

SSEN Transmission

Southwest Harmonic Filter

Medium Sized Investment Project (MSIP) Submission

January 2023



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Executive Summary

In accordance with Part C of Special Condition 3.14 Medium Sized Investment Projects (MSIP) Re-opener, this application presents the case for the installation of a harmonic filter in the southwest (Kintyre Peninsula) region of the SSEN Transmission licence area. This submission is asking Ofgem to only provide a decision on approving the **need**, and not the preferred solution and associated allowances. We intend to request the full project allowance as part of the January 2024 MSIP submission window.

The southwest region is located geographically within Argyll and extends southwards towards Carradale 132kV substation. There are two 220kV subsea cables connecting the SSEN Transmission and ScottishPower Transmission (SPT) licence areas. In recent years, we have been monitoring power quality issues in this region of our network. This has manifested in voltage distortions at Crossaig Substation. The disturbances remain above the planning threshold for the system and show no trend towards resolution without physical intervention in the network.

Following a series of system tests undertaken to isolate the cause and location of the effect, it has been determined that the background fifth harmonic in the SPT area at Hunterston is being amplified over the Kintyre-Hunterston High Voltage Alternating Current (HVAC) link into the southwest region. This testing was also successful in eliminating the Western HVDC Link¹ as a source of the problem but ultimately identifies harmonic dampening benefits obtained from its HVDC convertor station filters which are normally lost when it is not in operation.

The elevated harmonic levels, caused by the amplification of background harmonics in the SPT region through the two subsea cables, will not dissipate without intervention and it is anticipated that the issue will only get worse because of increased customer connections in the area. The detrimental impact of not intervening can lead to the maloperation of equipment; system overloading; degradation in lifetime of assets; and subsequent impacts on end consumers due to the resultant earlier replacement of assets.

Our current preferred solution involves the installation of a harmonic filter on the Argyll side of the Kintyre Hunterston HVAC link at Crossaig Substation. System testing has identified this location as providing optimal system benefit (as described further within chapter two). Furthermore, by aligning the installation of the filter with the proposed Argyll 275kV reinforcement works at Crossaig we further improve efficiency of installation through concurrent platform construction and site works. We are currently engaging with an external consultancy to carry out the filter design work, paralleling our current engagement with the regulator for approval.

Next steps

We will continue to refine our optioneering and detailed cost estimate during 2023. We intend to seek approval for a preferred option and request the full project allowance as part of the January 2024 MSIP submission window, at which point we will have identified a site for the filter and completed key procurement activities.

¹ [Western HVDC Link - SP Energy Networks](#)

Project Name	Southwest Harmonic Filter
Project Reference	LT466
Investment Driver	Engineering Recommendation (EREC) G5/5 <i>“Harmonic voltage distortion and the connection of harmonic sources and/or resonant plant to transmission systems and distribution networks in the United Kingdom”</i>
Start Year	2021
End Year	2028
Total Installed Cost Estimate (£m 18/19)	██████████
Cost Estimate Accuracy (%)	████████████████████
Project Spend to date (£m 18/19)	██████████

1 Introduction

1.1 Scope

This document sets out the need for intervention and initial cost estimates associated with the development of an AC harmonic filter in the southwest (Kintyre peninsula) region of the SSEN Transmission licence area.

In accordance with Scottish Hydro Electric Transmission Plc's Special Licence Condition '3.14 Medium Sized Investment Projects Re-opener and Price Control Deliverable (MSIPRE)' we are submitting this reopener application in line with paragraph 3.14.6 (h) ii: "*Harmonic Filtering projects that are needed following system studies by the System Operator or the licensee showing a need for additional Harmonic Filtering on the National Electricity Transmission System*".

This project meets the materiality threshold set out within our transmission licence. This submission is asking Ofgem to only provide a decision on approving the **need**, and not the preferred solution and associated allowances. We intend to request the full project allowance as part of the January 2024 MSIP submission window.

1.2 Structure and content of MSIP Submission

Section 2: Need

This section provides an explanation of the "need" for the planned works. It provides evidence of the primary driver and, where applicable, secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the "need".

