwig represents the single largest loss on the system. This requires the Electricity System Operator (ESO) to hold generation reserve to mitigate negative effects on the wider system. This represents a cost for end consumers which historic data shows can be up to £[redacted] per day and means outages on either or both cable circuits must be managed.

In a ten-year period, the Dinorwig-Pentir cable circuits have been out of service frequently: a total of [redacted] days and [redacted] days for circuit 1 and circuit 2, respectively. This figure is for planned and unplanned outages and represents an average time of [redacted] weeks per year per circuit. These outages are linked to known condition issues and route specific issues associated with the cables. A summary of both are presented in Table 2 below.

Table 2: List of known conditions and route specific issues

Known condition issues	**Route specific issues:**
Joint failures have been encountered on both circuits (2002, 2012, 2013). Investigations have shown that cable joints have been subjected to thermo-mechanical forces caused by constant heating and cooling due to load cycling. This has accelerated the rate of cable degradation beyond those that were anticipated.	The proximity between the cables has meant work cannot be conducted on one circuit whilst the other circuit is in service, therefore, both circuits must be taken out of service for cable maintenance work to be undertaken.
The plastic outer sheath of the cable is prone to cracking (see Figure 2) and requires annual inspection and maintenance. If the cable sheath is not repaired properly this will lead to more regular faults and eventually cable failure. The only way to resolve this issue permanently is to replace the cable.	All cables and joints are surrounded by a Cement Bound Sand (CBS) backfill material. This is standard practice due to the material's thermal properties but means that fault location and repair is time-consuming and requires specialist equipment to expose the cables for repair (see Figure 1).
An inherent failure mode associated with the cooling pipes means they are prone to longitudinal cracking (splits along the length of the pipe) when subjected to	Water cooling pipes are laid between and parallel to the cables and are surrounded by the same backfill material as the cables.

higher pressures. When this occurs the cooling pipe must be replaced.	
The cooling system requires constant monitoring and maintenance to ensure it is working correctly. Loss of cooling due to leaks and valve failure result in a loss of cable transfer capacity.	The cable traverses Snowdonia National Park and runs alongside a Site of Special Scientific Interest (SSSI). Oil leaks associated with the cable pose an environmental risk.
	The cable runs alongside a steam railway in a town that attracts tourists and the local council do not allow roads to be excavated during holiday periods (except for emergencies).

Figure 1: Cable excavation

Figure 2: Sheet cracking

Expenditure associated with managing the cables ‘known conditions’ and ‘routing specific issues’, have been high. Approximately £[redacted] was incurred in maintenance and repair costs between 1998 and 2013 with a further £[redacted] having been spent since 2013. These costs are small in comparison to the system costs of unplanned outages of these cables. As an example, in 2013 constraint costs associated with the repair of a failed joint was circa £[redacted] per day and the outage remained for several weeks. £[redacted] has been spent on monitoring equipment to detect joint failure at the earliest opportunity to mitigate these high system costs. This does not prevent the failure of a cable joint but reduces the time the cable is out of service and enables joint replacement to be planned. As such it is a temporary palliative measure rather than a long-term solution.

4.1.2 Dinorwig 400kV Substation Considerations

Any investment to improve the availability of the connections to Dinorwig Power Station must consider the 400kV substation at Dinorwig which only serves the power station. The substation was installed at the same time as the cable circuits and is an early generation Gas Insulated Substation (GIS) constructed within an underground cavern. It is of non-optimal electrical configuration (due to the space constraints within the mountain) and contributes to the constraints placed upon the availability of Dinorwig. Due to the size of the old GIS equipment there is insufficient space to extend or re-configure the existing substation. However, modern GIS equipment is much smaller in size and would therefore facilitate the reconfiguration of the substation e.g. to accommodate the proposed three-circuit cable solution presented in this paper.

A combined replacement (coordinating work with the generator to manage the impact of outages to the system) is the most cost effective for the following reasons. The substation bays are due for refurbishment in 2020 to ensure they reach their predicted end of life in 2031/2032, however, this equipment is obsolete and largely unsupported by the original equipment manufacturer, providing more concerns for the availability of spare parts. Furthermore, the generator is planning a phased replacement of all High Voltage and associated equipment within the mountain complex.

From an environmental perspective, replacing the substation switchgear would remove [redacted] kg of SF_6 ([redacted] of National Grid's inventory) from the network. This would be replaced with modern, lower leakage equipment containing much less SF_6 unless SF_6-free options become commercially available in which case these alternatives will be considered.

Finally, the considerable system cost associated with asset replacement work means there are considerable benefits in aligning outages wherever possible.

4.2 How Asset Risk is Modelled Using Monetised Risk

We assess the need for intervention on an asset-by-asset basis (overview of approach is provided in Appendix A). The key considerations feeding into our assessment are set out below.

