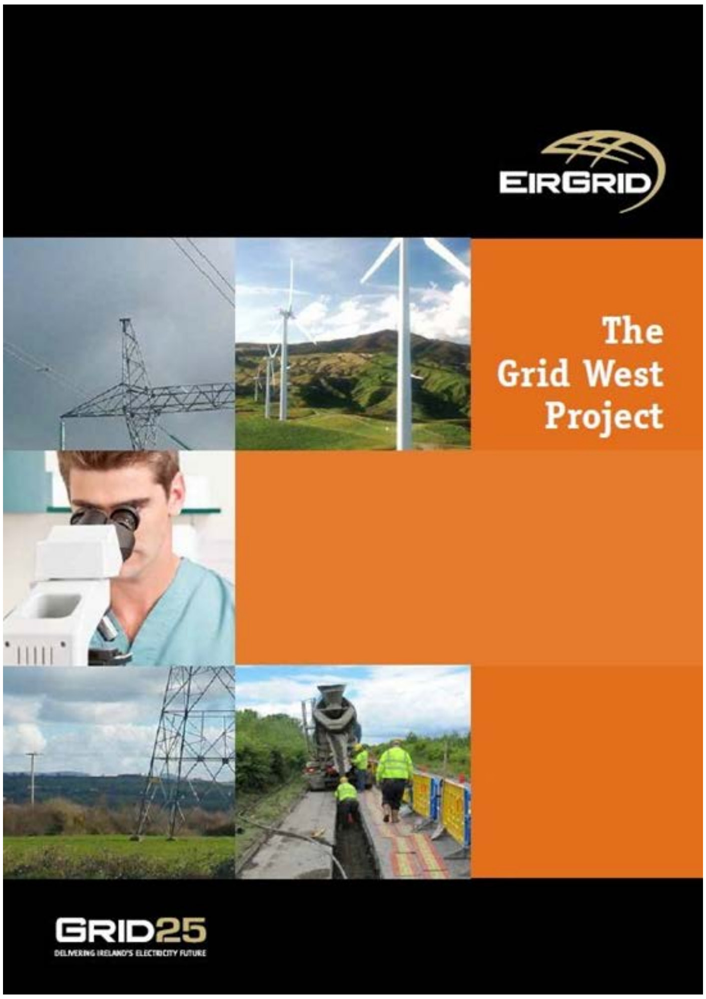
EirGrid

10344 – PSP019 - AC CABLE STUDIES FOR GRID WEST

Full and Partial AC Underground Solution



Main Report

30/01/2015

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EirGrid Project Number PSP0019
LPA Project Number 10344

REPORT AUTHORISATION SHEET

Client:	**EirGrid**
Project:	**10344 – PSP019 - AC Cable Studies for Grid west**
Report Title	**Cable Studies for Grid West**
Project Number	**10344**
Report Version	**Final Report**
Report Date	**30th January 2015**

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Version No.	Report Date	Comment	Author	Checked	Authorised
1.0	12/12/14	Initial Issue	CE	AJ	JS
2.0	30/01/14	Revised Issue with comments	CE	AJ	AJ

Contents

1 EXECUTIVE SUMMARY

London Power Associates was commissioned to evaluate the usage of AC underground cable as part of the North Mayo-Flagford circuit on the Grid West Project. The Grid West Project is a project proposed by EirGrid, the Irish Transmission System Operator, to facilitate the connection of large scale renewable energy sources in the North West of Ireland to a strong point on the national grid – subsequently identified as Flagford 220 kV substation in County Roscommon. Initially a 400 kV overhead line was considered as the preferred option for the Grid West project, but EirGrid is now focusing on developing an additional option for consideration that consists of a full or partial underground AC solution.

1.1.1 Scope of the AC Undergrounding Studies

The objective of this study was to identify the technically acceptable maximum length of the AC cable that could be installed between the 220 kV Flagford substation and the North Mayo region of the Irish transmission network. To evaluate the technical feasibility of the solution, reactive compensation and load flow studies have been completed on PSS/E, and frequency scans and transient studies have been carried out using ATP (Alternative Transients Program) which is an EMTP (Electromagnetic Transient Program) software.

1.1.2 Assumptions during the Studies

All proposed AC underground solutions were verified against a variety of network conditions, including operational scenarios. These scenarios considered normal operational conditions, and some of the most onerous possible outages. These are based on assumptions agreed between EirGrid's Transmission Network Planning team and London Power Associates.

A significant amount of investment in the transmission system in the north west of the country is expected over the next 10 years. This investment includes reinforcements to the existing 110 kV network along with the development of the Grid West project. A significant amount of generation in the North Mayo region is expected to connect to both the existing 110 kV network and via the proposed Grid West new circuit back to the Flagford 220 kV node. The practical scenarios chosen for the Grid West AC cable studies provide operational considerations for two main scenarios. The first includes a high percentage of wind generation in the Irish network and the second at times with little or no generation in the area of concern (this represents lower short circuit levels).

Two demand scenarios were chosen for this study, these are Winter Peak A and Summer Valley B, which represent the two extremes of normal network operational scenarios. These scenarios reflect the higher and lower limits of the range of system operational conditions under which the system must operate. The Winter Peak A case includes high wind operation in the study area to evaluate the system at a maximum short circuit level, whilst the Summer Valley B case represents a low wind generation scenario and hence a low short circuit level.

The Winter Peak A scenario stresses the power system for voltage issues and a higher short circuit level. This is due to the reactive power generated from the cable section of the Grid West circuit and in other areas, as a result of a heavily loaded Grid West cable. In this case the wind farms connected at North Mayo provide some reactive compensation for the cable. In the case of the Summer Valley B scenario, the network was stressed with high potential voltage issues, due to lower possible wind farm reactive absorption.

Network models were setup in both ATP and PSS/E for each of the scenarios using detailed information and latest assumptions provided by EirGrid's Transmission Network Planning team. Once constructed the models were validated to ensure correct operation.

1.1.3 Methodology and Acceptability Criteria

The PSS/E model was used to prove the steady state conditions of the network and the reactive power compensation required for the Grid West cable solution to ensure this functions within normal system operational and planning limits. The ATP transient model was used to perform frequency scans on the network at Flagford in order to determine the frequency response of the network and to identify any high magnitude resonance points when the cable is introduced to the system. Typically high magnitude resonance points (above 1000 Ω) cannot be tolerated below the 3rd harmonic, as these can lead to system instability and above this value further investigation is required in time domain simulations. Time domain simulations are then carried out to assess the outcome of various switching and fault scenarios, assess the magnitude of switching overvoltages and temporary overvoltages (TOVs) which are produced as a result of the addition of the cable. Switching overvoltages and TOVs which exceed the thresholds can damage equipment and their scale must be assessed with the use of power system studies. Temporary overvoltages need to be limited to 1.6 pu and switching overvoltages 2.5 pu, this is based on international standards and best practice. High magnitude resonance points when excited can produce significant temporary overvoltages, switching overvoltages are dependent on the length of the cable. Extension of the cable length can be considered with the use of filters to reduce high magnitude resonance points below the 3rd harmonic.

1.1.4 Partial 400 kV AC Cable

An initial study evaluated a partial 400 kV underground cable/overhead line option as a potential 400 kV solution. A study was carried out to consider a 10 km cable and 90 km overhead line 400 kV solution.

An assumption was made for the purposes of the study that the 10 km cable section would connect to the 220 kV Flagford substation and extend towards North Mayo, connecting to the overhead line section. Reactive power compensation studies were completed using PSS/E. These studies showed that reactive compensation of 125 Mvar at Flagford and 20 Mvar at North Mayo was required.