Section 3: Optioneering and preferred solution

This section presents all the options considered to address the "need" that is described in Section 3. Each option considered here is either discounted with supporting reasoning provided or is taken forward for further analysis. It presents a summary of the process undertaken to identify preferred technology, site and routes along with the clear criteria used to assess the various options. The preferred solution is described in terms of key features including how that option has addressed the need.

Section 4: Cost information

This submission is seeking approval of need only. The cost section provides a summary of the indicative project cost for information purposes only.

Section 5: Conclusion

This section provides summary detail of the selected option. It sets out the scope and outputs, costs and timing of investment and where applicable other key supporting information. The conclusion clarifies the next steps and reiterates critical timeline of project and key milestones such as Ofgem decision.

1.3 Requirement Mapping

Licence and Guidance Requirement	Submission Section
Statement setting out what MSIP the application relates to	Section 1
Clear statement on needs case	Section 2
Justification of technical need and, where relevant, the consumer benefit that the MSIP is expected to deliver	Section 2
Explanation of options assessment	Section 3
Clear description of preferred option	Section 3
Clear description of stakeholder engagement and whole system opportunities	Further stakeholder engagement (beyond industry) will be progressed during 2023 and further information will be provided in our MSIP reopener application in 2024. This will also identify potential whole system opportunities (beyond the mitigation measures currently in place with SPT).
Statement that costs (incurred or expected) exceed the Materiality Threshold, but are less than £100m	Section 4
Statement that costs are confined to those incurred or expected on or after 1 st April 2021	Section 4

Table 1: Submission mapping

2 Need

2.1 Investment Driver

As a Transmission Owner (TO), SSEN Transmission has a responsibility to support National Grid ESO in ensuring that the power quality on the system including (but not limited to) the deviation of voltage, frequency, and waveform of a power system from the established, standard values – is kept under control and remains within acceptable and manageable levels. A degradation of power quality across the network can have severe effects on the reliability of the system and therefore appropriate action must be taken should this condition arise.

One element of power quality is harmonics which are components superimposed on the fundamental frequency supply waveform with frequencies at integer multiples of the fundamental frequency. In the GB network, the fundamental frequency is 50Hz meaning the second harmonic order is 100Hz, the third harmonic order is 150Hz, etc. With the connection of increasing levels of generators and demand technologies incorporating power electronic technology, harmonics are becoming more prevalent on our system. Harmonic distortion can lead to a wide variety of issues including the overheating of assets and interference leading to the malfunctioning of equipment. It is therefore increasingly important for harmonics to be managed and kept under control. As an example, Figure 2.1 shows how the fundamental frequency supply waveform can become distorted because of harmonics being superimposed.