4.2.2. Assessment of Dinorwig-Pentir Circuit

The key factors to consider when determining the needs to replace cables, are the asset age, the risks associated with known failure modes, historical performance, environmental and safety factors and forensic evidence.

Cables are typically made up of a small number of high-value assets with high criticality and location-specific installation and environmental concerns. Dinorwig-Pentir is one such route. Optimal replacement of these assets requires careful consideration of aspects such as replacement timescales and deliverability in addition to the more technical considerations around asset condition and performance.

Condition and fault data are used to generate an End of Life (EOL) modifier score between 0 and 100 which is related to the probability of failure (PoF) of the asset as shown in Figure 3, which is the specific curve for the cable type found on both the Dinorwig-Pentir cables.

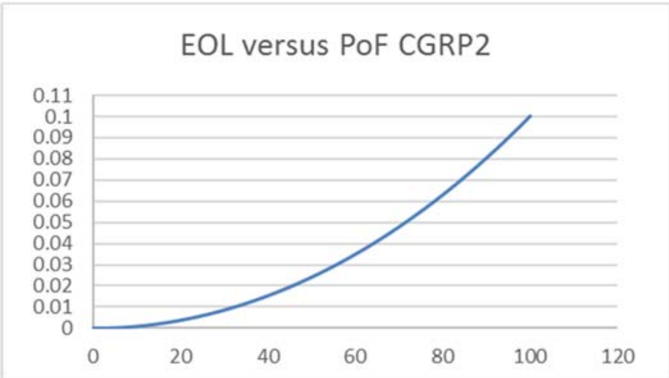


Figure 3: Probability of Failure vs End-of-Life Modifier curve

The end of life modifier is mapped onto our deterioration curves to determine a probability of failure. The probability of failure also maps to an equivalent age as shown in Figure 4. This equivalent age represents the state of the asset given the life it has experienced. There are instances where an asset has an equivalent age greater than its actual age as it has deteriorated quicker than expected. The equivalent age can be used as the starting point on a curve to forecast probability of failure. The target replacement date of the cable is when the effective age reaches the anticipated asset life of the cable.

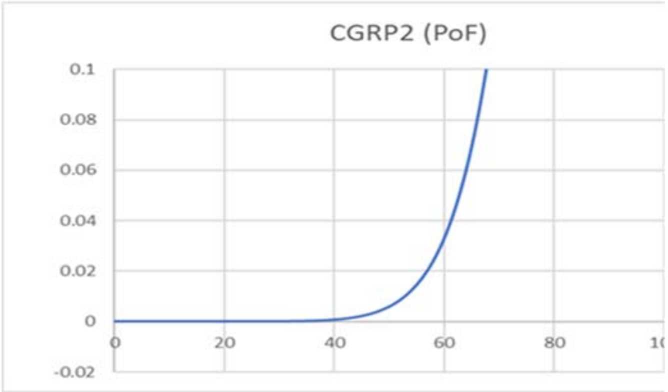


Figure 4: Probability of Failure vs Asset Equivalent Age for cable family type

The probability of failure is combined with the consequence of failure (expressed in £) to give a risk score (also expressed in £) for each asset. The sum of all these asset risks is equal to the network risk associated with the end of life failure modes.

Both Dinorwig-Pentir cables were installed at the same time and are of the same cable type. They occupy the same environment and merit the same system importance. From a Monetised Risk perspective, the only differentiating factor is the number of faults and defects each cable has experienced which gives a condition score that is higher for cable 1 than for cable 2. The methodology produces replacement dates for the Dinorwig – Pentir cables of 2026 for cable 1 and 2031 for cable 2 (Table 3).

Table 3: Cable Asset List

Cable	Length (km)	Optimised Replacement Date
Dinorwig - Pentir 1	[redacted]	2026
Dinorwig - Pentir 2	[redacted]	2031

4.1.2.1 Cable Monetised Risk During RIIO-T2

As noted in Section 4.1, stakeholders want us to maintain the current level of risk across our network and the assets detailed in this report directly influence the reliability and security of supply of the network. If no action is taken the Underground Cables would be at risk of condition related failure leading to system outages and availability (and potential Energy Not Supplied events), safety incidents and increased maintenance costs. By delivering on the planned replacements, National Grid will continue to maintain risks at the current levels as per stakeholder feedback.

Figure 5 shows the impact on monetised risk positions (an End of Life risk delta of £[redacted]m) for Underground Cables if no replacements are carried out in RIIO-T2. Figure 6 shows the risk delta of the cable assets in the RIIO-T2 plan.