Frequency scans were carried using ATP and these scans showed an initial resonance point just below the 3rd harmonic with a magnitude of above 1000 Ω. It is known that resonance can be excited, and has the potential to cause a system operational issue.

A time domain simulation was carried out using the Summer Valley B scenario using a trip-maintenance condition, Flagford-Louth outage, Cashla-Flagford auto-reclose condition, which is considered as the worst possible case, (N-1-1) situation. These results showed that this solution produced significant TOV issues around the local area which exceeded the limits. Studies therefore show that the 400 kV 10 km Cable/90 km Overhead line solution is not acceptable in the Flagford/North Mayo area of the Irish transmission system.

1.1.5 Full and Partial 220 kV AC Cable

As the Grid West circuit was deemed to be technically unacceptable as a 400 kV cable/overhead line hybrid, it was decided to consider options for acceptable hybrid configurations at a lower voltage of 220 kV. Initial analysis demonstrated a series of steps that were necessary to evaluate the solution and to determine the maximum length of 220 kV cable for the Grid West project.

Firstly an analysis was carried out on a full 220 kV underground cable of 120 km between Flagford and North Mayo. During the studies a large number of scenarios were considered, including combinations of the Winter Peak A and Summer Valley B with varying operational considerations. Various network scenarios were considered, these included various (N-1) and (N-1-1) outage conditions and allowed the studies to evaluate the most onerous situations to be considered from a planning point of view. These resulted in the (N-1-1) Flagford-Louth line Outage, Cashla-Flagford line auto-reclose onto a permanent fault to be considered as the worst case.

The studies completed on the full underground cable solution at 220 kV found that substantial reactive power compensation would be required at Flagford substation, of the order of 300 Mvar, and 250 Mvar would be required at North Mayo. Frequency scans for this combination showed that the first system resonance point was below the 2nd harmonic, with a magnitude just below the chosen limit. Time domain simulations were carried out to determine the magnitude of switching overvoltages and TOVs in ATP. Switching overvoltages were exceeding the limit of 2.5 pu, but can be mitigated with the application of surge arrestors, TOVs are outside of limits for this cable length. During the worst case scenario transformer saturation was observed for a significant period due to reactive power generated by the cable. Therefore a full 220 kV underground solution was deemed to be unacceptable.

The most onerous network scenario is an (N-1-1) with Flagford-Louth on outage and an autoreclose onto a permanent fault of the Cashla-Flagford line was identified in the fully underground option assessment. This was subsequently used as a screening case to identify potentially acceptable solutions for other underground/overhead ratios. This evaluation involved testing various overhead line and cable combinations with the following cable lengths examined – 100 km, 80 km, 70 km, 58 km, 40 km, 30 km, 20 km and 8 km with the remaining part of the circuit modelled as an overhead line. Initially, following the evaluation of these cable lengths, the 58km cable option and lengths below 30 km demonstrated favourable results from a TOV point of view. However detailed analysis of the 58 km option showed that this combination had a high magnitude harmonic resonance point which could lead to significant TOVs (shown in the 40 km to 70 km cases). Any future changes in the network configuration could increase TOV issues, as it was shown to be sensitive to system strength changes at Flagford 220 kV substation and the first resonance point could increase towards the 3rd harmonic or decrease towards the 2nd harmonic. Therefore this option is unacceptable.

Detailed analysis continued with evaluation of partial cable options with the 30 km and 20 km cable sections. As the study was sensitive to network changes in the Flagford area and sensitive to the cable along the Grid West circuit, it was required to make an assumption as to the exact locations of the cable sections on the Grid West circuit and the surrounding 220 kV circuits. It should be noted that chosen configurations are based on assumptions for the purposes of completing the study, and the outcomes will give an indication of the acceptability of the cable length in the 220 kV hybrid solution. They are not intended to represent a final solution on the preferred or proposed location of any of the cables.

1.1.6 Split 220 kV AC Cable

Following the consideration of the possible route for the cable and overhead line, associated possible options in the areas surrounding the North Mayo and Flagford substations were considered. The cable lengths in the 30 km and 20 km cable options were divided into three sections. The first section of the cable from Flagford was assumed to be 8 km in length and this represented part of the Flagford-Srananagh 220 kV line, i.e. the installation of cable to an existing circuit in the area to reduce 'wirescape' leading into Flagford station. This is not a usage of cable on the Grid West circuit itself, but has a direct effect on the cable analysis and so is included and considered as part of the project.

This was chosen as the Grid West circuit can use the final section, approximately 9km of the existing Flagford-Srananagh 220 kV line, on the entry to the Flagford substation, given its potential for conversion to a 400 kV circuit at a later date. The existing Flagford-Srananagh 220 kV line can then be cabled for the final 8km leading into the Flagford substation. The first section of the Grid West cable is assumed to be connected at the North Mayo 220 kV Substation, which is coupled to an overhead line/cable combination, with the final 2 km of the Grid West circuit leading into the substation modelled as 220 kV cable. Mid-span cable sections were then added to Grid West circuit. The total length for the 20 km option became 23 km in the total cable option. Details of the cable routes are shown in Table 1 below.

Case	Route	Section 1	Section 2	Section 3	Section 4	Section 5
1) 23 km	Flagford to North Mayo (23 km Cable)	8 km Cable	64 km OHL	13 km Cable	18 km OHL	2 km Cable
2) 30 km	Flagford to North Mayo (22 km Cable)	2 km Double circuit/OHL	72 km OHL	20 km Cable	11 km OHL	2 km Cable
	Flagford to Srananagh (8 km Cable)	8 km Cable	45 km OHL			

Table 1: Split cable evaluation

The 23km case requires a reactor of 100 Mvar at North Mayo and 25 Mvar at Flagford. In the case of the 30 km total cable length 50 Mvar of reactive support is required on the Flagford busbar and 100 Mvar of reactive support is required at North Mayo. The initial worst case study showed that the 23km cable was acceptable from a Frequency Scan perspective, while the 30 km cable option was just below the 3rd harmonic. The study also showed that TOVs were slightly above the limits in both cases and that switching overvoltages can be controlled by the use of surge arrestors.

As the 20 km, 23 km and 30 km cable solutions only failed marginally it was proposed that measures could be employed to mitigate the issues observed. It was also believed that these mitigation measures may enable the longer cable length of 30 km to be implemented. Hence the cable length chosen to be studied along with mitigation measures was 30 km.

Therefore, in the 30 km case, suitable mitigation is required to reduce the first resonance point, which is below the 3rd harmonic, to a value below 1000Ω. A 50 Mvar high pass filter was implemented to achieve this goal.

Based on the studies carried out which included a range of Winter Peak A and Summer Valley B practical operational scenarios and energisation, (N-1), (N-1-1) outages, it was demonstrated that the 30km case is an acceptable solution for the studied scenarios. It is recommended, that when more detailed design information is available for the cable and wind farms at North Mayo a further suite of studies to confirm this hybrid cable solution is completed. These studies should consider additional scenarios and network possibilities and consider the optimum location and rating for the surge arrestors.

2 INTRODUCTION

The Grid West project is the reinforcement of the network by way of an EHV circuit from Flagford to North Mayo to facilitate the transmission of large amounts of renewable generation in the North Mayo region. A number of options are under consideration including an AC option that utilises a cable or a partial cable solution. The objective of this study is to identify the maximum length of the AC cable that can be accommodated on the Grid West circuit from the region in North West Mayo in Co. Roscommon. Evaluation of the solution will be carried out at 400 kV and 220 kV to find the most technically acceptable solution. Once the maximum length of cable is found, mitigation techniques will be considered to find the optimum solution.