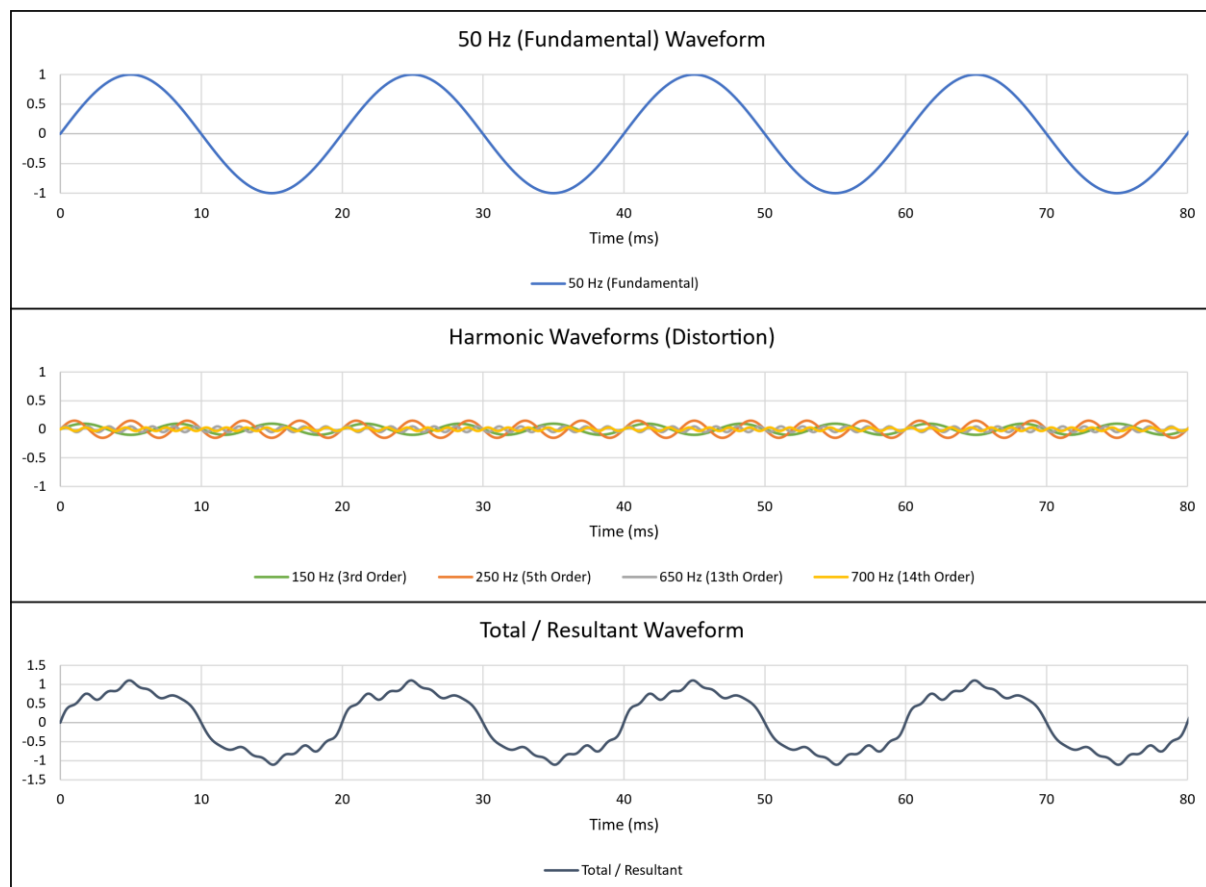


Figure 2.1 -Example of harmonic distortion on the fundamental waveform

A metric employed to monitor harmonic levels in the network is detailed in Engineering Recommendation (EREC) G5/5² which are planning levels and compatibility levels. Planning level is defined as the level of harmonic voltage distortion against which the connection of relevant equipment is assessed, and compatibility level is the level of harmonic voltage distortion below which the supply system should ideally be operated. Therefore, we must ensure that harmonic distortions on our network do not exceed the compatibility level and should be below the planning level.

As part of the regular monitoring programme conducted across our system for harmonics, unusually high levels of harmonic distortion at the fifth harmonic order were observed in the southwest region (Kintyre Peninsula – see Appendix B). Figure 2.2 below shows an illustration of the fifth order harmonics recorded at Crossaig substation (example circuits RC1 (132kV) and RH2 (220kV)) for the period between January and September 2022 (CP95³ values). It can be observed that these levels breach the planning limit and fluctuate within the band between the planning and compatibility levels. This trend has been observable on the system for some time and, although there is no clear indication of an increasing trend, action was taken to identify the root cause and develop a suitable mitigation measure.