[redacted]

Figure 5: Unconstained risk, underground cables

[redacted]

Figure 6: Risk mitigation during RIIO-T2 by asset subdivision

The risk impact of the Dinowig-Pentir circuits in the RIIO-T2 plan, contributes to a larger risk reduction than the uncontrained increase in monetise risk. This is in part due to bringing forward the replacement date of the second ciruict into RIIO-T2 (rather than 2031). Section 5 covers the optioneeiring, cost benefit analysis and qualitative assessment associated with the inclusion of both the Dinorwig-Pentir circuits in RIIO-T2, compared to a staggered approach (Option 1).

5. OPTIONEERING

To determine the optimal mix of interventions to make to Underground and Substation Cable assets, a Cost Benefit Analysis (CBA) was undertaken. We have analysed the CBA outputs for each of the options on a whole system basis, together with a wider technical and stakeholder justification for the work proposed to be undertaken. Detail of the analysis and outcome is presented below.

This justification report sets out the range of options we considered which needs to be considered in parallel with the quantitative assessment of the main options which are contained within the Cost Benefit Analysis spreadsheet with the following reference: NGET_A9.08_Dinorwig-Pentir cables_CBA01. Together they provide the comprehensive engineering and economic justification for our proposed costs.

5.1 Approach to Estimating Costs and Benefits

We have used a three-stage approach to identify the most cost-effective package of options for this paper.

1. Firstly, we have **identified potential intervention strategies** for Dinorwig-Pentir Cables. This identified several intervention strategies which were then tested for feasibility/applicability. They include a 'Do Minimum' option for the Cables assets. We have not considered non-network or whole systems options here since these cannot substitute for the type of investment we are considering in this paper.
2. Once the set of feasible options for Cables has been established, we combine these into **packages of options**. Quantitative **Cost Benefit Analysis (CBA)** is carried out on these options packages to identify the most cost effective.
3. We have included Investment Costs and Monetised Network Risk into our quantitative CBA, using the NPV calculation approach in the Ofgem template to arrive at an NPV estimate for each of the option packages. We have not quantified wider societal benefit instead addressed these impacts qualitatively in Section 5.6.

5.2 Option Identification

The proximity of the cables on part of the route means both circuits need to be out of service when work is being conducted on either cable. Replacing each cable at different times on the existing route would result in both circuits being out of service for longer periods than is necessary and generate system costs greater than replacing both circuits at the same time. Outages would need to be taken over several years, which would also cause greater disruption to the local community, local business and the generator (and potentially system operator).

The importance of these circuits to the operation of the generator, the high system costs associated with cable failure and the reported condition of the cable circuits means it is undesirable to delay intervention on Cable 2 beyond the optimised date of 2026.

The system consequence of cable failure is significant and would result in major cost for both National Grid Electricity Transmission (NGET) and ESO. Cable failure would cause an unplanned outage that could last between [redacted] months, which would not be co-ordinated with the customer or the local community and would have a wider system impact.

The optimised replacement dates for all Switchgear at Dinorwig substation is 2031 and 2032. The replacement of these assets, the cables and any high voltage equipment owned by Dinorwig Power Station should ideally be co-ordinated to minimise the system costs. Section 5.3 explores the costs associated with different replacement strategies and identifies a preferred way forward.

Against this background information, the following is a list of possible solutions to replace the Dinorwig–Pentir cables:

- 2 cable solution utilising the existing route;
- 2 cable solution utilising a new route;
- 2 tube Gas Insulated Line (GIL) solution utilising a new route;
- 3 cable solution utilising a new route;
- Overhead Line solution utilising existing route; and
- Cable tunnel utilising a new route.

5.3 Pre-assessment of Options

Prior to undertaking detailed analysis, we identified the following critical challenges that restrict some of the options mentioned above being taking forward:

1. Use of existing route - the main challenge of using the existing route as a replacement option is the high number of double circuit outages that would be required. The proximity of the cable circuits precludes work on one cable whilst the other circuit is in service requiring a significant period over several years when both circuits would be out of service. This would incur very high system costs which outweigh any benefits associated with using the existing route. ***On this basis, the option of using the existing route has been discounted.***
2. Use of a new route (2 or 3 cable) - Using an alternative route would allow most of the construction work to be conducted offline whilst the existing circuits remain in service. Outages would only be required when the new cables are connected to the system. This would greatly reduce the system costs compared to using the existing route whilst maintaining similar construction costs and ***as a result this has been taken forward.***
3. Gas Insulated Line (GIL) - For an offline build, it would be equally viable to use GIL in place of a cable system. The outage requirement and system costs would be similar, but construction costs are predicted to be higher and deliverability is less certain due to technological uncertainties, particularly regarding SF_6-free design of GIL. ***As there are no additional environmental or system benefits of using GIL it has been discounted as an option*** in this analysis however, we will continue to investigate the GIL option through our innovation portfolio such that it could be integrated into our plans when we are confident of deliverability.
4. Tunnel route - Installation of a tunnel route was considered due to limited options of new cables routes and restrictions associated with the existing tunnels. ***The high construction costs (circa £[redacted] million) of this option mean that it was discounted*** when the feasibility of non-tunnel options was confirmed.
5. Permanent or temporary overhead line - ***Overhead line solutions have been discounted based on foreseeable consenting and visual impact challenges*** and likely reputational damage of constructing OHL routes alongside SSSI and sensitive environments. As we are currently working to reduce the visual impact of towers in similar areas this is not considered an appropriate option to pursue.

