Mark Hill Harmonic Mitigation Works

NESO Driven EJP
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SP Energy Networks
RIIO-T3 Business Plan

Mark Hill Harmonic Mitigation Works			
Name of Scheme	SPT-RI-4057 Arecleoch Extension Harmonic Filter		
Investment Driver	Wider Works		
BPDT / Scheme Reference Number	SPT200874		
Outputs	• Flexible AC Transmission Systems (FACTS) – 1 unit • 132Kv CB (Switchgear - Other) – 1 units • Platform creation – 1 unit		
Cost	£7.76m		
Delivery Year	2028		
Applicable Reporting Tables	BPDT (Section 5.1 – Project Meta Data, Section 6.1 – Scheme C&V Load Actuals and 11.10 Contractor Indirects)		
Historic Funding Interactions	N/A		
Interactive Projects	N/A		
Spend Apportionment	ET2	ET3	ET4
	£0.59m	£7.18m	£0.00m

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1. Executive Summary

Network harmonic analysis has identified harmonic issues in the Mark Hill area caused by the large number of windfarms and high capacitance of the cables associated with the connections. It is essential to ensure the electricity system complies with harmonic level standards set by ENA Engineering Recommendation (EREC) G5/5 [1]. This Engineering Justification Paper (EJP) captures the optioneering behind selecting the most efficient and coordinated harmonic mitigation solution.

A complete description of the need case for development of the harmonic filter installation at Arecleoch Extension Windfarm substation in the southwest Scotland (SWS) area of the SPT's 132kV network, as well as full justification for the selected option are provided in the following sections. At a high level, however, the scheme will comprise the following:

- At the proposed Arecleoch Extension Windfarm substation, install a 132kV 20MVAr Harmonic Filter with the associated 132kV circuit breaker and 132kV disconnector.

The expected project delivery date for this reinforcement scheme is October 2028 with a total estimated cost of £7.76m.

This EJP is submitted for Ofgem's assessment of the need case for the project and the selection of the preferred option in order to provide sufficient funding for the pre-construction and early construction activities. It is anticipated that the project will be funded within the RIIO-T3 period by the proposed Load Use It or Lose It (UIOLI) pot, given the project is below the threshold of £25m.

2. Introduction

2.1. Background Information

The southwest Scotland (SWS) area is sparsely populated but rich in natural wind resources. It has therefore attracted an increasing interest from developers wishing to connect to the transmission system. A high number of large windfarms are being connected to relatively weak 132kV networks such as those in SWS 132kV network. These networks are also characterised by the increased use of long cable circuits. The combination of a relatively high source impedance with higher cable capacitance leads to resonance at lower frequencies in the network, typically below the 20th harmonic (1kHz). Therefore, there is a need to ensure the electricity system is complaint with harmonic level standards defined by ENA Engineering Recommendation (EREC) G5/5 [1].

2.2. Mark Hill and Arecleoch Extension Substations

Mark Hill 275kV substation is currently teed-off YY route which connects between Coylton and Auchencrosh 275kV substations. The substation is made up of a single 275kV busbar which currently feeds SGT1 (275/33kV 120MVA), SGT2 (275/132kV 240MVA) and the Kilgallioch Windfarms at 275kV. SGT3 (275/132kV 240MVA) is contracted to be installed 2026 which will accommodate the [redacted] Windfarm connections. The contracted SGT4 (275/132kV 240MVA) will accommodate the connections of both the [redacted] windfarms, with a further extension to the 275kV busbar accommodating the [redacted]. A ±75MVAr STATCOM is also scheduled to be connected via the Mark Hill 132kV network. The STATCOM will be accommodated by installing two new 132kV circuit breakers (and associated disconnector) between the Mark Hill 'A' and 'B' 132kV switchboards.

Arecleoch Extension substation is contracted to be completed by August 2026. It will comprise of a 132kV circuit breaker and associated 132kV disconnector, one 132/33kV 90MVA transformer and one indoor two-panel 33kV metering switchboard.

The existing configuration of transmission network in the area is shown in Figure 1. The diagram indicating geographical location of the proposed scheme can be found in Figure 2.

The volume of existing wind farm connections to Mark Hill is shown in Appendix A, Figure A-3. The Figure A-4 in Appendix A indicates the scale of currently contracted and the existing wind farm developments near Mark Hill. Table 1 shows the currently connected and contracted generation into Mark Hill substation.

A schematic of the proposed the proposed Arecleoch Extension substation with the harmonic filter with connectivity into Mark Hill substation is depicted in Figure 3, where the work scope of SPT-RI-4057 and SPT-RI-282 has been highlighted. Note that only the 132kV circuit breaker with the associated disconnectors between SGT3 132kV side (Mark Hill 'B') and the SGT4 132kV side (Mark Hill 'C') falls under the scope of this project (SPT-RI-4057).

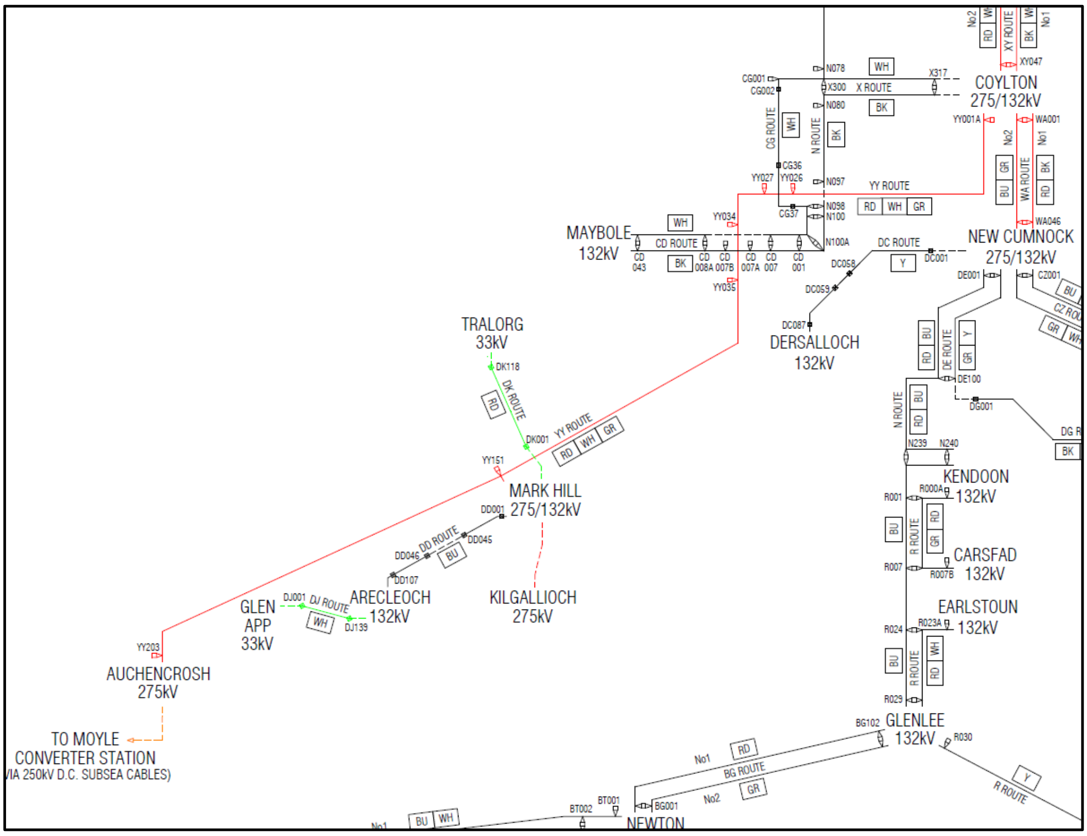

Figure 1 The existing transmission network in the area – extracted from Networks Diagram of the Existing SPT Systems shown in Appendix A (Figure A-1).

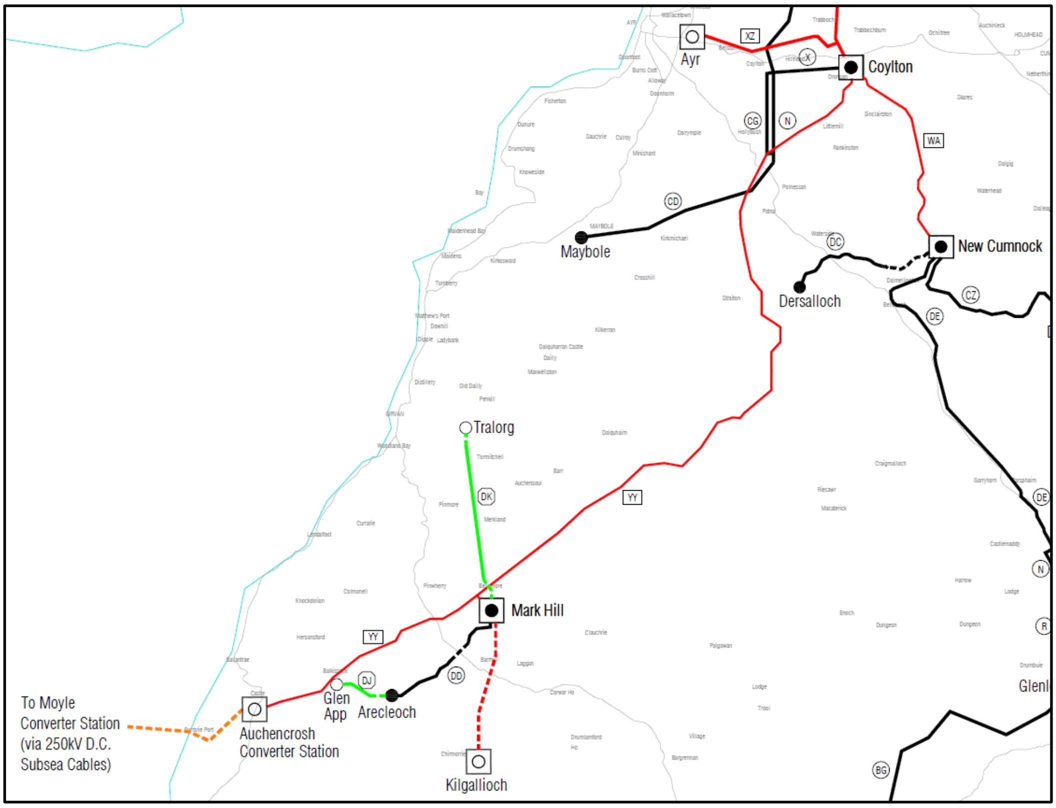

Figure 2 Geographical location of the proposed scheme with respect to the wider network in area - extracted from Networks Diagram Geographical Layout shown in Appendix A (Figure A-2).