Various cable lengths were considered, these included:

- a partial underground and overhead 400 kV option, with a 10 km of cable and 90 km overhead line;
- a full 220 kV cable evaluation of length 120 km;
- partial 220 kV overhead line and underground combinations including cable lengths of 99.7 km, 80 km, 58 km, 40 km, 30 km, 20 km, and;
- split overhead line and cable combinations of total cable length 23 km and 30 km were considered.

The study concluded by identifying a split 30 km 220 kV cable with overhead line, including a high pass filter, as the preferred solution.

3 METHODOLOGY

The methodology of analysing the maximum acceptable length for the Grid West AC cable between the 220 kV Flagford Substation and the North Mayo region of the Irish network can be split into several sections. These sections comprise of: selection of network scenarios, power system network construction and validation, reactive power compensation, power system study methodology, and selection of operational cases to study.

In order to evaluate the Grid West circuit, the surrounding transmission network needed to be accurately represented in the ATP case models. Evaluation of the Grid West circuit requires representation in the software model the power system networks adjacent to the area of study, including the central and northern sections of the Irish network. All 220 kV lines and transformers are modelled explicitly in the northern and the central midlands regions of the All-Island network, together with large sections of the 110 kV network. Equivalent representations are used on the surrounding 110 kV radial circuits. All transformers in the 220 kV are modelled including their saturation characteristics. Similarly network and shunt capacitances and reactors are also modelled.

The studies evaluated cable lengths which were split into several sections. Steady state load flow simulations, including reactive compensation were carried out using PSS/E version 32, and the corresponding frequency scans and transient studies using ATP (Alternative Transients Program). The studies consider two extreme operational scenarios for the Irish network; the strongest operational scenario Winter Peak A and the weakest operational scenario Summer Valley B. The worst case operation scenario is determined to consider the worst case scenario.

The steady state load flow simulations evaluate the reactive power requirements for each cable length tested and compensation between 70 – 80% of the reactive power generated by the cable is provided and these will be evaluated in the Summer Valley B and Winter Peak A networks before use.

Frequency scans examine any high impedance resonance points and allow the selection of a limited number of time domain simulations to be examined. Time domain simulations determine any issues relating to switching and temporary overvoltages with the sample cable. Finally mitigation solutions are employed to extend the cable length to the maximum length possible, when the potential viability of mitigation is identified based on related frequency scans.

3.1 Selection of Network Scenarios

The Grid West Partial AC Underground connection needs to be verified in a variety of different network conditions which were chosen to reflect the most onerous, but realistic flows on the network based on previous studies and the assumptions, which were provided by the Transmission Network Planning department in EirGrid.

The North Connaught area of the Irish network is expected to change significantly over the next decade with large investment planned in the transmission network, which includes the Grid West Project and other investments in upgrading the 110 kV network. These reinforcements are planned primarily to allow the connection of a large amount of Gate 3 wind generation in the area. The chosen study scenarios must verify the network when a high percentage of this wind is generating power but also at times of little or no generation in the region to verify the system at a low short circuit level.

Seasonal scenarios chosen for this study are the Winter Peak A and the Summer Valley B, as the two extreme operational scenarios. These reflect the range of system operation conditions under which the chosen full or partial cable solution must be capable of operating without any issues. Table 2 lists the scenarios considered in this study and the corresponding wind generation in each wind area for them. The Winter Peak case has high wind in the area which will test the system at maximum system strength in the region, while the Summer Valley case with low wind generation in the area will test the system at the lowest system strength.

The wind regions described in Table 2 are shown in Figure 1 below.

Scenario	Description	Wind Levels Areas A,B,C	Wind Levels Area NI	Other Wind Area Levels
WPA	High Wind North Region Low Wind South Region	80%	80%	40%
SVB	Low Wind North Region High Wind South Region	10%	10%	35% - Areas E, F, H2, I , J, K 60% - Areas D, G, H1

Table 2: Study Scenarios Examined in Cable Study

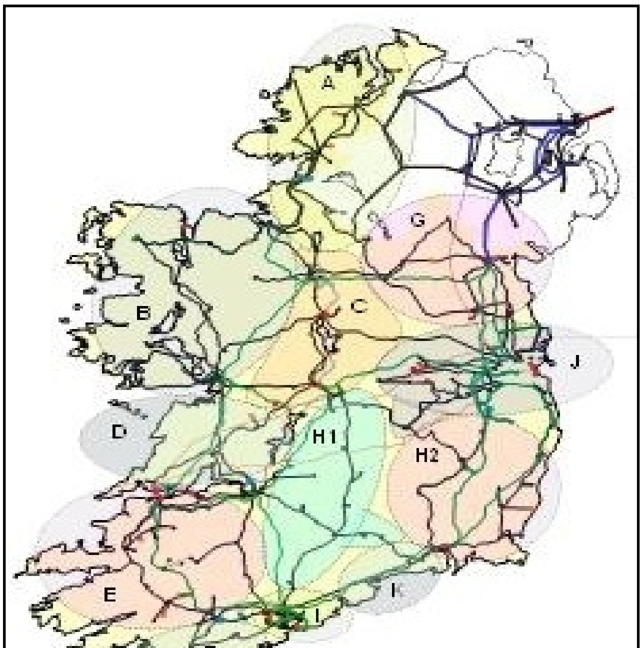

Figure 1: Map of Wind Areas by Gate 3 Connection Areas

High wind scenarios (WPA) in the north region stress the network with potential high voltage issues around the study area due to the Mvar generation from both generation and the transmission network and low voltage issues in other areas due to high reactive power consumption from distribution connected wind farms. The low wind scenario (SVB) in the north region stresses the network in an opposing way with potential high voltage issues arising from a lack of reactive power consumption from these wind farms at North Mayo.

The flow of wind generation in the Winter Peak A scenarios studied are shown in Figure 2 and the flows of wind generation in the Summer Valley B scenario is shown in Figure 3.

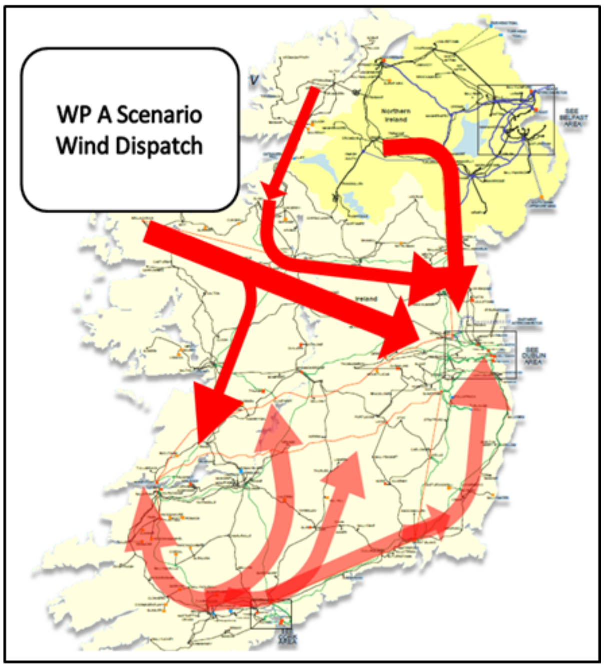

Figure 2: Winter Peak Dispatch Scenarios with red arrows showing general flow directions