Further sub-options are considered for Option 2 above (Use of a new route (2 or 3 cable)). As most of the costs generated by these circuits are system operations costs, a third circuit could be incorporated to reduce total costs over the lifetime of the asset. The construction costs would be higher than a two-cable solution, but this is predicted to be offset by the reduced system costs over the lifetime of the asset. Adding a third circuit would require the substation at Dinorwig to be replaced to create enough space for an extra bay connection. This option would need to consider the replacement of the substation at the same time as the cables as all other options consider substation replacement later.

On this basis three options (Table 4) have been shortlisted and subjected to a full CBA.

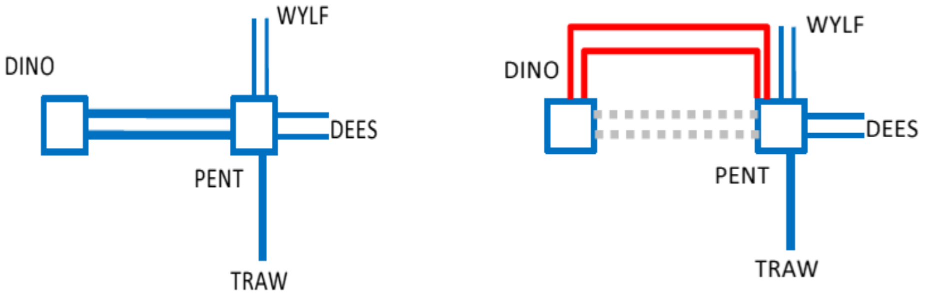
Table 4: Summary of CBA options

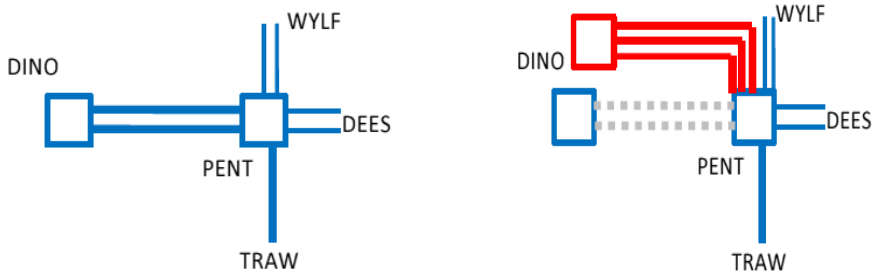
	Description
Option 1	[redacted] circuit offline cable replacement on a new route and substation replacement; all dates aligned with optimized monetised risk outputs
Option 2	[redacted] circuit offline cable solution on a new route and full substation replacement by 2026
Option 3	[redacted] circuit offline cable replacement on a new route by 2026. Substation replacement in 2031.

5.4 Potential Intervention Strategies

Details regarding the CBA can be found in Section 5.5 and the full list of the options considered are detailed in the Table 5 below.

Table 5: Summary of CBA options

Options	**Details**
Baseline: Replacement on failure	This is a minimal costs option where cable faults and repairs would be continued to be managed and cable circuits only replaced following a cable failure.
1: Two circuit offline cable replacement and substation replacement;	The scope for this option includes the offline build of two direct-buried single core per phase cable circuits from Dinorwig to Pentir. The new cable circuits would be terminated into existing substation bays at Dinorwig. One circuit would be replaced by 2026 and the second circuit and substation would be replaced by 2031. The total cable length installed would be [redacted] km  To construct this option, it is assumed one block of outages would be required in 2024 with further outages in 2029/2030/2031 to replace Dinorwig substation.

2: Three circuit offline cable solution and full substation replacement by 2026	The scope for this option includes offline build of three direct buried single core per phase cable circuits from Dinorwig to Pentir, a new double busbar GIS at Dinorwig and a new bay extension at Pentir. The total cable length installed would be [redacted] km.  This option allows the offline build of the circuits and the substation replacement at Dinorwig in such a way that only the first set of required outages would place Dinorwig at a single circuit risk. This reduces the constraint costs associated with this option. The first block of outages would be required in 2023 with further outages in 2024 and 2025.
3: Two circuit offline cable replacement by 2026. Substation replacement in 2031.	This is like Option 1, except that both cables will be replaced by 2026 and the substation will be replaced by 2031. To construct this option a block of outages would be required in 2023 and 2024 with a further set of outages in 2029/2030/2031 to replace Dinorwig substation. The total cable length installed would be [redacted] km.