Table 1 Mark Hill Connected and Contracted Generation

Connection	Technology	Substation Voltage	TEC (MW)	Status	TECA Score[1]	Energisation Date
Mark Hill Wind Farm	Wind	33kV	56.0	Connected	-	-
Arecleoch	Wind	132kV	120.0	Connected	-	-
Glen App	Wind	132kV	32.2	Connected	-	-
Tralorg	Wind	33kV	20.0	Connected	-	-

[redacted]

[1] Transmission Economic Connections Assessment (TECA) – this assessment represents SPT's best view of the contracted generation landscape to 2036 and forms the basis for evaluating the timely delivery of reinforcement works. This regular assessment activity provides updated projections of renewable development in Scotland, and feeds into SPT's plans, ensuring the investment best meets the needs of users and customers.

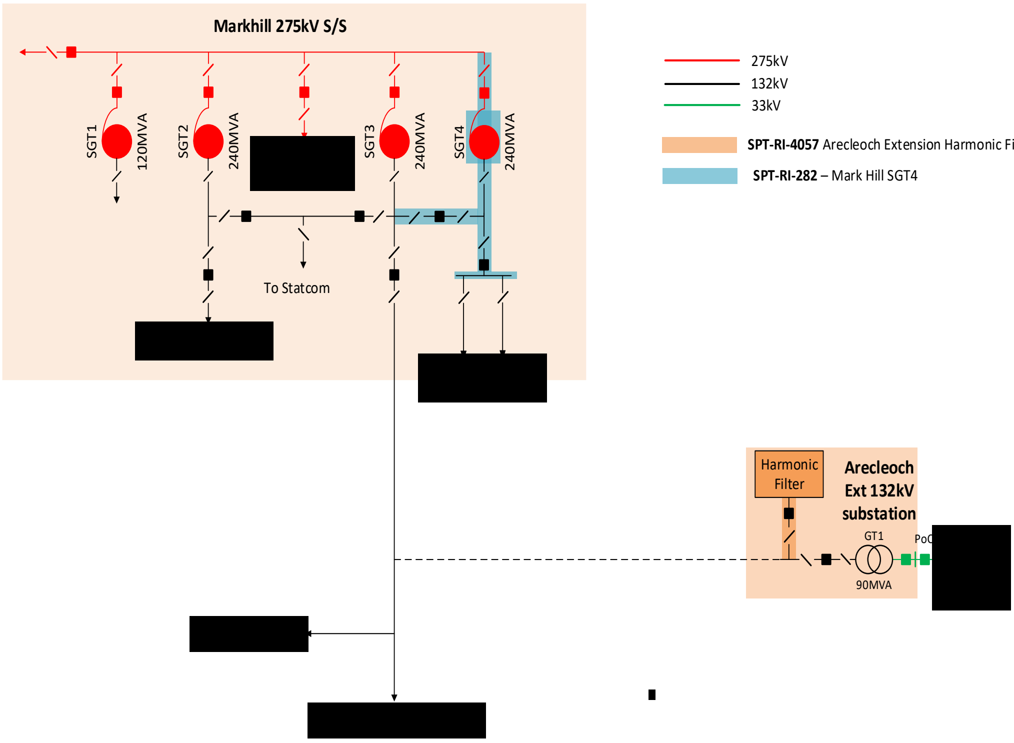

Figure 3 Single Line Diagram of the proposed Mark Hill substation works and the Arecleoch Extension Harmonic Filter.

2.3. Harmonic Compliance

Users are normally responsible for harmonic compliance at their connection point. This is based on the premise that harmonic voltages at the connection point are primarily due to harmonic injection from the User's plant, e.g., in the case of a HVDC converter. In such cases, the User can install harmonic filters to limit the harmonic injection to acceptable limits.

The harmonic injection from most modern wind turbines is very low and high harmonic voltages at the connection point arise primarily due to harmonics that already exist on the network, amplified by a resonant condition. For such resonant conditions, the harmonic levels at the connection point are a strong function of the network characteristics, making it very difficult for a User to design harmonic mitigation e.g.:

- The final network design is uncertain. The resonant frequencies of the network will move under outage conditions, or as the network is developed and new connections are made.
- The design of future windfarms and their harmonic emissions are unknown.
- Network outages (due to faults or for maintenance or construction) can have a significant impact on harmonic resonance.
- Mitigation designed by a User to deal with harmonic resonance is unlikely to be efficient from a whole-system point of view.
- Harmonic resonances do not only affect windfarm connection points but lead to increased harmonic voltages throughout the network. The best location for a harmonic filter may not be at the connection point, but elsewhere in the transmission network.
- Windfarm array cables contribute to the problem. However, high harmonics are due to the amplification of pre-existing background harmonics and generally not harmonics produced by windfarms.

From a 'whole system' point of view, it is therefore economic and efficient for SPT to design and install harmonic mitigation, consistent with the approach taken in RIIO-T2 and also previously proposed by two SP Energy Networks (SPEN) innovation projects; NIA_SPT_1506 and 1610 [2-4] As part of a regulated business, SPEN evaluates compliance of the connection applications with respect to industry standards including compliance with ENA Engineering Recommendation (EREC) G5/5 for harmonic voltage levels. Users are normally responsible for harmonic mitigation at their point of connection. However, it is expected that the harmonic injection from recent wind farm contracts to be very low due to the modern structural design of their wind turbines. With respect to this and also acknowledging the transmission network in SWS area is relatively weak (i.e. has high network impedance), the high harmonic voltages at the connection point arise primarily due to harmonics that already exist on the network. In this case, analyses have shown the most economic and coordinated solution is the installation of standardised damped (C-type) harmonic filters by SPT, consistent with the approach adopted in RIIO-T2 period. A similar approach has been also considered by other transmission owners such as NGET in relation to the connection of large offshore wind farms to a relatively weak 132kV network [6]. This approach also solves a number of problems:

- Harmonic headroom in the network can be managed better and apportioned more fairly.
- Mitigation costs are distributed more equitably between Users e.g., a situation where windfarm B avoids filter installation costs because windfarm A nearby has already installed filters becomes much less likely.
- Reduces the risk of late detection of harmonic problems.
- Improves filter redundancy e.g., a coordinated approach would avoid extensive harmonic problem arising from the failure or unavailability of a single harmonic filter bank. Note that disconnecting the associated windfarm would not necessarily solve the problem.

2.4. Proposed Damped Harmonic Filter

The layout and parameters of the harmonic filter derived from the power system simulations are shown in Figure 4. These parameters are chosen to maintain a homogenous criterion with other filters that are going to be installed in the network but also target problematic harmonic orders in the Mark Hill area. The harmonic filter was tuned to the 7^{th} harmonic order (frequency of 350Hz) with parallel resistance set to 200Ω.

One of the main advantages of the proposed C-type filter design is that it provides damping to a wide range of harmonic frequencies, rather than being sharply tuned to a specific harmonic. This characteristic is important for this project but comes at the expense of increased losses. In such standardised harmonic filters although the devices are similar, note that a discharge VT as installed on MSCDNs is not required for the harmonic filters. After de-energising a harmonic filter, it is sufficient to enforce a time-delay to allow the capacitors to discharge before the filter can be switched in again.

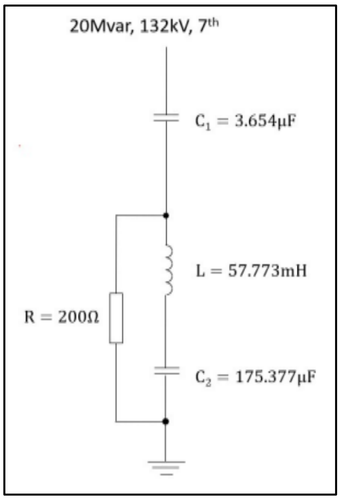

Figure 4 Schematic of the proposed harmonic filter – Filter Layout and Parameters.

Additionally, insulation coordination must be considered in further detail but note that a high-energy surge arrester is likely to be required across the resistor. The switching duty for the associated circuit breaker is not unusually onerous and a standard 132kV circuit breaker rated for capacitive switching duty can be employed.