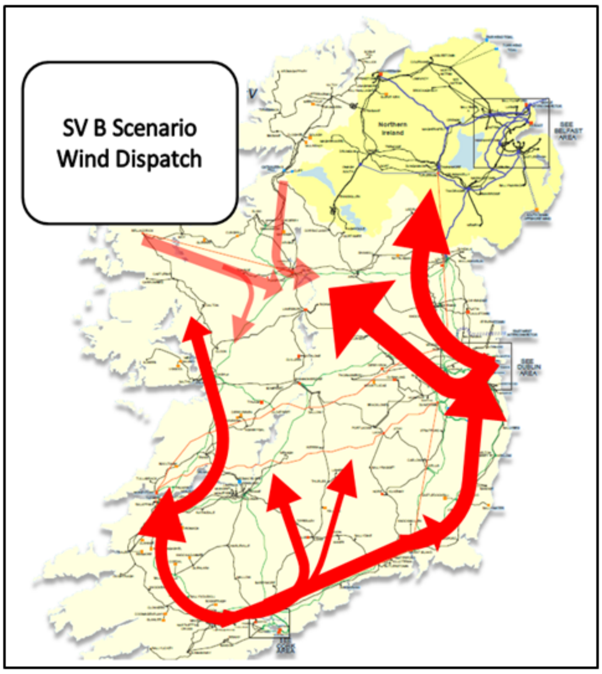

Figure 3: Summer Valley Dispatch Scenarios with red arrows showing general flow directions

3.2 Power System Studies Methodology

The power system studies focus on determining the longest length of 400 kV or 220 kV cable possible for the Grid West circuit. An iterative approach is used in this process whilst evaluating various underground and overhead line options, as the 100% cable option produced issues, the cable length was reduced by approximately 10 km steps until a solution was found. This general approach is shown in the flow chart below.

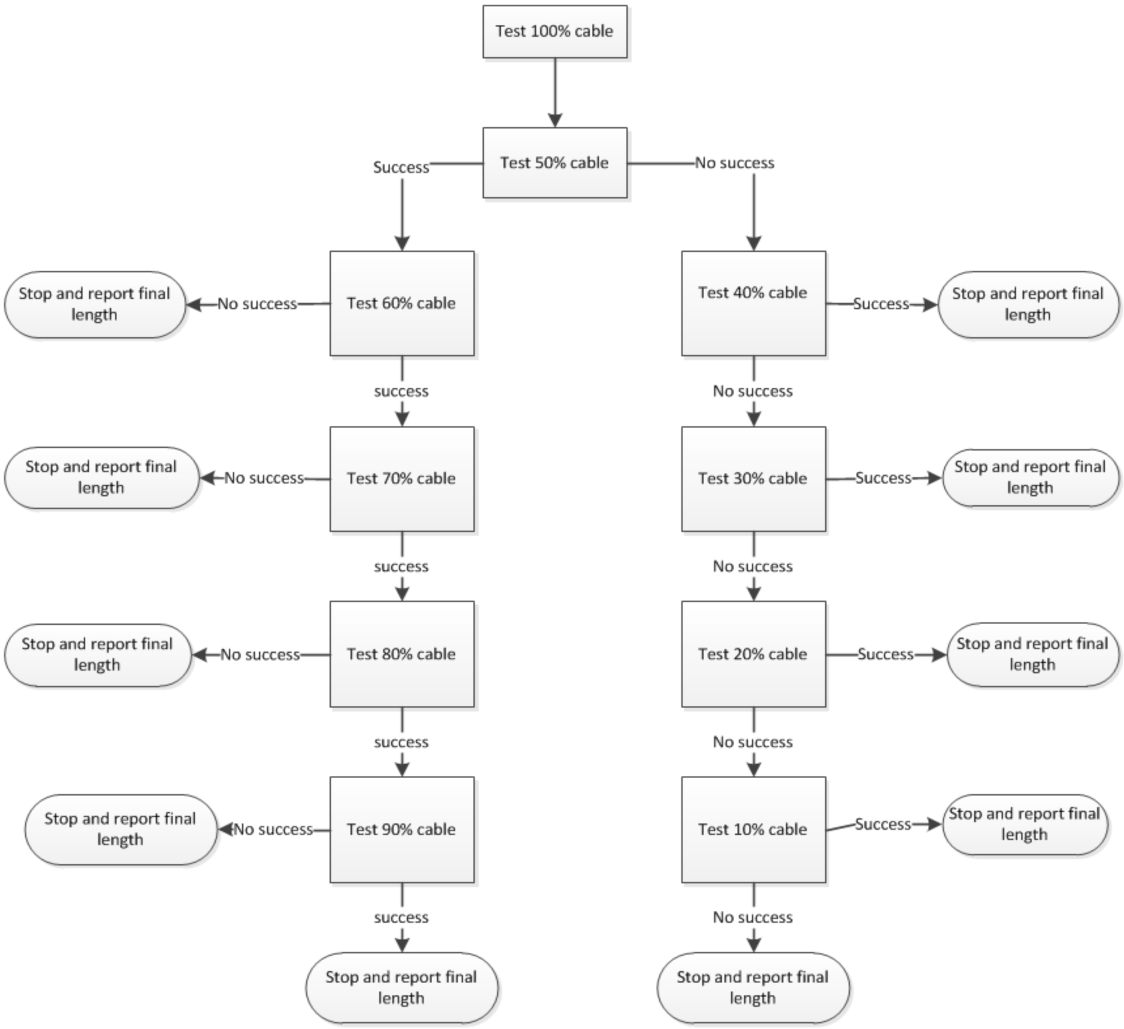

Figure 4: 220 kV Cable study methodology

The networks in the model that were studied were constructed for the Summer Valley B and Winter Peak A scenarios prior to any evaluation. Following this model construction the studies were completed in the following sequence:

1. Determine the compensation requirements using PSS/E.
2. Verify any additional reactive compensation devices required using the Summer Valley B and Winter Peak A networks.
3. Conduct frequency scans in ATP to highlight any potential issues with resonances.

4. Run time domain simulations to confirm, if any issues with switching overvoltages or temporary overvoltages arise.
5. If any issues arise with the resonant points in the frequency scans, result in switching voltages, or TOVs that are not acceptable, consider a shorter length.
6. Once the final solution has been found, consider mitigation techniques to increase the length of the cable where mitigation appears viable.

The Grid West connection was evaluated for various cable lengths to find the maximum technically acceptable solution.

3.3 Power system network construction

A detailed ATP model of the Irish network was constructed of the transmission lines, transformers, cables that combined from the network and utilised equivalent networks for a significant section of the 110 kV system. A detailed map of the Irish transmission system expected in the year 2022 is shown below.