5.5 Detailed Cost Benefit Analysis

Table 6 provides a summary of the total forecast expenditure and the Total NPV calculated for each option (CBA File: NGET_A9.08_Dinorwig-Pentir cables_CBA01).

For lead assets, such as Transmission cables, as well as the direct costs of investment, the NPV also accounts for:

- Changes in Monetised Risk because of interventions (benefits vs Do Minimum baseline, shown separately in tables below)
- Societal benefits from reduced oil leakage where applicable (versus Do Minimum baseline, incorporated within NPV)
- Avoided costs that would have been incurred by the transmission operator such as constraint charges driven by the system operator
- Safety impacts: preventative measures captured within investment costs, benefits versus Do Minimum baseline captured in NPV

Table 6: Cost Summary

	RIIO-T2 investment cost (£m, undisc)	Total investment cost (£m, undisc)	Change in monetised risk (£m, disc)	Total NPV (£m, disc)	**Total NPV inc monetised risk (£m)**
Option 1	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Option 2	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Option 3	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The preferred option from this analysis is Option 2. The forecast capital expenditure for this option is higher than the alternatives but the reduced requirement for outages during replacement means that the overall cost is lower than both 2-circuit options.

Comparison of the 2-cable options shows that unbundling the cable replacement work to different years in Option 1 causes an increase in capital expenditure. This is expected as mobilisation costs increase. Option 1 aligns one of the cable replacements with the substation replacement reducing the overall system costs due to a reduced outage program. The outcome of this is that Option 3 is marginally better than Option 1 when considering overall costs despite being considerably better when only considering capital expenditure. Option 3 has the additional benefit of reduced impact on local stakeholders and the generator. Replacing cables at different times would mean construction work will last for almost a decade.

Options 2 and 3 were subjected to a CBA by the ESO. The CBA has taken account of the Net Present Costs (NPC) to construct each option as well as ESO operating costs associated with both construction and the lifetime operation of the asset. Costs were calculated for each of the four Future Energy Scenarios and a least Regret Analysis was then performed. The preferred option based on this approach is Option 2, which represents the overall best value.

Table 7 below shows the output of the Least Regrets Analysis:

Table 7: Least Regret outcome

Regrets Table (£m)	Two Degrees	Community Renewables	Steady Progression	Consumer Evolution	Worst Regret
Option 2 (Baseline)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Option 3	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

To change the results of the Least Regret Analysis would require Option 3 to decrease by between £[redacted] - £[redacted] (dependent on energy scenario modelling) or Option 2 to increase by the same amount. Risks and assumptions associated with this selection are detailed in Section 7.

The outcome of the CBA and Least Regret Analysis is that the 3-circuit option is lower in cost than either of the 2-circuit options when lifetime costs are considered. The additional circuit means that lifetime maintenance and unplanned outage costs virtually disappear when compared to 2-circuit options. Replacing the substation at the same time as the cable represents an optimised outage strategy. The overall outage periods are reduced, and the system cost associated with most of these outages disappear. The additional benefit of a third circuit is that the system impact of any future cable failure is drastically reduced as it will not leave Dinorwig Power Station at single circuit risk.

5.6 Qualitative Assessment

A supporting qualitative assessment of the two options was completed and is set in Table 8 below and confirms that Option 2 is the preferred option, while highlighting the improvement in system resilience.

Table 8: Qualitative Assessment; good performance proportional black fill

	Option 2	Option 3
NPC (NGET Capital Costs)	◑	●
NPC (ESO Operation Costs)	●	◔
Programme	●	●
Land & Consents	●	●
Environmental impact	◑	◑
Community impact	●	●
Construction Constraints	◕	●
System Resilience	●	◔
Overall Score	●	◑

There are also several key qualitative considerations to also be aware of:

Environmental Impact – The route runs along the edge of the Snowdonia National Park and near a SSSI. It is important that both the selected option and construction methodology minimise the impact on the environment. Replacement of the oil filed cables with XLPE cables will significantly reduce the environmental risk posed by the assets. In addition, we are also working closely with Natural Resources Wales to ensure minimum environmental impact from our construction activities and to provide a Net Gain to the local environment.