2.4.1. Losses of the proposed damped harmonic filter

In an ideal scenario, there will not be any current passing through the filter's parallel resistor (i.e., R in Figure 4)[2] at 50Hz frequency, therefore losses at the fundamental frequency are normally very low. In practice, some losses result due to component tolerances or deviation of the system frequency from 50Hz. The filter losses due to harmonic currents depend on the levels of background harmonic distortions and the topology of the network. If it is assumed that all harmonic voltages are at the maximum compatibility limit allowed by EREC G5/5, the losses could be in excess of 500kW. However, such a condition is unlikely to arise and would not persist for very long. Losses are normally not expected to exceed 60kW – 70kW.

Generally, lower harmonic voltage distortions across the network will reduce losses at harmonic frequencies and therefore contribute to a reduction in total network losses. However, extensive network simulations are required to estimate these losses. As harmonic losses are low compared to 50Hz losses, this has not been attempted.

2.4.2. System Requirements

The system requirements and design parameters of the proposed scheme are summarised in Table 2.

[2] L and C_2 are tuned to 50 Hz to bypass the resistor.

Table 2: System Requirements and Design Parameters

System Design Table	Circuit/Project	Arecleoch Extension Harmonic Filter and Associated Mark Hill 132kV Works
Thermal and Fault Design	Existing Voltage (if applicable)	132kV
	New Voltage	132kV
	Existing Continuous Rating (if applicable)	N/A
	New Continuous Rating	N/A
	Existing Fault Rating (if applicable)	N/A
	New Fault Rating	20/50kA
ESO Dispatchable Services	Existing MVAR Rating (if applicable)	N/A
	New MVAR Rating (if applicable)	20
	Existing GVA Rating (if applicable)	N/A
	New GVA Rating	N/A
System Requirements	Present Demand (if applicable)	N/A
	2050 Future Demand	N/A
	Present Generation (if applicable)	N/A
	Future Generation Count	9
	Future Generation Capacity	711MW
Initial Design Considerations	Limiting Factor	N/A
	AIS / GIS	AIS
	Busbar Design	Single Busbar
	Cable / OHL / Mixed	N/A
	SI	The proposed standardised harmonic filter mitigates the harmonic issues in the 275kV / 132kV network in Mark Hill area.

3. Optioneering

This section provides a description of the options that were considered to ensure network compliance with EREC G5/5 limits. A summary of each option is described in Table 5.

3.1. Baseline: Do Nothing / Deferral

A 'Do Nothing' or 'Delay' option is not credible in relation to this project and would be inconsistent with SPT's statutory duties and licence obligations. Such option would lead to increasing harmonic levels on the transmission network, which can reduce the lifespan or damage network equipment, cause various disturbances to users and overall deteriorate the power quality across the network. Due to the background network harmonics in the Mark Hill area and resonant conditions forming in across the network, system analysis studies have indicated that harmonic levels would exceed the EREC G5/5 compatibility levels.

3.2. Option 1: Installation of harmonic filters only at wind farm sites

This option was the employed approach prior to the RIIO-T2 price control period. As discussed in section 1, this option is neither economic nor efficient from a whole-system point of view. Also, it will not eliminate excessive harmonic voltages in all areas of the network. Furthermore, these filters could change the network impedance in way in which they could introduce overall more G5/5 limits excursions and would require additional tuning and coordination. Considering these reasons, this option was discounted in advance of detailed cost estimating exercise.

3.3. Option 2: Installation of 33kV standard harmonic filters

This is a variation of the Option 1 (i.e., installing a standardised filter at wind farms' 33kV connection points). This would lead to the installation of a high number of filters (between 5 and 10 installations), but these would not be effective in controlling harmonic voltages in all areas of the network, especially at higher voltage levels. Further detail on this option has been provided in the SPEN NIA project; NIA_SPT_1506 [2-3]. Considering this reason, this option was discounted in advance of detailed cost estimating exercise.

3.4. Option 3: Installation of active harmonic filters

This option is to use power electronic converters and a suitable control system to provide harmonic filtering. This technology is often deployed as part of an equipment such as STATCOM (i.e., a system that provides reactive compensation and harmonic filtering). The capital and operational costs for this option are very high, and the technology is effective only at low harmonic orders. The availability of the active harmonic filters is significantly lower than that of a passive filter. Also, their losses and noise emissions are high. Considering these reasons, this option was discounted in advance of detailed cost estimating exercise.

Note that it is planned to install a STATCOM at Mark Hill substation as part of a separate project. The STATCOM is required for voltage regulation in the area and is not expected to provide active harmonic filtering. The STATCOM was included in the network studies assessing the harmonics penetration in the Mark Hill area.

3.5. Option 4: Installation of bespoke harmonic filter for each site

It could be possible to design bespoke filters for each site in the Mark Hill area. This would provide more efficient filtering at specific harmonics with a reduced filter rating. However, such filters could themselves become part of an unintended resonant condition. They would be very sensitive to network changes and may require re-tuning or extension in future. Also, these filters will not be very efficient to procure as each site requires a different type of filter. Considering these reasons, this option was discounted in advance of detailed cost estimating exercise.

3.6. Option 5: Installation of 132kV standard harmonic filters

This approach was shown to provide the best technical solution, able to mitigate harmonic levels in the 132kV network in an economic, coordinated and efficient manner by NIA projects; NIA_SPT_1506 and 1610 [2-4] and through RIIO-T2 rollout. The proposed standardised 132kV filter design provides damping across the full range of harmonic frequencies. This ensures a high level of immunity to network outages or changes. The use of a standard design should also assist in achieving efficiencies in procurement, delivery, spares holding, replacements etc.

A proposed layout for the considered harmonic filter installation is shown in Figure 4 and fully described in Section 2.1. A large number of power system simulation studies have been carried out, considering connected and contracted connections in the SWS area, under intact and under different system outage scenarios, to investigate the mitigation effect of installing 132kV harmonic filters in the network connected to Mark Hill network. These in-depth studies can be found in Appendix C. The studies were carried out using DIgSILENT PowerFactory and the ETYS 2023 winter peak model Y06 (2026/27). As per the current contracted position, it is not expected that the Mark Hill 132kV network will change significantly after 2026/27 so future ETYS years were not studied.

Table 3 and Table 4 below show the background harmonic penetration on the 132kV (highlighted in black) and 33kV (highlighted in green) for an intact network, prior to installing any harmonic filter.

Table 3 includes the results when all wind turbine generators have infinite impedance and do not contribute to the damping of the network harmonic resonances. This is a pessimistic assumption, but it is a realistic scenario for the low (or very high) wind conditions when the wind turbines are not generating, with the collector cable networks remain energised. Table 4 includes results where the wind turbine impedances were considered in the network model. Harmonic issues are prominent at the 7th harmonic order as well as at the 13th and 23rd orders. Significant G5/5 planning, and compatibility limit breaches are present across the Mark Hill network under outage conditions as well, highlighting the need for harmonic mitigation in the Mark Hill area. The main problems arise because of the interaction between the connections assets for the wind farms and the main network resulting in resonances around the 7th, 13th and 23rd harmonic orders.

Table 3 Background Harmonics Penetration across the Intact Mark Hill Network, Low Wind Conditions

[redacted]

Table 4 Background Harmonics Penetration across the Intact Mark Hill Network, WTGs Impedance Included

[redacted]

Multiple filter locations across the Mark Hill network were investigated using power system simulation tools. The following sub-sections include details about each filter location and aim to justify the selection of the most coordinated and efficient solution.

3.6.1. Option 5a – Installation of 132kV standard harmonic filter at Arecleoch Extension 132kV Substation

This option covers the proposition to install a single 132kV standard C-type harmonic filter at Arecleoch Extension 132kV substation as schematically indicated in Figure 3. The results from the conducted harmonics studies, included in Appendix C, indicate a single 132kV harmonic filter at Arecleoch Extension was most effective in harmonic mitigation. It was able to eliminate all 132kV G5/5 planning limit excursions. A small number of 33kV G5/5 planning limit excursions remained throughout the intact and outage scenarios that were considered. However, none of the studied filter locations was able to fully eliminate all harmonic excursions.

The harmonic filter shall be connected via a 132kV circuit breaker and a disconnector. The electrical layout for installation of the harmonic filter in the Arecleoch Extension 132kV substation has been provided in Appendix A, Figure A-5.

The estimated total cost for installing the standard 132kV harmonic filter at Arecleoch Extension substation is approximately £7.108m. Note, that to improve the effectiveness of the filter across the Mark Hill 132kV network, a circuit breaker between the Mark Hill 'B' and Mark Hill 'C' 132kV boards will need to be installed. The Mark Hill substation works associated with the installation of the new circuit breaker are approximately £1.115m.

3.6.2. Option 5b – Installation of 132kV standard harmonic filter at [redacted]

This option covers the proposition to install a single 132kV standard C-type harmonic filter at [redacted]. The results from the conducted harmonics studies, included in Appendix C, indicate a single 132kV harmonic filter at [redacted] was less effective in harmonic mitigation compared to a filter at [redacted]. The [redacted] filter was not able to eliminate all 132kV G5/5 planning limits excursions. A similar number of 33kV G5/5 planning limit excursions remained throughout the intact and outage scenarios that were considered.

Detailed engineering design and costs analysis was not carried out for the harmonic filter at [redacted]. It is expected that the associated works and costs would be similar to the ones for [redacted].