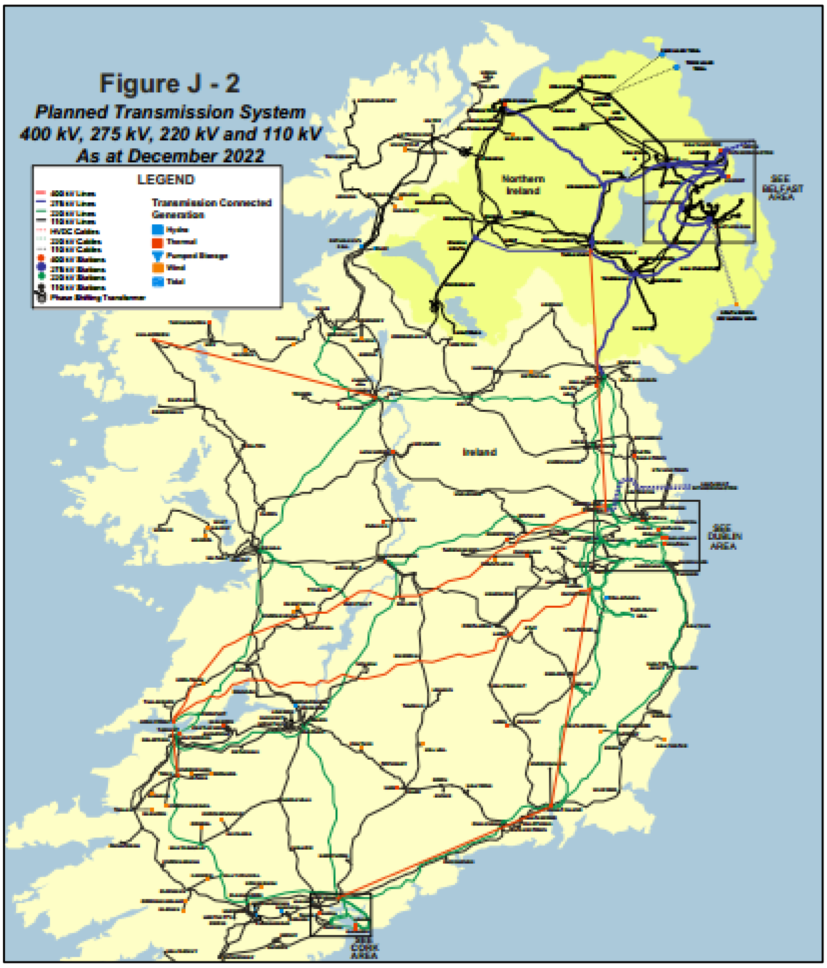

Figure 5: Irish transmission system

The north and central regions of the Irish network have been modelled in detail, including all sections of the 220 kV network and equivalents of the 110 kV supporting network. This included transformers, shunt reactors, capacitors and detailed models of transmission lines. An example of the ATP network adjacent to the Grid West circuit is shown below.

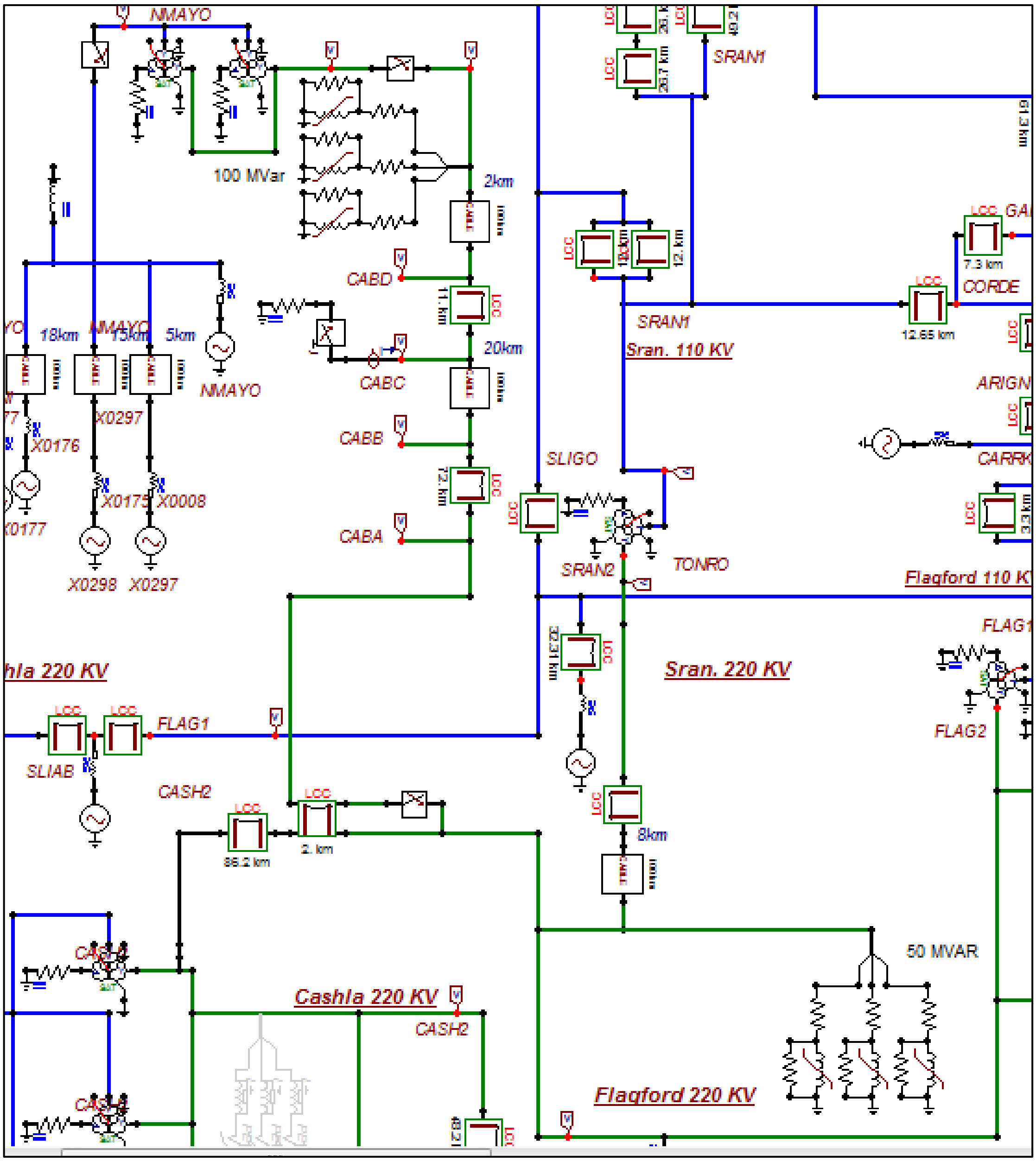

Figure 6: ATP Diagram showing local area around the Grid West Circuit

3.3.1 Power system network validation

The ATP network models in the Winter Peak A and Summer Valley B cases were constructed for the year 2020. These were verified against the PSS/E cases supplied for the same year. A summary of the verification is included below.

The verification was completed by placing three phase faults in both the ATP and PSS/E networks and recording the resulting currents. A summary of the results is included in the tables below.

The Winter Peak A (WPA) model validation using the RMS break currents is shown below.

Station Name	Voltage	PSS/E	ATP
		RMS break	RMS break
Flagford	220 kV	8.279 kA	8.716 kA
North Mayo	110 kV	7.419 kA	7.902 kA
Old Street	400 kV	7.929 kA	8.503 kA
Cunghill	110 kV	6.089 kA	6.216 kA
Srananagh	110 kV	11.060 kA	11.349 kA
Enniskillen	110 kV	8.084 kA	8802 kA
Kells	110 kV	23.432 kA	22.857 kA
Gorman	110 kV	14.010 kA	14.457 kA
Meentycat	110 kV	5.513 kA	6.152 kA
Cashla	220 kV	9.990 kA	10.320 kA
Lanesboro	110 kV	10.664 kA	11.321 kA

Table 3: Winter Peak A – Validation RMS Break Currents

The Summer Valley B (SVB) model validation using the RMS break currents is shown below.

Station Name	Voltage	PSS/E	ATP
		RMS break	RMS break
Flagford	220 kV	7.993 kA	8.614 kA
North Mayo	110 kV	7.366 kA	7.716 kA
Old Street	400 kV	7.366 kA	8.0032 kA
Cunghill	110 kV	5.982 kA	6.215 kA
Srananagh	110 kV	10.500 kA	10.641 kA
Enniskillen	110 kV	8.140 kA	8.871 kA
Kells	110 kV	23.361 kA	23.513 kA
Gorman	110 kV	13.285 kA	13.603 kA
Meentycat	110 kV	5.314 kA	5.881 kA
Cashla	220 kV	9.520 kA	9.673 kA
Lanesboro	110 kV	8.715 kA	9.412 kA

Table 4: Summer Valley B - Validation

3.4 Reactive Power Compensation

The Grid West 400 kV or 220 kV AC cable solution requires reactive compensation at both ends of the cable. This is achieved by using shunt reactors which consume approx. 70 – 80% of the reactive power generated by the cable. The reactive power requirements of the cable were determined under steady state conditions using PSS/E 32. Since only one 400 kV case was considered and was not deemed to be practical, reactive power compensation focuses around the 220 kV cases.