Community impact – Access to repair defects on this route creates disruption for local landowners and residents as the route runs within the road. Replacement of the cables will be disruptive to the local community. The least disruptive option is Option 2 as it minimises the number of circuits being installed and will have the shortest construction programme. Initial feedback from local stakeholders; Gwynedd Council, and Natural Resources Wales have shown support for this option. The project will work closely with local stakeholders to work out ways to minimise the impact of cable construction to the community.

Construction constraints – Geographical constraints and the local environment make replacement of these cables extremely challenging. Option 3 is preferable because it minimises the number of cables which are required to be installed. However, Option 2 could use the existing cable route for the third circuit.

Stakeholder feedback (transmission resilience) – Option 2 provides an additional benefit to the ESO due to the provision of the third circuit because the ESO must secure headroom on the network and Dinorwig is a significant contributor to this service. When Dinorwig is at single circuit risk this headroom must be procured elsewhere at a higher cost. Our customer the owner of Dinorwig Power Station, Engie, is also supportive of this option as it reduces the likelihood of them having their generation constrained.

Overall Option 2 provides the most economical solution considering capital and operation costs. It also aligns to stakeholder feedback for National Grid to continue to maintain the same network reliability standard and consideration for the whole network, provided at the minimum cost overall solution.

6. ASSESSMENT OF COST EFFICIENCY

The engineering solution for Option 2 has been reviewed to ensure a proposal that is the minimal cost solution that addresses the asset condition driver. The route length has been optimised to ensure minimum route length, considering construction and geographical constraints.

The selected option is to ***replace the existing cables and switchgear with a three-circuit cable solution, a new GIS substation at Dinorwig and substation extension at Pentir***. The description below outlines the key design and construction activities required for this option.

Cable:

- Design, installation and commissioning of two new [redacted] km direct buried single core per phase cable circuits between Dinorwig and Pentir Substation rated to [redacted] MVA.
- Design, installation and commissioning of a third [redacted] km direct buried single core per phase cable circuit to Penisa'r Waun where the circuits connects into the existing [redacted] OHL Route.
- Cable accessories including joint bays, bracketing and cable sealing ends for the [redacted] km of new cable.

The cable circuits will be laid along new routes, as identified in the CBA as it is not economical to complete in-situ replacements. The existing route is also along a major road which is not preferred due to major disruption likely to happen and also because there is insufficient space in parts of the route to install another cable. Detailed surveys including Ground Penetrating Radar (GPR), Ecology, Archaeology, and ground investigation will be required in addition to the initial surveys and desk top assessments that have already been completed. Easements for the new route will also need to be obtained, along with consultations with the local council and other local stakeholders to coordinate and enable access for the construction works.

Substation:

- Design, installation and commissioning of a new double busbar substation inside the mountain at Dinorwig to replace the existing single busbar substation. This will be a stage installation over multiple years to align with the cable installation programme and minimise outage requirements. Access to the substation within the mountain is restricted and needs to be fully coordinated with the power station's activities.
- Design, installation and commissioning of a new Air Insulated Switchgear (AIS) bay at Pentir substation. This will require the extension of Pentir substation. Detailed surveys including GPR, Ecology and, ground investigation will be required in addition to initial surveys already completed. The Town and Country Planning Consent will be required for the substation extension.

The scope of the substation works also includes bay, coupler, busbar, and feeder Protection & Control replacement, substation control system up-grade and database changes as well as associated civils, earthing requirements at both sites and upgrades to associated auxiliary equipment where required.

6.1 Benchmarking

[redacted]

[redacted]

[redacted]

7. ASSUMPTIONS, RISKS AND PLAN

The key assumptions, risks and programme plan which will affect RIIO-T2 volumes and costs are set out below:

7.1 Assumption

[redacted]

7.2 Risks

[redacted]

7.3 Indicative Programme

This project is in the development phase currently, and work is progressing in line with the indicative programme below (Figure 10) which will be updated as the project evolves. The programme shows the critical path which means that some activities shown start earlier and take place concurrently.