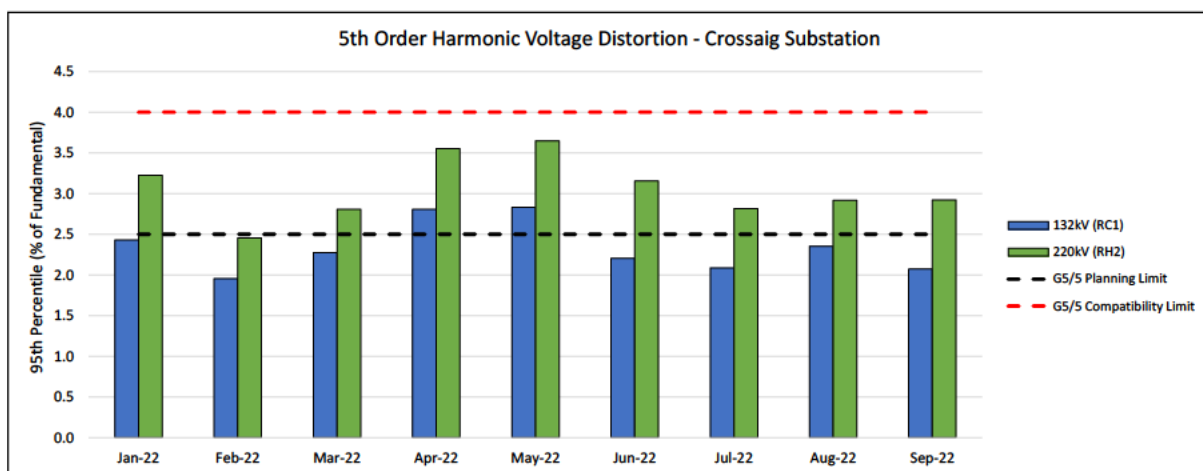


Figure 2.2 – Example fifth Order Harmonic Voltage Distortion (Crossaig Substation)

2.2 Root Cause Analysis

A detailed study identified that the cause of the issue is the amplification of the harmonic within the ScottishPower Transmission (SPT) license area caused by the Kintyre – Hunterston 220kV subsea cables. It is important to stress that the fifth harmonic distortion within the SPT area is not above planning levels and that it is the physical characteristic of the 220kV cables that result in the amplification across and into the SSEN Transmission license area.

A transfer coefficient can be calculated between two nodes within a power system and used to determine if a harmonic injected at one node is either amplified or attenuated at the remote node. If the transfer coefficient is above unity, then this signifies that the harmonic will be amplified. Figure 2.3 provides an example of the calculation between Hunterston (SPT) and Crossaig (SSEN Transmission) under minimum fault level conditions within a 2022/23 model for harmonic orders up

² Engineering Recommendation G5, Issue 5, “Harmonic voltage distortion and the connection of harmonic sources and/or resonant plant to transmission systems and distribution networks in the United Kingdom”, 2020.

³ CP95 refers to the cumulative probability, 95th percentile of a value.

to the 10th. The figure shows that the transfer coefficient is high between the fifth and sixth harmonic orders meaning that these harmonics will be amplified across the 220kV subsea cables. Based on monitoring, it is the fifth harmonic which is most susceptible to this phenomenon.