3.6.3. Option 5c – Installation of 132kV standard harmonic filter at Mark Hill 'B' 132kV Substation

This option covers the proposition to install a single 132kV standard C-type harmonic filter at Mark Hill 'B' 132kV substation. The results from the conducted harmonics studies, included in Appendix C, indicate a single 132kV harmonic filter at Mark Hill 'B' was less effective in harmonic mitigation compared to a filter at [redacted] The Mark Hill 'B' filter was not able to eliminate all 132kV G5/5 planning limits excursions. A higher number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered.

Detailed engineering design and costs analysis was not carried out for the harmonic filter at Mark Hill 'B'. This solution would also not be technically feasible due to space constrains at Mark Hill 275/132kV substation and the inability to extend the substation compound.

3.6.4. Option 5d – Installation of 132kV standard harmonic filter at [redacted]

This option covers the proposition to install a single 132kV standard C-type harmonic filter at Clauchrie 132kV substation. The results from the conducted harmonics studies, included in Appendix C, indicate a single 132kV harmonic filter at [redacted] was less effective in harmonic mitigation compared to a filter at [redacted]. The [redacted] filter was not able to eliminate all 132kV G5/5 planning limits excursions. A higher number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered.

Detailed engineering design and costs analysis was not carried out for the harmonic filter at [redacted]

3.6.5. Option 5e – Installation of 132kV standard harmonic filter at [redacted]

This option covers the proposition to install a single 132kV standard C-type harmonic filter at [redacted]. The results from the conducted harmonics studies, included in Appendix C, indicate a single 132kV harmonic filter at [redacted] was less effective in harmonic mitigation compared to a filter at [redacted]. The [redacted] filter was not able to eliminate all 132kV G5/5 planning limits excursions. A higher number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered.

Detailed engineering design and costs analysis was not carried out for the harmonic filter at [redacted]. It is expected that the associated works and costs would be close to the ones for [redacted].

3.6.6. Option 5f – Installation of 132kV standard harmonic filter at Mark Hill 'C' 132kV Substation

This option covers the proposition to install a single 132kV standard C-type harmonic filter at Mark Hill 'C' 132kV substation. The results from the conducted harmonics studies, included in Appendix C, indicate a single 132kV harmonic filter at Mark Hill 'C' was less effective in harmonic mitigation compared to a filter at [redacted]. The Mark Hill 'C' filter was not able to eliminate all 132kV G5/5 planning limits excursions. A higher number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered.

Detailed engineering design and costs analysis was not carried out for the harmonic filter at Mark Hill 'C'. This solution would also not be technically feasible due to space constrains at Mark Hill 275/132kV substation and the inability to extend the substation compound.

3.6.7. Option 5g – Installation of two 132kV standard harmonic filters at [redacted]

This option covers the proposition to install two 132kV standard harmonic filters – one at [redacted] and one at [redacted]. The results from the conducted harmonics studies, included in Appendix C, indicate this combination of filters was slightly more effective in harmonic mitigation compared to a filter at [redacted]. It was able to eliminate all 132kV G5/5 planning limits excursions. A lower number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered but still the 33kV excursions were not completely resolved.

Detailed engineering design and costs analysis were not carried out for the combination of harmonic filters at [redacted] and [redacted]. It is anticipated that the project cost would be approximately double of the [redacted] filter costs. This solution was deemed not economically effective because of the high costs compared to the marginally better harmonics mitigation.

3.6.8. Option 5h – Installation of a 40MVAr 132kV harmonic filter at [redacted]

This option covers the proposition to install a 40MVAr rated filter at [redacted] instead of the standard 20MVAr filter. The results from the conducted harmonics studies, included in Appendix C, indicate this higher rated filter was less effective in harmonic mitigation compared to a filter at [redacted]. The 40MVAr [redacted] filter was not able to eliminate all 132kV G5/5 planning limits excursions. A higher number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered.

Detailed engineering design and costs analysis were not carried out for this option due to the higher project cost and worse harmonic mitigation compared to the standard 132kV harmonic filter at Arecleoch Extension.

3.6.9. Option 5i – Installation of two 132kV standard harmonic filters at Arecleoch Extension 132kV Substation & [redacted]

This option covers the proposition to install two 132kV standard harmonic filters – one at Arecleoch Extension 132kV substation and one at [redacted]. The results from the conducted harmonics studies, included in Appendix C, indicate this combination of filters was slightly more effective in harmonic mitigation compared to a filter at [redacted] It was able to eliminate all 132kV G5/5 planning limits excursions. A lower number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered but still the 33kV excursions were not completely resolved.

Detailed engineering design and costs analysis were not carried out for the combination of harmonic filters at [redacted] and [redacted]. It is anticipated that the project cost would be approximately double of the [redacted] filter costs. This solution was deemed not economically effective because of the high costs compared to the marginally better harmonics mitigation.

3.6.10. Option 5j – Installation of a 40MVAr 132kV harmonic filter at Arecleoch Extension 132kV Substation

This option covers the proposition to install a 40MVAr rated filter at [redacted] 132kV substation instead of the standard 20MVAr filter. The results from the conducted harmonics studies, included in Appendix C, indicate this higher rated filter was slightly more effective in harmonic mitigation compared to a filter at Arecleoch Extension. The 40MVAr Arecleoch filter was able to eliminate all 132kV G5/5 planning limits excursions. A lower number of 33kV G5/5 planning limit excursions was observed throughout the intact and outage scenarios that were considered.

Detailed engineering design and costs analysis were not carried out for this option. This solution was deemed not economically effective because of the high costs compared to the marginally better harmonics mitigation.

3.6.11. 132kV Circuit Breaker between Mark Hill 'B' and Mark Hill 'C' Discussion

Harmonic analysis was conducted with and without a circuit breaker between the Mark Hill 'B' and Mark Hill 'C' 132kV boards. A comparison of the results is included in Appendix C. It was concluded that, once Mark Hill SGT4 is installed, adding a circuit breaker would provide better harmonic mitigation when a single 132kV filter is installed. The alternative would be to install two filters– one to address the harmonic issues on the Mark Hill 'B' 132kV network and one to address the issues on the Mark Hill 'C' network. Such alternative solution would be less cost effective than installing a single harmonic filter with the circuit breaker. The costs for the harmonic filter at Arecleoch Extension are approximately £7.76m and for the Mark Hill substation works associated with the installation of the new circuit breaker are approximately £1.23m. The electrical layout for installation of the harmonic filter in the Arecleoch Extension 132kV substation has been provided in Appendix A, Figure A-6.

3.6.12. Preferred Filter Location Discussion

Comparing the results from the power system studies and costs associated with the different filter locations and setups, it was concluded that option 5a, installing a single standardised 132kV harmonic filter at Arecleoch Extension substation, is the optimal solution to mitigate against harmonic issues in the Mark Hill 132kV network, noting the requirement for a 132kV circuit breaker and associated disconnector to be installed as part of an updated scope of SPT-RI-282 (Mark Hill SGT4).

3.7. Selected Option – Installation of a 20MVAr Harmonic Filter at Arecleoch Extension Windfarm (Option 5a)

As discussed, the most optimal solution of providing harmonic mitigation within the Mark Hill 132kV network is to install a 20MVAr Type C Harmonic Filter at the propose Arecleoch Extension Windfarm substation. A 132kV circuit breaker and associated disconnectors will also be installed between the Mark Hill 'B' and 'C' switchboards to parallel the Mark Hill 132kV network.

A staged approach is proposed for **SPT-RI-4057** to install the 132kV disconnector associated with the harmonic filter alongside the Arecleoch Extension Windfarm substation works, contracted to complete in 2026, to minimise future outages associated with the harmonic filter installation / energization. The below scope of works is proposed for the Arecleoch Extension harmonic filter installation.

Stage 1:

- Install a 132kV disconnector at the Arecleoch Extension Windfarm 132/33kV substation.
- All associated protection and control work.
- All associated environmental and civil works.

Stage 2:

- Install a 132kV circuit breaker at the Arecleoch Extension Windfarm 132/33kV substation.
- Install a 132kV 20MVAr Harmonic Filter at the Arecleoch Extension Windfarm 132/33kV substation.
- All associated protection and control work.
- All associated environmental and civil works

It is proposed to update the scope of SPT-RI-282 to include the installation of a 132kV circuit breaker between the Mark Hill 'B' and 'C' switchboards as part of the harmonic filter mitigation works. A reconfiguration of the current Mark Hill 132kV layout proposal is required to accommodate the proposed 132kV circuit breaker. These works require a *scope change* for **SPT-RI-282**, and are therefore outwith the scope of this paper (noting that they must be completed in line with the installation of SPT-RI-282 to have the full benefits of the Harmonic Filter.

3.8. Whole System Outcomes

It should be noted that our optioneering approach has identified "Whole System" solutions in the development of our proposed options to deal with the harmonic problem and has considered the appropriate "Whole System" outcome by proposing employment of standardised harmonic filters.