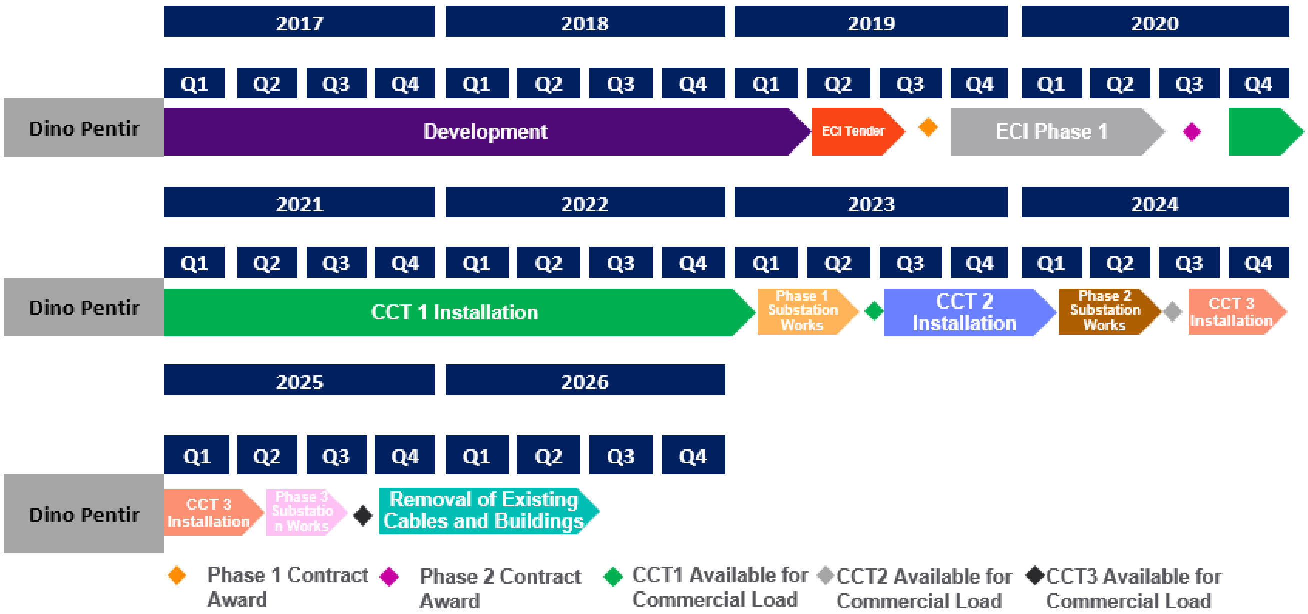


Figure 7: Preliminary development programme for Dinorwig Pentir

8. CONCLUSION

This report provides justification for our RIIO-T2 Dinorwig-Pentir (Lead Asset) replacement plan, based on a monetised risk approach at a total of £[redacted]m over a 5-year T2 period.

Section 3 informs there was no work planned for Dinorwig-Pentir in T1, however, due to the increased rate of deterioration of these cables the work was brought forward to formulate a replacement strategy and developments to be undertaken in T1 with delivery in T2.

Section 4 sets out the investment need for RIIO-T2, covering investment drivers and our approach to identify where interventions are required based on the NARMs methodology. Showing that the risk impact of the Dinowig-Pentir circuits in the RIIO-T2 plan, contributes to a larger risk reduction than the uncontrained increase in monetise risk. This is in part due to bringing forward the replacement date of the second ciruict into RIIO-T2 (rather than the later date of 2031).

Section 5 sets out the Cost Benefit Analysis which utilises the options identified in Section 4 and identified that for Dinorwig-Pentir the proposed option to take forward was Option 2 'Three-circuit single core per phase cable solution with parallel replacement of Dinorwig substation and a bay extension at Pentir'. This option has been identified as the most economic and efficient plan to maintain network reliability, providing the lowest overall cost to the consumer and meets the needs of the ESO, Dinorwig Power Station and stakeholders.

Section 6 explains that the unit costs for the RIIO-T2 Dinorwig-Pentir replacement project is [redacted]

Section 7 identifies the potential risks to the deliverability of the proposed investments and how we propose to mitigate these.

Appendix A – Asset Risk is Modelled Using Monetised Risk

To identify and prioritise assets in need of intervention we apply an assessment of failure *likelihood* and then the impact that any failure may have on the electricity system, the safety of people and the environment. This impact is described as the *criticality* or *consequence* of an asset, should it fail in service.

Failure likelihood may simply be expressed as a probability up to 100% (or 1). This scoring system, which places assets into discrete bands of '1' to '4' was used for all Lead assets for RIIO-T1. It was combined in a matrix with an asset criticality score, again banded from 1 to 4 to arrive at 'Replacement Priorities'. The management of the volumes of assets in each replacement priority band was the basis for the capital plan submitted for RIIO-T1 and one of the Network Output Measures in Special Licence Condition 2C.

The new approach developed for Lead assets and forming the basis of the Network Asset Risk Metric (NARM) achieves a greater level of maturity than the Criticality approach that preceded it. It does this in several ways:

1. A simple probability of failure for each asset provides for a greater resolution of asset risk of failure. The low number of discrete bands employed by the Criticality approach produces a lower resolution measure and doesn't allow for prioritisation within those bands.
2. By monetising the consequences of asset failures, it is possible to measure whole network risk and enable decision making between different asset classes. The Criticality approach outputs volumes of asset 'Replacement Priorities'. It does not define a monetised impact of this risk and there is no equivalency between asset types (e.g. several transformers in Replacement Priority '1' is equal to some volume of overhead line conductor in the same or different replacement priority bands). This impedes any network-wide measure of risk and prioritisation between asset classes.