The steady state reactive power requirements of the cable have been determined by energising the cable from the Flagford busbar at 220 kV and disconnecting it from the North Mayo busbar to determine the worst case reactive power requirements without any shunt reactors fitted. At the outset of the project an indicative analysis was carried out to estimate the amount of reactive compensation required if reactor banks were installed only at Flagford station. The reactive power requirements for various ratios of cable/overhead line options are given in Table 5 below.

Length of cable (% of 120 km)	Reactive power requirements at Flagford (Mvar)
100% (120 km)	783
90% (108 km)	665
80% (96 km)	560
70% (84 km)	467
60% (72 km)	384
50% (60 km)	308
40% (48 km)	237
30% (36 km)	172
20% (24 km)	111
10% (12 km)	53

Table 5: Reactive power requirements for a 220 kV cable

However, bespoke analysis was carried out on each cable length with Table 5 used an initial starting point. This analysis involved ensuring that the addition of the cable did not breach EirGrid's voltage planning standards and the loss of one reactor bank did not result in a voltage step greater than 3%. Once the reactive compensation level has been determined in PSS/e, verification was completed within the relevant case in ATP for both the Summer Valley B and Winter Peak A cases to confirm the reactor sizes. The reactor sizes calculated for each length evaluated were installed and used to determine the suitability of the cable length. A detailed example of the reactor sizing for the final solution option is given in Section 3.5.

3.5 Reactor Validation for the Final 30 km case

As the emerging maximum cable length optimum solution for the hybrid Grid West cable/overhead line option was a 30 km cable, mitigation options to reduce any unwanted temporary overvoltages were considered for this option. An assessment of the required reactors at each end of the cable was carried out and it was determined that 100 Mvar of support was required at North Mayo and 50 Mvar of support was required at Flagford. To ensure that these conform to planning and operation requirements to maintain the operational voltage within 3% with the loss of a reactor bank, the reactor switching step size must be considered and this were verified using PSS/E. Therefore, to ensure N-1 compliance was maintained and step size limitations are achieved, it was determined that reactive compensation of 125 Mvar at North Mayo and 75 Mvar at Flagford is installed in banks of 25 Mvar.

In the Summer Valley B case, the worst case is considered to be energisation of the Grid West connection in the worst case scenario, without the wind farms at North Mayo connected. Results are shown in the tables below.

Condition	Size of reactor at North Mayo	Voltage at North Mayo
Minimum Size	40 Mvar	1.09 pu
Grid West Circuit Energisation (w/o North Mayo wind farms or transformers energised)	100 Mvar	1.00 pu
N-1 Reactor Bank (w/o North Mayo wind farms or 220/110kV transformers energised)	75 Mvar	1.028 pu
Voltage step at North Mayo (N-1) loss of one reactor bank (25 Mvar)		0.028 pu
Suggested size and configuration of reactor bank at North Mayo (N-1 Compliant)		125 Mvar (5x25MVar)

Table 6: Reactor configuration SVB – North Mayo

Condition	Size of reactor at Flagford	Voltage at Flagford
Minimum Size	No minimum size	Below 1.09 pu
Flagford – Srananagh energised (w/o Flagford reactor or Srananagh 220/110kV transformer)	N/A	1.030 pu
Flagford-Srananagh energised (w/o Srananagh 220/110kV transformer)	50 Mvar	1.016 pu
Voltage step at Flagford (N-1) loss of one reactor bank (50 Mvar)		0.014 pu
Intact conditions with Filter	50 Mvar	1.016 pu
Intact conditions with Filter tripped	50 Mvar	1.005 pu
Voltage step at Flagford (N-1) loss of filter		0.011 pu
Suggested size and configuration of reactor bank at Flagford (N-1 Compliant)		75 Mvar (3x25Mvar)

Table 7: Reactor configuration SVB – Flagford

Condition	**Size of reactor at North Mayo**	**Voltage at North Mayo**
Minimum Size	65 Mvar	1.09 pu
Grid West Circuit Energisation (w/o North Mayo wind farms or transformers energised)	100 Mvar	1.033 pu
N-1 Reactor Bank (w/o North Mayo wind farms or 220/110kV transformers energised)	75 Mvar	1.062 pu
Voltage step at North Mayo (N-1) loss of one reactor bank (25 Mvar)		0.029 pu
Suggested size and configuration of reactor bank at North Mayo (N-1 Compliant)		125 Mvar (5x25MVar)

Table 8: Reactor configuration WPA – North Mayo

Condition	**Size of reactor at Flagford**	**Voltage at Flagford**
Minimum Size	No minimum size	Below 1.09 pu
Flagford – Srananagh energised (w/o Flagford reactor or Srananagh 220/110kV transformer)	N/A	1.055 pu
Flagford-Srananagh energised (w/o Srananagh 220/110kV transformer)	50 Mvar	1.042 pu
Voltage step at Flagford (N-1) loss of one reactor bank (50 Mvar)		0.013 pu
Intact conditions with Filter	50 Mvar	1.040 pu
Intact conditions with Filter tripped	50 Mvar	1.028 pu
Voltage step at Flagford (N-1) loss of filter		0.012 pu
Suggested size and configuration of reactor bank at Flagford (N-1 Compliant)		75 Mvar (3x25Mvar)

Table 9: Reactor configuration WPA – Flagford

The above assessment shows 100 Mvar is required at North Mayo with a maximum bank size of 25 Mvar. Therefore it is recommended 125 Mvar is installed in 5 banks of 25 Mvar to ensure N-1 compliance. The above assessment also shows 50 Mvar is required at Flagford to maintain normal voltage ranges due to the addition of the cables in the area and the 50 Mvar capacitive filter which is installed. Therefore, although no voltage step limit is breached with the loss of the 50 Mvar reactor, to ensure healthy N-1 voltages it is recommended 75 Mvar is installed in 3 banks of 25 Mvar.

3.6 Operational Case Scenarios

In order to complete a wide range of studies and to verify the operation of the Grid West solution a selection of cases were undertaken for the Winter Peak A and Summer Valley B networks to consider a range of possible configurations during routine maintenance and normal operation. Nine possible configurations were agreed with the transmission planning department in EirGrid and considered as part of these studies.

Case scenarios in the development of the Grid West Project:

- Case 1: (N) Normal Operating Condition
- Case 2: (N-1) Cashla-Flagford Autoreclose onto Fault
- Case 3: (N-1) Flagford-Louth Line Autoreclose onto Fault
- Case 4: (N-1) Flagford-Srananagh Line Trip
- Case 5: (N-1) Trip Grid West Cable
- Case 6: (N-1-1) Cashla-Flagford Autoreclose onto Fault/Flagford-Louth Line out
- Case 7: (N-1-1) Cashla-Flagford Line Autoreclose onto Fault/Flagford-Srananagh Cable/Line Out
- Case 8: (N-1-1) Flagford-Louth Line Autoreclose onto Fault/Flagford-Srananagh Cable/Line Out
- Case 9: (N+1) Energise Grid West Cable

Following analysis in ATP it was determined that the worst case scenario for the area around Flagford was Case 6: (N-1-1) Cashla-Flagford Autoreclose onto Fault/Flagford-Louth Line out. This provided the lowest short circuit level with the most sever system operation condition.