Table 5: Summary of considered options to respond to the harmonic problem

Options	Map	Layout of Substation/Connection	Layout of all Route Works	Relevant Survey Works	Narrative Consenting Risks	Narrative Preferred Option	Narrative Rejection
Proposed – Option 5a: Installation of a 132kV standard harmonic filter at Arecleoch Extension substation and a circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards as part of SPT-RI-282.	Refer to Figure 3	N/A	N/A	N/A	N/A	The solution provides the most economic and efficient solution as it is able to resolve most of the G5/5 planning limits excursions and is more cost-effective compared to other alternatives which perform marginally better in mitigating harmonic issues.	N/A
Rejected – Baseline: Do Nothing / Delay	N/A	N/A	N/A	N/A	N/A	N/A	Inconsistent with SPT's various statutory duties and licence obligations. The network is not compliant with EREC G5/5 and a large number of excursions are observed at 132kV and 33kV.
Rejected – Option 1: Installation of harmonic filters at problematic wind farm sites	N/A	N/A	N/A	N/A	N/A	N/A	It is neither economic nor efficient from a "whole system" perspective. It also is unlikely to eliminate excessive harmonic voltages in all areas of the network.

Rejected – Option 2: Installation of 33kV standard harmonic filters	N/A	N/A	N/A	N/A	N/A	N/A	This option would lead to the installation of high number of filters but would not be effective in controlling harmonic voltages in all areas of the network.
Rejected – Option 3: Installation of active harmonic filters	N/A	N/A	N/A	N/A	N/A	N/A	The active harmonic filters technology is effective only at low harmonic orders. Their availability is significantly lower than that of a passive filter. Also, their losses and noise emissions are high. Higher costs can be expected compared to passive filters.
Rejected – Option 4: Installation of bespoke harmonic filter for each site	N/A	N/A	N/A	N/A	N/A	N/A	Having bespoke filters for each site can itself become part of an unintended resonant condition. These filters would be very sensitive to network changes and may require re-tuning or extension in future. Additionally, these filters will not be very efficient to procure as each site requires a different type of filter.
Rejected – Option 5b: Installation of 132kV standard harmonic filter at [redacted] 132kV Substation and a circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.	N/A	N/A	N/A	N/A	N/A	N/A	Not as effective at harmonic mitigation as Option 5a.
Rejected – Option 5c: Installation of 132kV standard harmonic filter at Mark Hill 'B' 132kV Substation and a circuit	N/A	N/A	N/A	N/A	N/A	N/A	Not as effective at harmonic mitigation as Option 5a. Inability to extend the Mark Hill substation compound to allow for the filter installation.

breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.							
Rejected – Option 5d: Installation of 132kV standard harmonic filter at [redacted] 132kV Substation and a circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.	N/A	N/A	N/A	N/A	N/A	N/A	Not as effective at harmonic mitigation as Option 5a. Clauchrie has recently been refused planning permission. The developer has also applied to have their connection date delayed to 2034.
Rejected – Option 5e: Installation of 132kV standard harmonic filter at [redacted] 132kV Substation and a circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.	N/A	N/A	N/A	N/A	N/A	N/A	Not as effective at harmonic mitigation as Option 5a.
Rejected – Option 5f: Installation of 132kV standard harmonic filter at Mark Hill 'C' 132kV Substation and a circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.	N/A	N/A	N/A	N/A	N/A	N/A	Not as effective at harmonic mitigation as Option 5a. Inability to extend the Mark Hill substation compound to allow for the filter installation
Rejected – Option 5g: Installation of two 132kV standard harmonic filters at [redacted] 132kV Substation & [redacted] 132kV Substation and a	N/A	N/A	N/A	N/A	N/A	N/A	Marginally more effective at harmonic mitigation than Option 5a but comes at a higher project because two harmonic filters will need to be installed.

circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.							
Rejected – Option 5h: Installation of a 40MVAr 132kV harmonic filter at [redacted] 132kV Substation and a circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.	N/A	N/A	N/A	N/A	N/A	N/A	Not as effective at harmonic mitigation as Option 5a and comes at a higher project because two harmonic filters will need to be installed.
Rejected – Option 5i: Installation of two 132kV standard harmonic filters at Arecleoch Extension 132kV Substation & [redacted] 132kV Substation and a circuit breaker to connect the Mark Hill 'B' and Mark Hill 'C' 132kV boards.	N/A	N/A	N/A	N/A	N/A	N/A	Marginally more effective at harmonic mitigation than Option 5a but comes at a higher project because two harmonic filters will need to be installed.

4. Proposed Works & Associated Cost

4.1. Project Summary

It is proposed to install a 20MVAr Harmonic Filter along with the 132kV circuit breaker and disconnector at Arecleoch Extension 132kV substation.

The proposed electrical layout of the Arecleoch Extension and Mark Hill 132kV substations can be found in Appendix A, Figure A-5 and Figure A-6.

4.2. Pre-Engineering Works

The following list is indicative based on previous experience of such sites and as such should not be read as definitive. Where recent surveys have already been carried out information gathered at this time will be used to minimise the scope of the additional surveys. The following surveys will be carried out:

- Topological survey of the site.
- GPR survey of areas to be re-excavated to validate approximate locations of buried services.
- Ground bearing capacity checks.
- Geo Environmental Investigation to identify the relevant geotechnical parameters to facilitate the civil engineering design works.
- Earthing Study.
- Insulation Co-ordination Study.
- Transport Survey to assess the access of the new Equipment.
- Environmental Study.

4.3. Arecleoch Extension 132kV substation

A staged approach is proposed for **SPT-RI-4057** to install the 132kV disconnector associated with the harmonic filter alongside the Arecleoch Extension Windfarm substation works, contracted to be completed in 2026, to minimise future outages associated with the harmonic filter installation / energization. The disconnector would allow to isolate the Arecleoch Extension Windfarm – Mark Hill 132kV circuit during the installation of the harmonic filter and avoid a planned outage on the circuit. The below scope of works is proposed for the Arecleoch Extension harmonic filter installation.

Stage 1:

- Install a 132kV disconnector at the Arecleoch Extension Windfarm 132/33kV substation.
- All associated protection and control work.
- All associated environmental and civil works.

Stage 2:

- Install a 132kV circuit breaker at the Arecleoch Extension Windfarm 132/33kV substation.
- Install a 132kV 20MVAr Harmonic Filter at the Arecleoch Extension Windfarm 132/33kV substation.
- All associated protection and control work.
- All associated environmental and civil works

The civil engineering works associated with this element of the project entail:

- The design and construction of foundations and structures necessary to construct the site civil platform in the Arecleoch Extension substation area.
- The design and construction of foundations and structures necessary to construct the harmonic filter's site civil platform.
- The design and construction of foundations and structures necessary to support the equipment within the substation area.
- Enabling works to achieve the above requirements to facilitate temporary and/or enduring accesses for construction, operation, and maintenance purposes.

4.4. Project Cost

4.4.1. Allocation of Harmonic Filter Costs

As outlined in the previous sections, users are normally responsible for harmonic mitigation and therefore the full cost of mitigation. For users that are significant sources of harmonic emissions, this is consistent with a "polluter pays" approach. However, most windfarms are not a significant source of harmonics (i.e., they are not by themselves polluters). In some parts of the SPT's 132kV network, they simply form part of a wider resonant system that amplifies background harmonics caused by a range of sources, including consumer devices and equipment. This suggests that part of the cost of harmonic mitigation should be socialised, rather than penalising individual Users for resonant conditions that are largely out of their control.

It is anticipated that the harmonic filter installation proposed in this paper will be funded fully via the RIIO-T3 price review, using the proposed Use It or Lose It funding. However:

1. The responsibility for harmonic compliance should not be removed from users to ensure that they remain liable if they connect polluting equipment to the network.
2. User choice could have a significant impact on harmonic resonance (e.g., the use of cable instead of an overhead line connection). In such cases, where there is deemed to be an increased risk of harmonic resonance, a harmonic filter should be included in the offer as a one-off cost.

This approach is consistent with the "polluter pays" principle while ensuring that harmonic compliance is managed in an economic and efficient manner across the transmission system.

4.4.2. Estimated Total Project Cost

A Business Plan provision and estimated cost of the project is indicated in the following table. Cost below include direct, indirect, and contingency costs.

Project costs are summarised in the Cost Breakdown below:

Table 6: Project Cost Breakdown

Item	Description	Estimated CAPEX (£m 23/24)
[redacted]		

Expenditure incidence is summarised below:

Table 7: Summary of Expenditure Incidence

Energisation Year	Yr. 2025: CAPEX	Yr. 2026: CAPEX	Yr. 2027: CAPEX	Yr. 2028: CAPEX	Yr. 2029: CAPEX	RIIO-T2 Total: CAPEX	RIIO-T3 Total: CAPEX	**Total: CAPEX**
2028	£0.03m	£0.56m	£1.62m	£3.98m	£1.58m	£0.59m	£7.18m	**£7.76m**

4.5. Regulatory Outputs

The indicative primary asset outputs are identified in table below:

Table 8: Indicative Primary Asset Outputs

Asset Category	Asset Sub-Category Primary	Voltage	Intervention	Forecast Addition[3]	Forecast Disposal[4]
Circuit Breaker	CB (Live Tank)	132kV	Addition	1 unit	-
Harmonic Filter	20MVAR standardised damped (C-type) harmonic filter	132kV	Addition	1 unit	-
Substation Platform	Platform Creation	132kV	Addition	1 unit	-

4.6. Environmental and Consents Works

Consultation has taken place with Statutory stakeholders including SEPA and Nature Scot in relation to the proposals. Consultation was also undertaken with all other relevant stakeholders including the wider public and landowners.

5. Deliverability

We have applied SPT project management approach to ensure that this project work is delivered safely, and in line with the agreed time, cost and quality commitments. We have a proven track record of delivering essential transmission network upgrade projects and will draw upon this knowledge and experience to effectively manage these works. We have assigned a dedicated Project Manager to the works at every stage who is responsible for overall delivery of the scope and is the primary point of contact for all stakeholders.