Our approach is summarised in the Table 11:

Table 9: Summary of NARMs approach for identifying interventions:

Principle	Likelihood of Asset Failure	Consequence of Asset Failure	Risk is a function of Likelihood of an event and its consequence
Monetised Risk	Each asset has a probability of failure. This probability is arrived at by use of an 'End of Life Modifier'. This is a score that maps an asset to a place on a probability of failure plot, specific to each asset class.	For each asset failure event, there may be safety, system and environmental consequences- these are monetised.	The probability of failure of an asset multiplied by the probability of an event with a monetised consequence produces the monetised risk of asset failure. The monetised risk of asset failure can be aggregated to give us a whole network measure of risk and allows us to make prioritisation decisions between different assets.

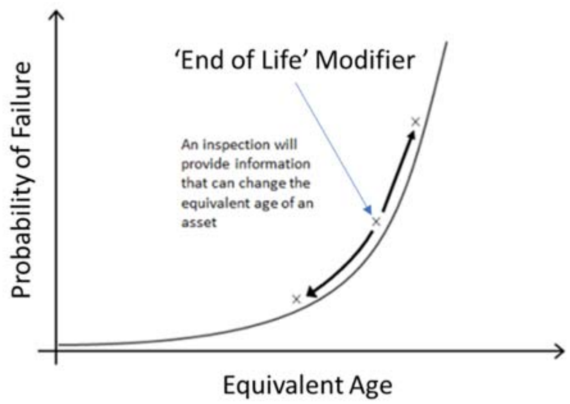


Figure 8: End of Life modifier

Figure11 illustrates the principle of the End of Life Modifier. The rise in monetised risk is governed by an asset's probability of failure plot, the magnitude of the risk at any given point in time is a function of the probability of failure (variable) and the probability of an event with a monetised consequence (fixed).

Our monetised risk calculations are underpinned by detailed condition information for our assets.

Appendix B - Justification Report - RIIO-T2 Lead Asset Tables (Cables)

EoL Score	Description
98-100	Definite evidence exists of a serious problem with the cable which covers a significant portion of the cable or is distributed along the route. The problem has been identified and it is considered that it will lead to an unacceptable condition in a relatively short period of time (within 10 years, due to the long lead times associated with cable replacement schemes, particularly if there is a requirement for tunnelling). This unacceptable condition is likely to lead to cable failure. No cost-effective repair method is available, refurbishment would not address the problem and replacement is therefore the most economic solution.
55-98	Evidence exists of a problem with the cable, possibly with a specific section that is particularly problematic. The cable system would be expected to deteriorate to Priority 1 within 5 years.
21-55	Cable known to have faults or defects – some of which could cause failure. May be a known issue with the cable family.
0-21	Good condition - no known specific or general life limiting problems with the cable.

**This is not related to AHI*

This list has been redacted

Appendix C - Drivers of the EoL Assessments

To determine the end of life assessment of an asset, several different data types may be called upon. Cable assessments rely heavily on modelling the deterioration based on the age of the asset, condition data from periodic inspection and the history of known defects.

The below table summarises the end of life scoring approach for transformers based on the types of data employed and the various factors that make up an assessment.

Cables are inspected on the following frequencies:

Inspection Type	Frequency
Route Walks Monitor 3rd Party Activity, check for signs of leaks, check condition of route markers and trench covers.	3 monthly Frequencies can be increased on high risk circuits.
Routine ▪ Inspect walkways, troughs and cable bridges. ▪ Inspect accessories and pipework containing oil for leaks, particularly near water courses. ▪ Read gauges where fitted. ▪ Examine all visible parts of outer sheath for damage.	3 monthly
Basic ▪ Perform Route Walk and Routine Inspection. ▪ Inspect Equipment, supporting structures and Ancillary Equipment for damage ▪ Check condition of secondary wiring and security of the earth tapes. ▪ Inspect Plumbs where accessible. ▪ Confirm hydraulic profile details of Fluid Filled cables and test alarms.	1 yearly
Major (Outage) ▪ Perform Route Walk and Basic Maintenance. ▪ Inspect and repair link boxes and link Pillars and bonding leads. ▪ Inspect and Test Sheath Voltage Limiter (SVLs). ▪ Perform Serving Tests and repair faults in outage where possible. ▪ Perform Fluid Sampling, Testing and Remedial flushing.	3 yearly for Transmission Routes; 6 yearly for Cables entirely within Substation.
Cable Sealing Ends (CSE) Infra-red and Thermovision inspection of top ends	To Substation Routine frequencies.