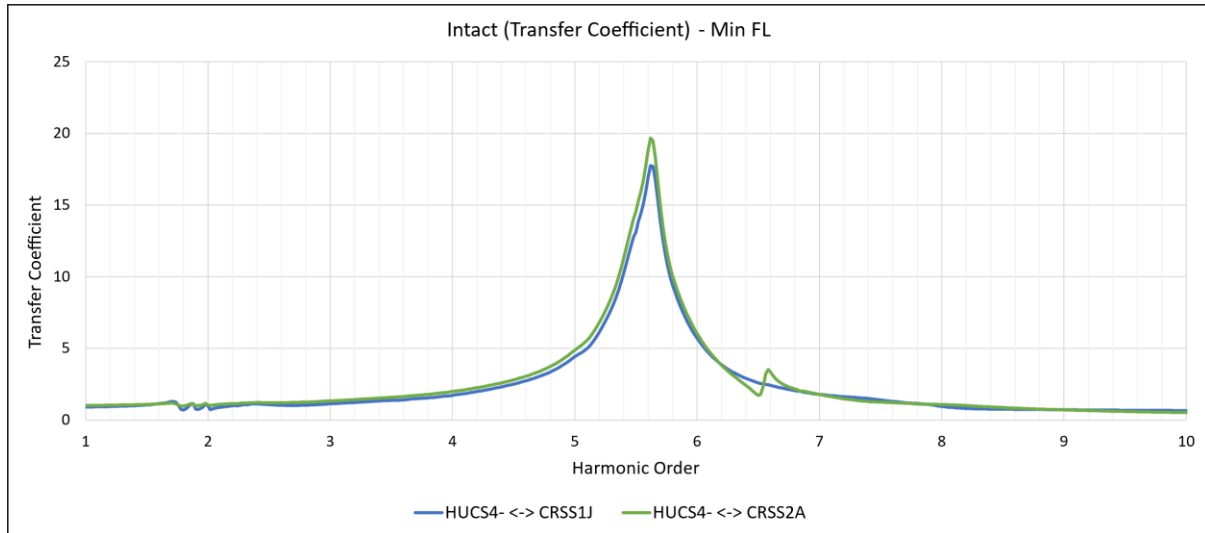


Figure 2.3 - Transfer coefficient profile between Hunterston and Crossaig substation (under minimum fault level)

A further review of the monitoring data in a time series format found that the fifth harmonic is not consistently above the planning level – but rather it appears to have step changes above and below the threshold. The net effect of this behaviour are CP95⁴ monthly harmonic values being recorded above the planning level. A review of potential causes of step changes in harmonic levels in the SPT area identified the Hunterston HVDC converter station and its associated AC filters as being a likely source.

To test this conclusion, a system test was arranged jointly with the ESO and SPT to switch an AC filter bank tuned to the fifth harmonic at the converter station into service whilst the Western HVDC Link was not operating. Figure 2.4 shows the recorded fifth harmonics on 22 July 2021 and two clear step changes can be observed in the results which correspond to the exact times of filter bank switching.

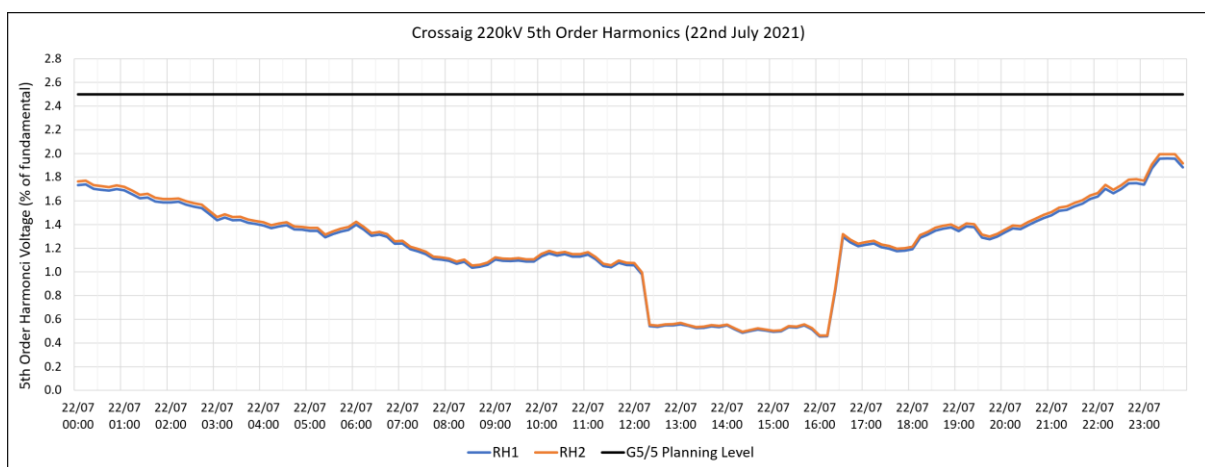


Figure 2.4 - Fifth order harmonics at Crossaig 220kV for 22/07/2021

Both the analytical work and system monitoring has confirmed that the periods of fifth harmonic being above the planning level correspond to those points in time where the harmonic background level within SPT's transmission area is at a maximum with the Western HVDC Link out of service. As is standard practice, the AC filters at Hunterston are only in service when the converter station is operational to provide local filtering and reactive compensation for the link transfer.

For completeness, the future reinforcements planned for the southwest region of our network have been studied and do not have any significant impact – either positive or negative – on the amplification of fifth harmonic into the region. The transfer coefficient between Hunterston and the region is not materially impacted by the proposed reinforcements in the Argyll and Kintyre project.