5.1. Delivery Schedule

A standard approach has been applied to the planning phase of these works and that will continue for the reporting and the application of processes and controls throughout the lifecycle. Table below summarises the key milestones within the delivery schedule of this project.

[3] Forecast Additions are indicative pending further detail design.
[4] Forecast Disposals are indicative pending further detail design.

Table 9: Summary of Key Milestones within the Project Delivery Schedule

Item	Project Milestone	Estimated Completion Date
1	Technical Approval	September 2024
4	Harmonic Filter ITT	February 2026
6	Harmonic Filter Contract Award Date	September 2026
9	Substation Site Works Commencement	December 2027
10	Harmonic Filter On stie	January 2028
11	Commissioning	October 2028

Regular meetings with the Project and Construction Management Teams shall be undertaken to assess the ongoing effectiveness of the Project Management interfaces.

The Project Manager will facilitate internal Project Team Meetings, in which project progress and deliverables will be reviewed and any arising risks or issues will be discussed and addressed.

5.2. Risk and Mitigation

A Project Risk Register will be generated collaboratively during the initial project kick-off meeting to identify any risks, which if realised, could result in deviation from the delivery plan. Mitigation strategies will also be developed to manage the risks identified and these will be implemented by the Project Manager. The risk register shall remain a live document and will be updated regularly by the project team. The key risk for this project is the interaction with existing projects, which will be mitigated by regular meetings between the relevant Project Managers to ensure the works continue to align.

5.3. Quality Management

SPT adopts a "life cycle" approach to Quality Management in major project delivery. Our Management Systems are certified to ISO 9001, ISO 14001 and ISO 45001. Various areas applicable to these standards ensure a quality product is delivered. The significant areas detailed below:

5.3.1. Quality Requirements During Project Development

Any risk or opportunity that may affect the quality of the product are detailed in the Project Risk Register. The suppliers of main equipment may also receive a Factory Acceptance Test Inspection when the asset is being built.

5.3.2. Quality Requirements in Tenders

Each contract that SPT issues has a standard format. Specifically in relation to quality, this will include a Contractors' Quality Performance Requirement (CQPR). This CQPR represents a specification that details roles and responsibilities for all parties during the works, frequency and format of reporting. It will also specify the document management process to be adhered to during the delivery of the project. In addition to the CQPR, each project has a contract specific Quality Management Plan, detailing the inspection and testing regime for works as well as the records to be maintained.

5.3.3. Monitoring and Measuring During Project Delivery

SPT Projects undertake regular inspections on projects and contractors to monitor and measure compliance with SPT Environmental, Quality and Health and Safety requirements, as detailed in the contract specifications for the work. All inspections are visual, with the person undertaking the inspection ensuring that evidence of the inspection and any actions raised are documented.

The following inspections are completed:

- Quality Inspections (monthly)
- Environmental Inspections (monthly, with weekly review by third party Environmental Clerk of Works)
- Safety Assessments & Contractor Safety Inspection (daily, with full time Site Manager)
- Project Management Tours (monthly)

The scope of audits and Inspections is to determine compliance with:

- Procedures & Guides
- Planned arrangements for ISO 9001, 14001 & 18001
- Legal and other requirements.

5.3.4. Post Energisation

SPT Projects and SPT Operations within SPEN carry out a Defect Liability Period Inspection within the Contract Defect Liability Period with the aim of identifying any defects and rectifying them with the contractors.

5.4. Environmental and Wayleave Considerations

5.4.1. Environmental Planning

The following environmental surveys will require to be carried out prior to any work commencing on site:

- Ecology: Phase 1 habitat survey
- Ecology: Protected species survey
- Archaeology: Desktop based survey
- Archaeology: Field evaluation*
- Archaeology: Watching brief for any ground-breaking works within identified areas*

*May only be required if any proposed ground-breaking works encroach on areas of interest.

The intention should be to use low bearing pressure vehicles where possible. Access routes and formation may be supplementary to existing roads and tracks and should use sustainable materials which can be reutilised where possible. Any compaction of ground should be rectified.

5.4.2. Wayleave Issues

Landowner agreements will be required to deliver these works. SPT will take a co-ordinated approach to all aspects of these works in view of the need to deliver an overall and integrated solution which recognises potential interaction and cumulative impacts.

5.4.3. Environmental Sustainability

IMS-01-001 encompasses all activities undertaken within and in support of SP Energy Networks three Licences. This includes operational and business support functions concerned with management of SP Transmission, SP Distribution and associated regulatory and commercial interfaces, products, services and their associated environmental, social and economic impacts. The policy makes the following commitments which shall be respected in any works associated with this scheme.

SP Energy Networks will incorporate environmental, social and economic issues into our business decision-making processes, ensuring compliance with or improvement upon legislative, industry, regulatory and other compliance obligations. We will deliver this by being innovative and demonstrating leadership on the issues which are important to us and our stakeholders, and will:

- Ensure the reliability and availability of our Transmission and Distribution network whilst creating value and delivering competitiveness by increasing efficiency and minimising losses.
- Reduce greenhouse gas emissions in line with our Net Zero Science Based GHG target, which is a target of 90% reduction in GHG emissions by 2035 (TBC) from a 2018/19 baseline.
- Integrate climate change adaptation requirements into our asset management and operations processes to support business resilience and reduce the length and time of service interruptions.
- Consider whole life cycle impacts to reduce our use of resources to sustainable levels, improve the efficiency of our use of energy and water and aim for zero waste.
- Improve land, air and watercourse quality by preventing pollution and contamination and protecting and enhancing biodiversity in our network areas.
- Improve our service to local communities, supporting their economic and social development, protecting vulnerable customers, and respecting human rights.

ENV-04-014 gives specific guidance on the management of incidents with environmental consequence, or potential for environmental consequences, over and above the general requirements for the management of incidents.

5.5. Stakeholder Engagement

SPT is committed to delivering optimal solutions in all the projects we undertake. A key part of this is engaging with relevant stakeholders throughout the project development and delivery process. Stakeholders can include customers, regulatory bodies and other statutory consultees, national and local government, landowners, community groups, and local residents and their representatives (e.g., MPs, MSPs and councillors). Community impacts associated with construction activities are considered at project initiation by completion of a Community Communications Plan, which details the stakeholders relevant to the project, the communication channels that will be used to engage with them, the information that will be provided to and sought from them, and the timescales over which this will happen. It considers any sensitivities that may require increased stakeholder consultation and details specific events that will be held with stakeholders during the development of the project.

As part of this project, SPT will engage with statutory consultees associated with the planning application for these works - the Local Authority, SEPA and Nature Scot - and the third-party landowner.

Due to the location and nature of this project, no particular sensitivities or community impact issues have been identified, but a general level of interest from local representatives has been noted and we will continue to engage with them throughout the project. Stakeholder engagement to date has informed the details of the construction and permanent drainage details for the works.

6. Conclusion

This EJP demonstrates the need to install harmonic mitigation within the Mark Hill 132kV network. A 20MVAr harmonic filter is proposed to be installed at the Arecleoch Extension substation, with the update to SPT-RI-282 132kV circuit breaker and disconnectors installed between the Mark Hill 'B' and 'C' switchboards to parallel the 132kV network once Mark Hill SGT4 is installed.

The increasing number of large wind farm connections into the SWS area is leading to amplification of background harmonics to levels above the EREC G5/5 planning levels. This issue can be mitigated by the installation of standardised harmonic filters to provide a coordinated and efficient solution.

The main conclusions of this submission are:

- To ensure network compliance with EREC G5/5 it's necessary to install a 132kV 20MVAr damped (C-type) harmonic filter at the proposed Arecleoch Extension 132kV substation.
- The proposed reinforcement scheme plays a vital role in reaching legislated net zero targets and is aligned with SPT's RIIO-T3 strategic goals.

We request that Ofgem accepts the needs case set out within this EJP and propose that this project is fully funded within the RIIO-T3 period by the Load UIOLI pot, due to its scope and cost.