3.7 Definition of Switching and Temporary Overvoltage Limits

International standards state that a transient overvoltage is a short duration high damped, oscillatory or non-oscillatory overvoltage with a duration of a few milliseconds or less. Transient overvoltages are classified as lighting and switching events, the time duration determines the maximum withstand capability of items of equipment.

3.7.1 Switching Overvoltage Limits

Switching overvoltage limits are defined by IEC60071-1:2006, these state for a 300 kV rms system the switching overvoltage limit is 750 kV, these can be scaled for the 220kV cable to give a switching overvoltage limit of 449.07 kV peak, or 2.5 pu peak voltage.

3.7.2 Temporary Overvoltage Limits

Temporary overvoltages are an oscillatory phase to ground or phase to phase overvoltage at a given location of a relatively long duration (seconds or minutes), this is likely to be un-damped or weakly damped. Temporary overvoltages arise from switching clearing operations (e.g. load rejection, single phase faults, faults on high impedance networks) or from non-linear sources such as ferroresonance effects or harmonics.

AC Cables have been proven by type test with the application of a voltage test at ambient temperature with a power frequency waveform, as stated in IEC62067. This test verifies the performance of a 220 kV cable with a voltage of 318 kV rms for a duration of 30 minutes, therefore this can be stated as the power frequency voltage withstand for 30 minute and is referred to as the cable withstand for a generic cable. The table below considers typical system events that produce temporary overvoltages.

However, type tests address a small portion of the cable system and accessories and can only prove that technology is feasible.

There is evidence, that the configuration and layout of the cable test is of paramount importance, especially for large cable projects and can mitigate risk of failure due to:

- Cable and accessories transportation
- Cable installation on site
- Cable and accessories assembling

IEC62067 suggest a minimum requirement for voltage testing and duration.

A typical example of overvoltages produced on a power system is shown in Table 10. For more information see Chapter 14.2.

Based on the above documents, London Power Associates and EirGrid considered after laying test voltage as a reference value for the acceptance criteria when considering time domain simulations, in particular:

1. A phase-to-ground Temporary Overvoltage, as defined in [IEC60071], must be below the instantaneous test voltage of 1.7Uo, 311 kV and 565 kV for a 220 kV and 400 kV cables respectively.
2. A phase-to-ground Temporary Overvoltage, as defined in [IEC60071], must be below 20% of the previous value within one second, 249 kV and 452 kV for a 220 and 400 kV cable respectively.

Temporary Overvoltage	Important Parameters	Overvoltage Magnitudes	Typical Durations
Fault application	Fault location, System X0/X1 ratio, Fault current magnitude	1.0 – 1.4 pu	2 – 10 cycles
Load rejection	Power flow, System short circuit MVA, System Capacitance, Generator AVR's	1.0 – 1.6 pu	Seconds
Line Energising	Line capacitance, System short circuit MVA	1.0 – 1.2 pu	Seconds
Line Dropping/ Fault Clearing	Fault conditions, Line capacitance, Shunt reactors, Breaker opening sequence	1.0 – 1.5 pu	
Reclosing	Line capacitance, Shunt reactors Trapped charge levels, Fault conditions	1.0 – 1.5 pu	seconds
Transformer energising	System Short circuit MVA, Transformer saturation characteristics, Frequency response characteristics, System voltage level	1.0 – 1.5 pu	0 – 2 seconds

Table 10: Typical temporary overvoltage events

(Extracted from Cigré document 33-210; Temporary Overvoltages: Causes, effects and evaluation)

It is likely that surge arrestors are required to be fitted at Flagford, North Mayo and Srananagh substations due to the magnitude of switching overvoltages generated by events. Surge arrestors can be damaged by events with a duration longer than one second and overvoltages above 1.6 pu, due to the energy rating and the short term withstand. In a typical power system temporary overvoltages should not generally exceed 1.6 pu, therefore the limit chosen for cable temporary overvoltages will be 1.6 pu.

3.8 Frequency Scans

Inductances and capacitances in the power system create series and parallel resonant frequency points. The amount and frequency of these resonances depend on interactions between power system components. Switching operations and nonlinear elements such as iron cores can produce a wide spectrum of high-frequency voltage and current components, which may then trigger oscillations at system resonant frequencies.

The first step in the evaluation of the network is to determine the resonant frequency points in a power system with the Grid West cable connected, and to determine if they are in series or parallel resonance points in nature. In the Grid West frequency scan analysis, one ampere current is injected at the bus of interest and the resulting bus voltage response is equal to the impedance in ohms.

Frequency scans for the Winter Peak A and Summer Valley B networks were completed for the various network outage and normal operating conditions, considering the loss of major circuits. Frequency Scans for the various cable lengths were verified to determine if any potential series or parallel resonance points can produce an issue for the installation and surrounding area up to the 20th harmonic. The frequency scan sweep was completed between 0 – 1000Hz and all resonant points below the 3rd harmonic (150 Hz) must be below 1000 Ω in order to be deemed acceptable, see acceptance criteria for details.

Frequency scans provide an indication of potential resonance issues in the network, which then can be analysed further in time domain simulations. Power system networks with cables will tend to have lower resonant frequencies, due to capacitance of the cable added to the system, which may interact with inductive elements in the system, due to capacitance of the cable added to the system to produce TOVs and other issues.

3.9 Time Domain Simulations

Temporary overvoltages (TOVs) occur typically in a power system as a result of series and parallel resonances in the system, transformer energisation, load shedding or system islanding, switching transients due to energisation or fault clearing. It should be noted that TOVs will influence surge arrester specifications in the design stage of any equipment.

The first step in the evaluation of the time domain network is to determine any high switching overvoltages and TOVs. The frequency scans provide an indication of cases with potential issues. In the time domain analysis, equivalent networks using simple AC sources were used to represent the collective generation sources.

Time domain simulations for the various cable lengths were completed after the frequency scans. Further issues from switching to temporary overvoltage conditions, were analysed for the Winter Peak A and Summer Valley B cases for a suitable time period of 6 seconds. This time period was chosen to analyse the decay of transients and detailed analysis for short term events for a period of 2 seconds is also shown.

Time domain simulations considered three phase contingencies which include; autoreclosing of major lines in the North West area of the Irish network, outages of significant circuits, faults on the Grid West connection and the energisation of the Grid West cable.

3.10 Power System Modelling

The Grid West Project was modelled in ATP using standard techniques for the frequency scan and transient studies. Representing the power system components correctly is an important aspect to the studies. Modelling of the system can be split into several sections, these include: Grid West Cable representation, modelling of wind farm cables, transmission lines, transformers and shunt connected devices.

3.10.1 Grid West Cable Representation

The 220 kV cable was modelled as a series of discrete PI sections, each of a 1km length using the physical dimensions of the cable. It has been shown from a previous EirGrid studies that a number of small length PI sections represented the cable more accurately than a distributed cable section. In the previous EirGrid studies both a distributed parameter model and PI section was tuned to a set frequency, but it was shown that the distributed parameter model produced significant errors outside this frequency, which was not the case with the PI section model.