2.3 Current Operational Mitigation

As demonstrated above, maintaining a single AC filter bank in service when the Western HVDC Link is not operational can mitigate the issue in the SSEN Transmission area. However, AC filters deliver capacitive reactive power to the system at fundamental frequency and can therefore act to increase the voltage at their point of connection.

The ESO has investigated if this operational measure can be applied and found that there are a small number of outage combinations within the SPT area when it cannot be used due to problematically high post fault voltage conditions. As a result of this, the ESO control room will, where possible based on system conditions, retain an AC filter bank in service when the Western HVDC is not operative. However, although this does not present a complete mitigation, the harmonic levels within the southwest region have not been found to breach the compatibility levels and no customer complaints have been received.

2.4 Failure to Develop an Enduring Mitigation Measure

As with many power quality issues, it is difficult to make quantitative projections of future growth in harmonic distortion due to the complex nature of the phenomena. However, given the increase in generation connections expected within the region which have the potential to incrementally add to local harmonic distortion, taking no action to develop a comprehensive mitigation measure would expose the system and its users to risks. Because of this, SSEN Transmission has identified that the installation of a dedicated passive AC filter within the southwest region is a necessary and effective system reinforcement. If no filtering is deployed then new connections could incur additional costs to attempt, on a site by site basis, to compensate for the elevated fifth harmonic. This would be inefficient with the optimal placement of filtering being more effective within the TO network.

The detrimental impact of not intervening could potentially lead to the maloperation of equipment; system overloading; degradation in lifetime of assets; and subsequent impacts on end consumers due to the resultant earlier replacement of assets.

3 Optioneering & Preferred Option

The installation of harmonic filters to resolve issues such as this is common practice where major AC cables are installed as it is not feasible to change the design of the cable system (without incurring significant cost and consenting challenges). The mitigation of the harmonic issue in the southwest region must address the impact of the physical characteristics of the cable if the solution is to be enduring and independent of other wider system constraints.

During our investigations, SPT and National Grid ESO agreed to a proposal by SSEN Transmission, to switch-in a filter at Hunterston converter station for a period of assessment, to determine the impact this has on the elevated fifth order harmonics observed in the southwest region. In collaboration with SPT and ESO, a study was conducted, including a switching sequence to extract the full harmonic data from monitoring devices set up at Crossaig substation. The results concluded that switching the filters would have an immediate impact on the fifth order harmonics observed at Crossaig substation. We therefore focussed further optioneering on those substations in the immediate vicinity of the Crossaig substation (at differing voltage levels) to ensure we select the most economic and effective solution.

The development of an AC filter solution will be progressed using an external consultancy to provide detailed design services. Table 2 outlines our current list of options under consideration. A filter installed anywhere in the region has the potential to be beneficial and its relative effectiveness will be balanced against the practical constraints of installing it at existing substations (option 4) or at the new Crossaig North substation being developed as part of the wider programme of regional reinforcement.

The current preferred option is to install a harmonic filter at the proposed Crossaig North substation which forms part of our Argyll and Kintyre Strategy⁵ due to the economies of scale and reduced disruption during construction. As noted above, this is currently under development as part of SSEN Transmission’s wider network reinforcement planned under the Argyll and Kintyre Large Onshore Transmission Investment (LOTI) mechanism, which currently has been granted Initial Needs Case (INC) approval from Ofgem and is currently being prepared for a Final Needs Case (FNC) submission. If, through more detailed optioneering, we identify a more economic and effective solution at the other locations listed, this will be included within our cost submission in January 2024, securing further benefits for consumers.

At this stage in development, no final site within the region has yet been selected and is expected to be confirmed by October 2023. We will provide the costs associated with each option as part of our 2024 MSIP submission.