7. Appendices

Appendix A – Maps and Diagrams

Appendix B – Reference to Supporting Documents

Appendix C – Power System Simulation (Harmonic Filter Studies)

Appendix A: Maps and Diagrams

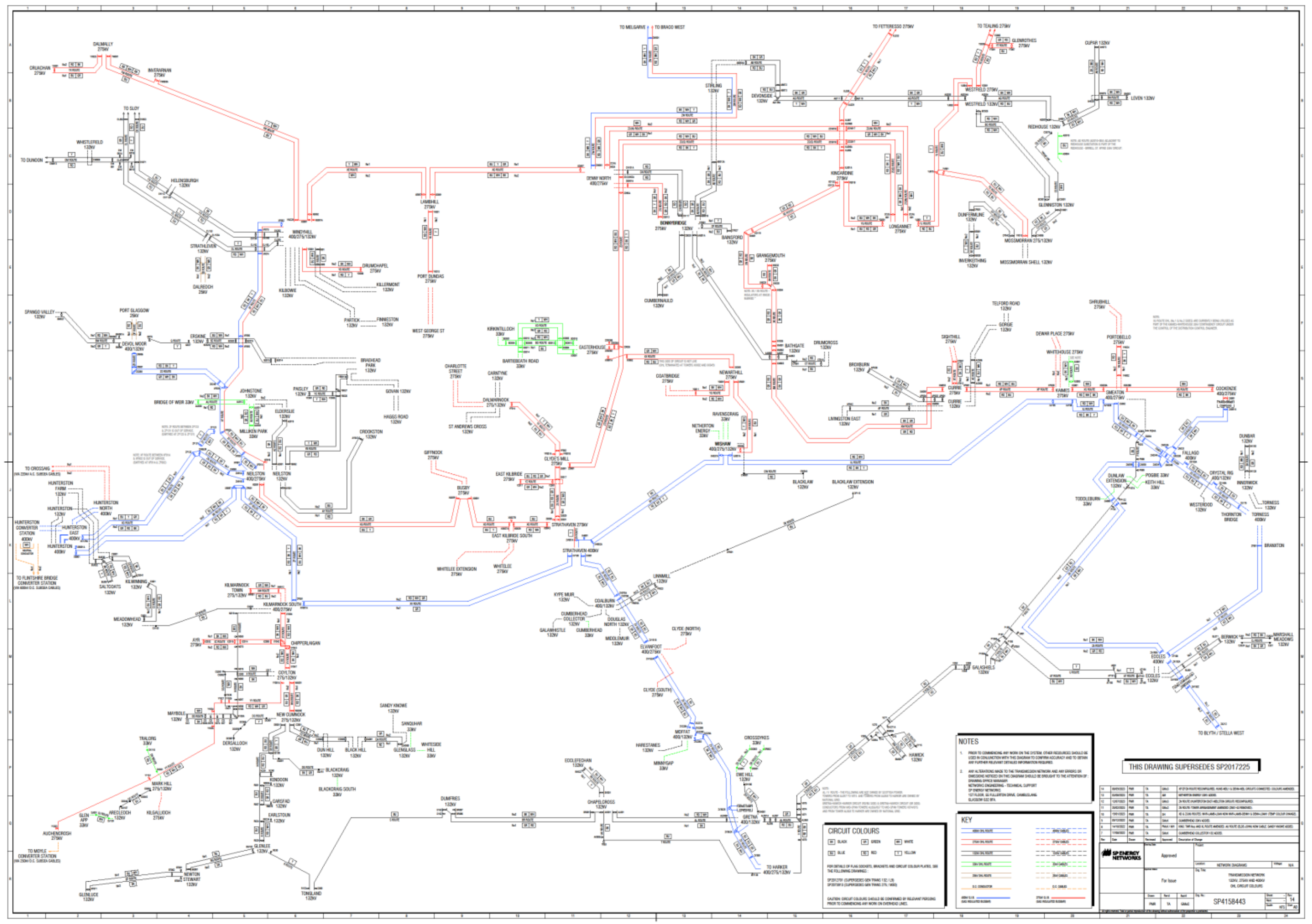

Figure A-1: Networks Diagram of the existing SPT systems – Single Line Diagram

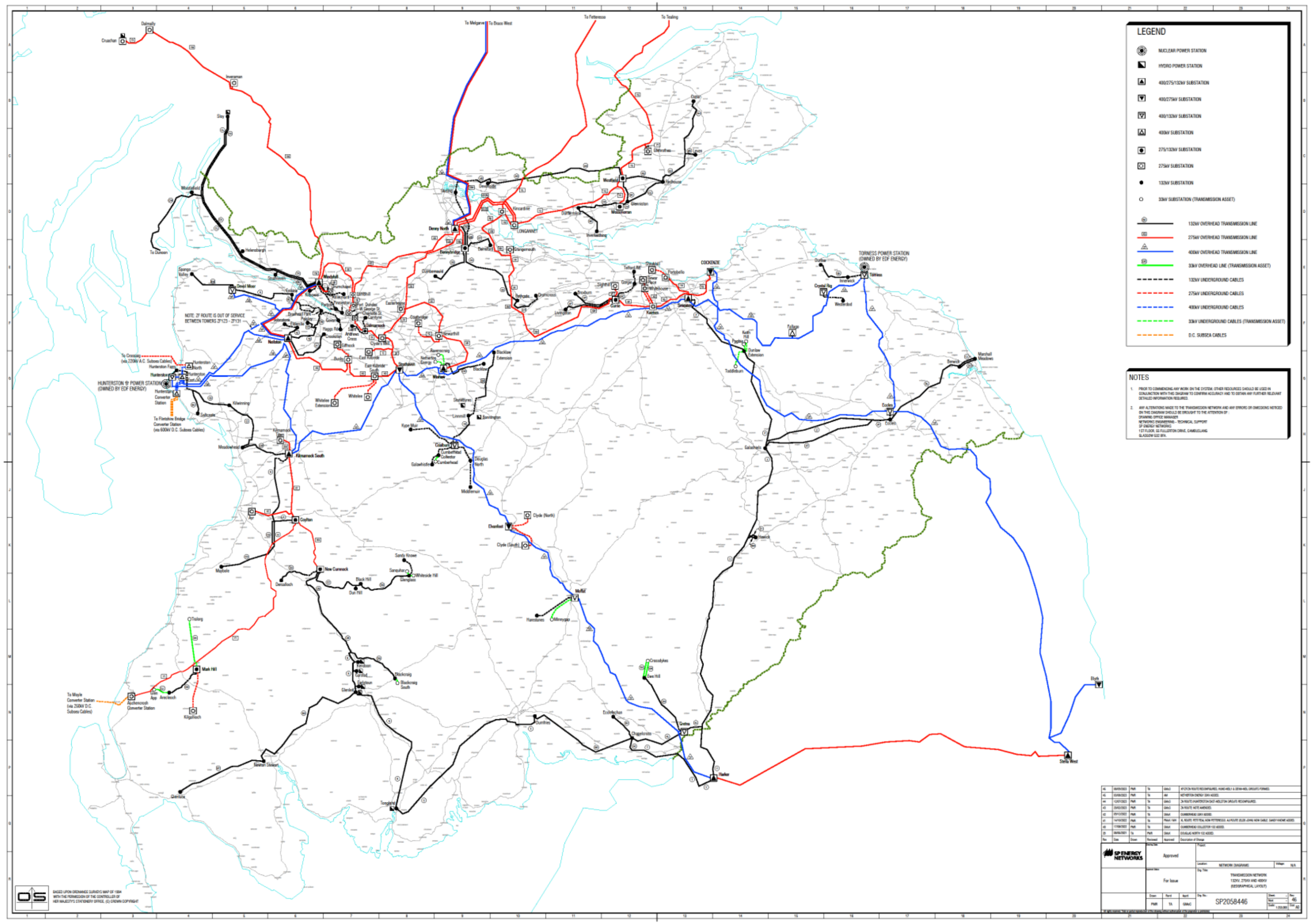

Figure A-2: Networks Diagram of the existing SPT system - Geographical Layout

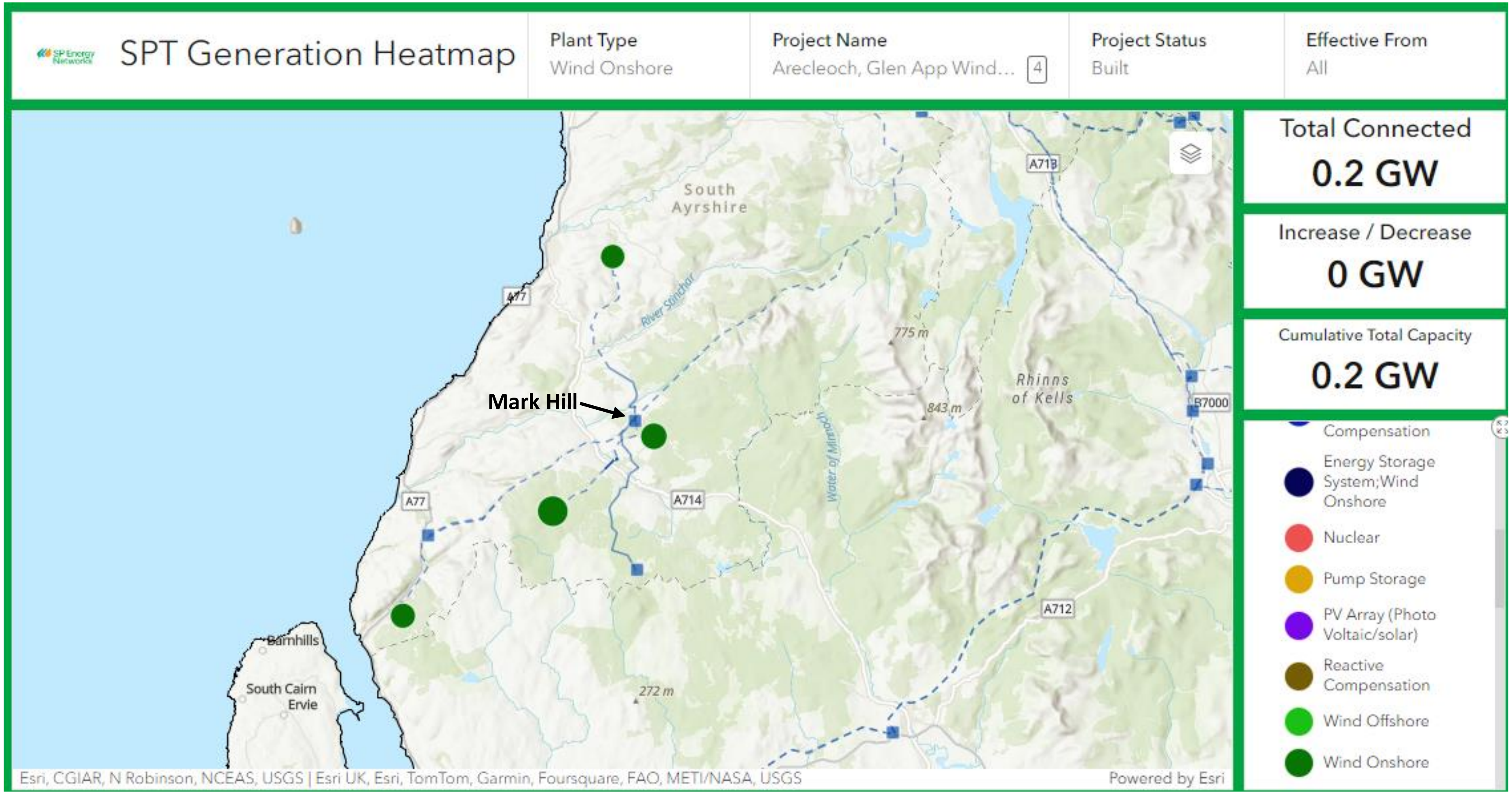

Figure A-3: Wind Farm Generator Developments currently connected to Mark Hill substation, Extracted from Transmission Generation Heat Map

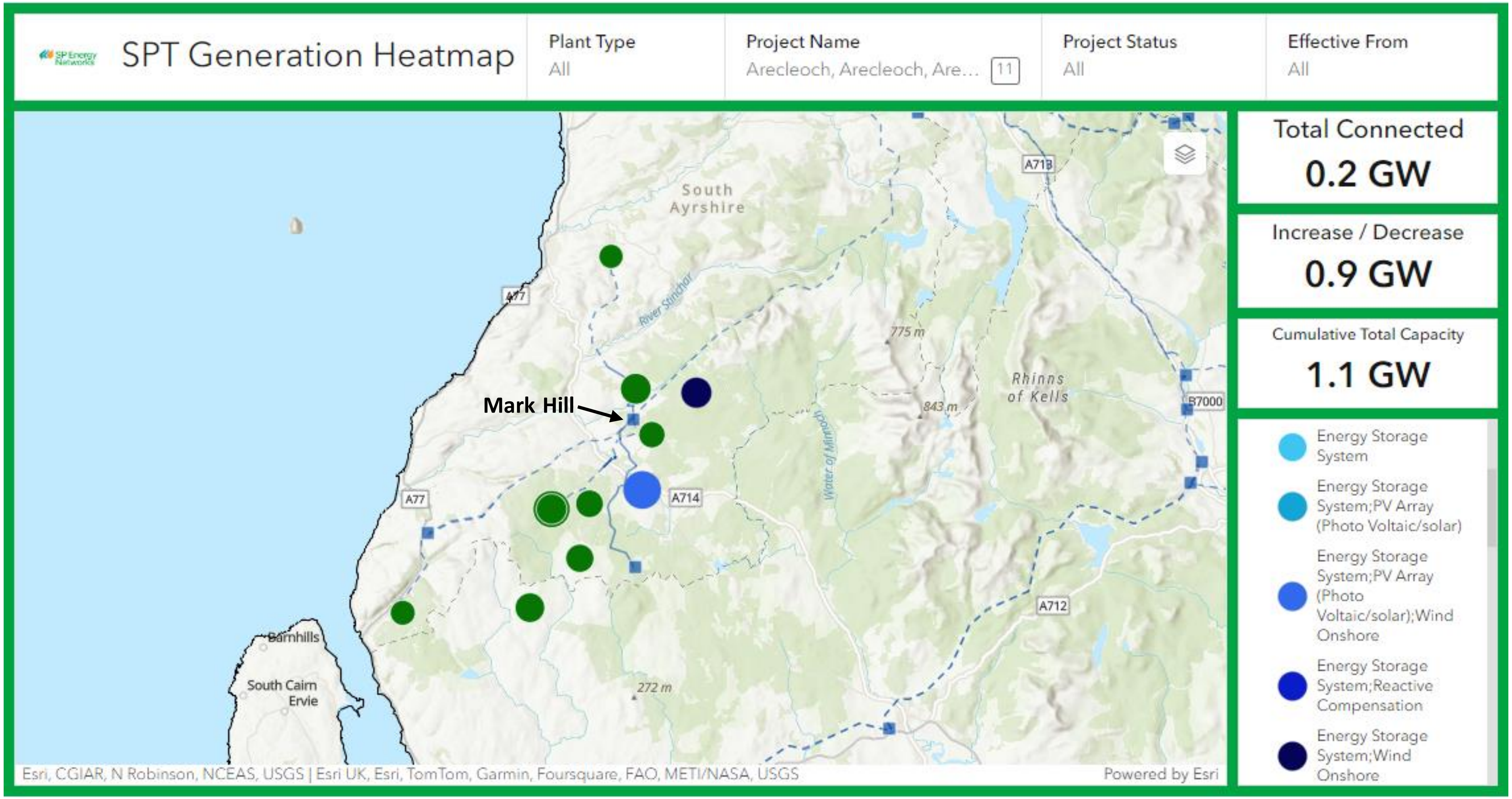

Figure A-4: Contracted and Connected Wind Farm Developments proposed for connection to Mark Hill substation, Extracted from Transmission Generation Heat Map

[redacted]

Figure A-5: Electrical layout for option 5a (i.e., a 132kV harmonic filter in the Arecleoch Extension substation)

[redacted]

Figure A-6: Electrical layout to capture the installation of 132kV circuit breaker between Mark Hill 'B' and Mark Hill 'C'

Appendix B: Reference to Supporting Documents

1. ENA Engineering Recommendation G5 "Harmonic voltage distortion and the connection of harmonic sources and/or resonant plant to transmission systems and distribution networks in the United Kingdom", Issue 5, 2020.
2. WSP Parsons Brinckerhoff, "Development of a Standard 33kV Harmonic Filter – Stage 1", June 2016 (NIA project NIA_SPT_1506, Development of a Standard 33kV Damped Harmonic Filter Design).
3. WSP Parsons Brinckerhoff, "Development of a Standard 33kV Harmonic Filter – Stage II", February 2017 (NIA project NIA_SPT_1506, Development of a Standard 33kV Damped Harmonic Filter Design).
4. Electric Power Research Institute (EPRI), "South West Scotland Harmonics Study – Filter Design and Analysis Results", July 2017 (NIA project NIA_SPT_1610, Innovative Approach for Transmission Harmonics Issues).
5. Dr Brozio C.C, IP1 "Harmonic Filters for 132kV Network", RIIO-T2 Works, January 2020.
6. NIA_NGTO018 (Harmonic compliance management), https://www.smarternetworks.org/project/nia_ngto018
7. Mark Hill Area Harmonic Filter Studies Optioneering Report (Link Below)

Appendix C: Power System Simulations – Harmonic Filter Studies

Various studies were carried out for intact and outage conditions to assess how effective each filter location was in mitigating against harmonic issues across the Mark Hill network. Each filter location was assessed on the ability to provide harmonic mitigation within the network with a comparison made between the number of G5/5 planning limits voltage distortion excursions associated with each harmonic filter setup option across the identified intact and outage scenarios.

ETYS 2023 winter peak network for Y06 (2026/27) was assessed with multiple filter locations and setups listed as variations in Option 5.

Both operating conditions, low (or excessively high) wind speed when the wind turbines are not operational and when the wind turbine generators are generating, were studied.

Table 10 shows the various operation scenarios and outage conditions considered in the conducted harmonic analysis. Note that the operation scenarios are represented by their assigned letter throughout some of the visuals in Appendix C and the table below can be used to cross-reference with the respective operation scenario.

[redacted]

[redacted]		
[redacted]		
[redacted]		
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C.1 No Harmonics Mitigation

Study assumptions: no harmonic filters, intact network, wind turbines not operational, no circuit breaker between Mark Hill 'B' and 'C' 132kV boards

[redacted]

Study assumptions: no harmonic filters, intact network, wind turbines are operational, no circuit breaker between Mark Hill 'B' and 'C' 132kV boards

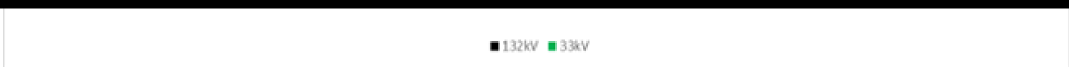
[redacted]

C.2 Harmonic Filters Performance

Study assumptions: wind turbines not operational, no circuit breaker between Mark Hill ‘B’ and ‘C’ 132kV boards

Number of G5/5 planning limits excursions are summed throughout all operation scenarios considered.

[redacted]



[redacted]

Study assumptions: wind turbines not operational, including circuit breaker between Mark Hill 'B' and 'C' 132kV boards

Number of G5/5 planning limits excursions are summed throughout all operation scenarios considered.

[redacted]

Study assumptions: wind turbines are operational, no circuit breaker between Mark Hill 'B' and 'C' 132kV boards

Number of G5/5 planning limits excursions are summed throughout all operation scenarios considered.

[redacted]

[redacted]

Study assumptions: wind turbines are operational, including circuit breaker between Mark Hill ‘B’ and ‘C’ 132kV boards

Number of G5/5 planning limits excursions are summed throughout all operation scenarios considered.

[redacted]

132kV 33kV

[redacted]