ID	Option Description	Progressed	Reason
1	Do nothing	No	The problem will not be resolved, and it is likely that there will be an increase in the fifth harmonic as further generation connects in the region. If no action is taken, then it is likely that this will start to impact on customer equipment.
2	Delay investment	No	The issue is not causing complaints at present or any noticeable detrimental impact on system operation. However, delaying the installation of a

⁵ [Argyll and Kintyre 275kV Strategy - SSEN Transmission \(ssen-transmission.co.uk\)](https://www.ssen-transmission.co.uk)

			harmonic filter would potentially expose the system to medium term risks. The difficulty in forecasting increases in harmonics makes this approach difficult to justify.
3	Operational mitigation using current Hunterston HVDC Converter Filters	Yes	Although this method is currently in use, it is not comprehensive, cannot be relied upon and will incur a degree of operational costs.
4	Harmonic Filter in the southwest region of SSEN Transmission network	Yes	Subject to review in detailed filter design studies currently underway. At this stage possible locations options include: <ul style="list-style-type: none"> • Crossaig 132kV substation • Carradale 132kV substation • Crossaig 33kV substation (tertiary winding connection) • Crossaig North 33 kV substation

Table 2: Summary of mitigation options

Installation of a harmonic filter in the region is therefore the only enduring option available to address the issues outlined within chapter two. Based on there being only one technically feasible option, there is no requirement to carry out a full cost benefit analysis (CBA) to select a preferred option.

4 Cost Information

4.1 Cost Summary

The purpose of this section is to provide an indicative estimated project cost which is currently at a Class 0 or 'Project Screening' stage of maturity.

The total cost for the [REDACTED] estimate is [REDACTED] including pre-construction costs which we will be seeking approval of upon submission of the costs in the January 2024 submission window. The costs set out within this submission only include costs incurred or expected to be after 1 April 2021 and meet the materiality threshold set out within the Licence.

Category	Project Class-0 estimate (£m) (Price Base – 18/19)	SSEN Transmission Project Cost Class	SSEN Transmission Indicative Estimate Tolerance
Total	[REDACTED]	[REDACTED]	[REDACTED]

Table 3: Cost summary

- The estimate has a [REDACTED] range from [REDACTED] based on the project status and scope maturity as identified in Chapter 3. Any material change in scope will result in the project cost estimate being updated accordingly

The estimate has been produced in line with our Costing Methodology and all principles contained therein adhered to.

4.2 Project Costing Next Steps

Following the submission of this MSIP Needs Case we will continue to develop and refine the costs for this project in line with our Large Capital Project governance. We expect to complete early engagement with the supply chain during Winter 2023 and are likely to have market tested estimates during Spring 2024. We will continue to engage with Ofgem on project costs throughout 2023/2024, following this submission.

4.3 Procurement Strategy

Our procurement and contracting strategy is being developed and will consider all potential options to drive efficiency and will deliver the most competitive prices that the current international market has to offer.

5 Conclusion

This submission is seeking Ofgem approval of the need to address the harmonic distortion in the southwest region of our network through the installation of a harmonic filter. Our preferred location is in the immediate vicinity of Crossaig Substation. This investment is the only enduring option available to address the issues associated with fifth order harmonic distortion (as outlined within chapter two).

This submission outlines a minimum requirement to install a harmonic filter in the southwest region of SSEN Transmission's network. The purpose of this installation is to reduce fifth order harmonic distortion in the region. As evidenced within section two, failure to do so will not address the problem and return harmonics in the region to below acceptable planning levels. In the meantime, it has been agreed with National Grid ESO that the current operational mitigation will continue to be used (where feasible). We will continue with routine monitoring and report to National Grid ESO should there be any indication that the problem is increasing or reducing in severity.

This submission is not requesting approval of either the location of the solution or associated allowances. Based on system testing, we know that installation of a harmonic filter would have an immediate impact on the fifth order harmonics observed at Crossaig substation. We therefore intend to focus further optioneering on those substations in the immediate vicinity of the Crossaig substation (at differing voltage levels) to ensure we select the most economic and effective option as our preferred option.

Next steps

We will continue to refine our optioneering and detailed cost estimate during 2023. We intend to seek approval for a preferred option and request the full project allowance as part of the January 2024 MSIP submission window, at which point we will have identified a site for the filter and completed key procurement activities.

Appendix A Glossary of terms

Acronym	Definition
AC	Alternating Current
CP95	95% Cumulative Probability
EREC	Engineering Recommendation
HVDC	High Voltage Direct Current

Appendix B Southwest Region Map