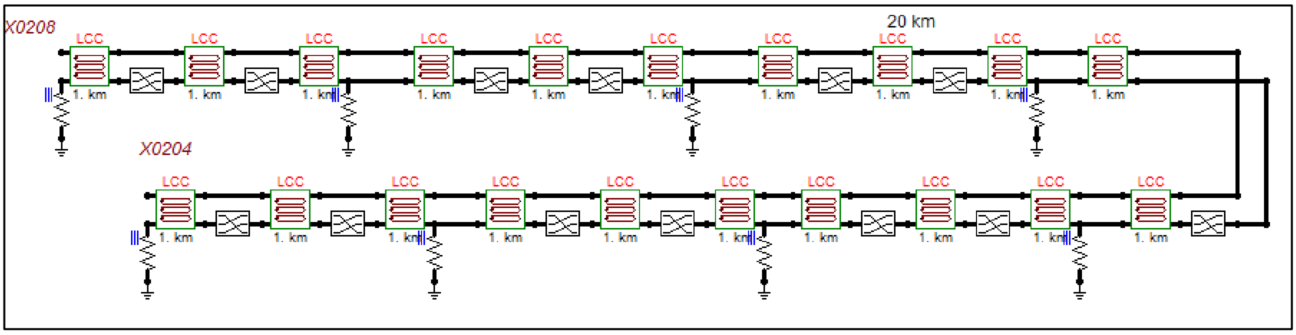

Figure 7: ATP Diagram showing 220 kV cable modelling

The 220 kV cable was modelled as single core cable sections with a 1 km length as a lumped PI sections. A low earthing resistance and a twisted sheath was used to reduce induced earth currents.

The table below provides further details on the cable modelled in this analysis.

Cable Details	XLPE 220 kV 1x2500 Cu – ESB Specification 18090
Manufacturer	NKT Cables
Size	2500 mm^2
Nominal Diameter	61.30 mm
Inner Semi-Conducting Layer	2.2 mm
Insulation thickness	22.0 mm
Outer Semi-Conducting Layer	1.4 mm
Nominal diameter over core screen	115 mm

Table 11: Cable Parameters – 220 kV Cable

3.10.2 North Mayo Wind Farm Cables Representation

The 110 kV circuits connecting the wind farms to the North Mayo node were modelled as cables. The 110 kV cable was modelled as a series of discrete PI sections, each of a 1 km length using the physical dimensions of the cable.

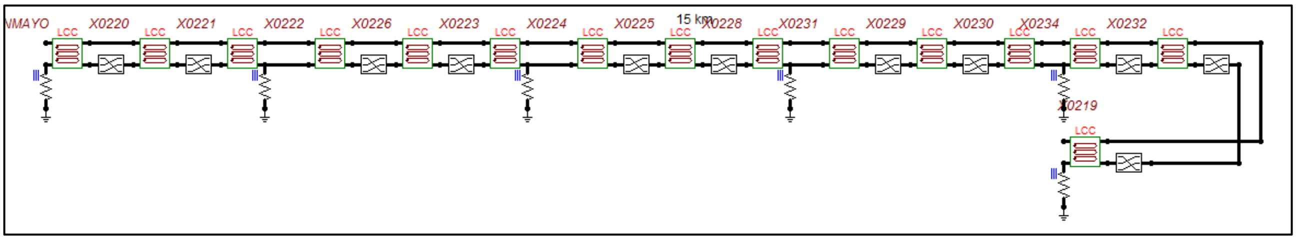

Figure 8: ATP Diagram showing 110 kV cable modelling

The 110 kV cable was modelled as single core cable with a 1 km length as a lumped PI section. A low earthing resistance and a twisted sheath was used to reduce induced earth currents.

Cable Details	XLPE 110 kV 1x1000 Cu –
Manufacturer	NKT Cables
Size	1000 mm^2
Nominal Diameter	39.00 mm
Inner Semi-Conducting Layer	1.3 mm
Insulation thickness	12.0 mm
Outer Semi-Conducting Layer	0.9 mm
Nominal diameter over core screen	67.4 mm

Table 12: Cable Parameters – 110 kV Cable

3.10.3 Modelling of transmission Lines and transformers

The transmission lines have been modelled with a JMarti, frequency dependent model with constant transformation matrix with the skin effect simulation enabled. The frequency range has been set between 50 – 500Hz.

The transformers in the networks are of a saturation type and have a non-linear magnetizing branch, with a knee point of 1.2 pu, this ensures a true representation of the transformer, including saturation effects.

3.10.4 Modelling of the Cable Reactors

Cable reactors are required on either end of the Grid West Cable Link circuit to absorb reactive power generated by the cable(s).

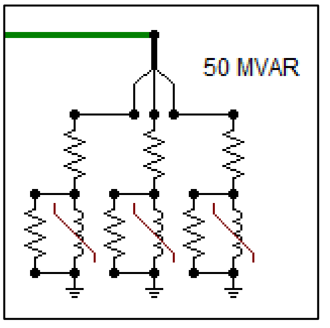

Figure 9: Shunt Reactor

Design parameters for the cable reactors are shown in the table below.

Parameters	Design value
Voltage	220 kV
Series Resistor	0.001Ω
Non-Linear Reactor	Peak Current depends on rating
Parallel Resistor	Calculated considering 0.7% losses for reactor

Table 13: Design parameters for cable reactors

3.10.5 Design of the High Pass Filter

The maximum 220 kV AC cable length solution was one with an overall cable length of 30 km (22 km Grid West/8km Flagford – Srananagh 220 kV circuit). As part of this design a filter was required at the Flagford 220 kV busbar. Configuration of the high pass filter is shown below.

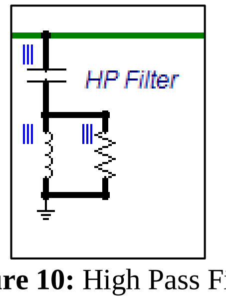

Figure 10: High Pass Filter

Design parameters for the High Pass filter are shown in the table below.

Parameters	Design value
Voltage	220 kV
Corner Frequency	143.9 Hz
Capacitance	3.289 µF
Reactance	372 mH
Resistance	500 Ω
Rating of Capacitor (Mvar)	50.01

Table 14: High Pass Filter Ratings

4 SUMMARY OF THE RESULTS

In order to determine the maximum length of cable possible for the 'hybrid' AC solution for Grid West, a variety of cable lengths or overhead line and cable combinations were studied to determine the maximum possible length of cable. A summary of the most significant results are included in this section.

4.1 Acceptance Criteria

The following acceptance criteria was developed and followed during the studies:

1. Frequency scan results
   - All resonant points below the 3rd harmonic (150 Hz), must have a impedance below 1000 Ω. The limit of 1000 Ω was based on previous EirGrid experience and studies on the All-Island power system.
   - Any values above 1000 Ω must be evaluated with time domain simulations.
2. Time domain simulation results
   - No transformer saturation
   - TOVs do not exceed a magnitude of 287.32 kV peak (1.6 pu) and are within 229.85 kV with one second for a 220 kV cable installation, i.e. a 20% decrease in TOVs to alleviate stress on all system components. A safety margin has been included to reduce the maximum TOV limit 1.7 pu to 1.6 pu.
   - Switching over-voltages do not exceed 449.073 kV (2.5pu) for a 220 kV cable installation.

For more detail on acceptance limits see section 3.7 and 3.8.

4.2 Case 1 – 400 kV – Cable length 10 km/90 km Overhead line

A partial 400 kV cable solution was considered with a 10km cable length together with 90 km overhead line for the Summer Valley B configuration. Detailed results are shown in Appendix A.

4.2.1 Impedance Scan – Cable length 10 km/90 km OHL – Summer Valley B

Conditions for impedance scan:

1. Summer Valley B network
2. North Mayo to Flagford 400 kV Circuit - 10 km Cable/90 km OHL
3. Reactors – North Mayo 20 Mvar/Flagford 125 Mvar
4. LPA 400 kV Cable Model used with 0.566 km PI Sections

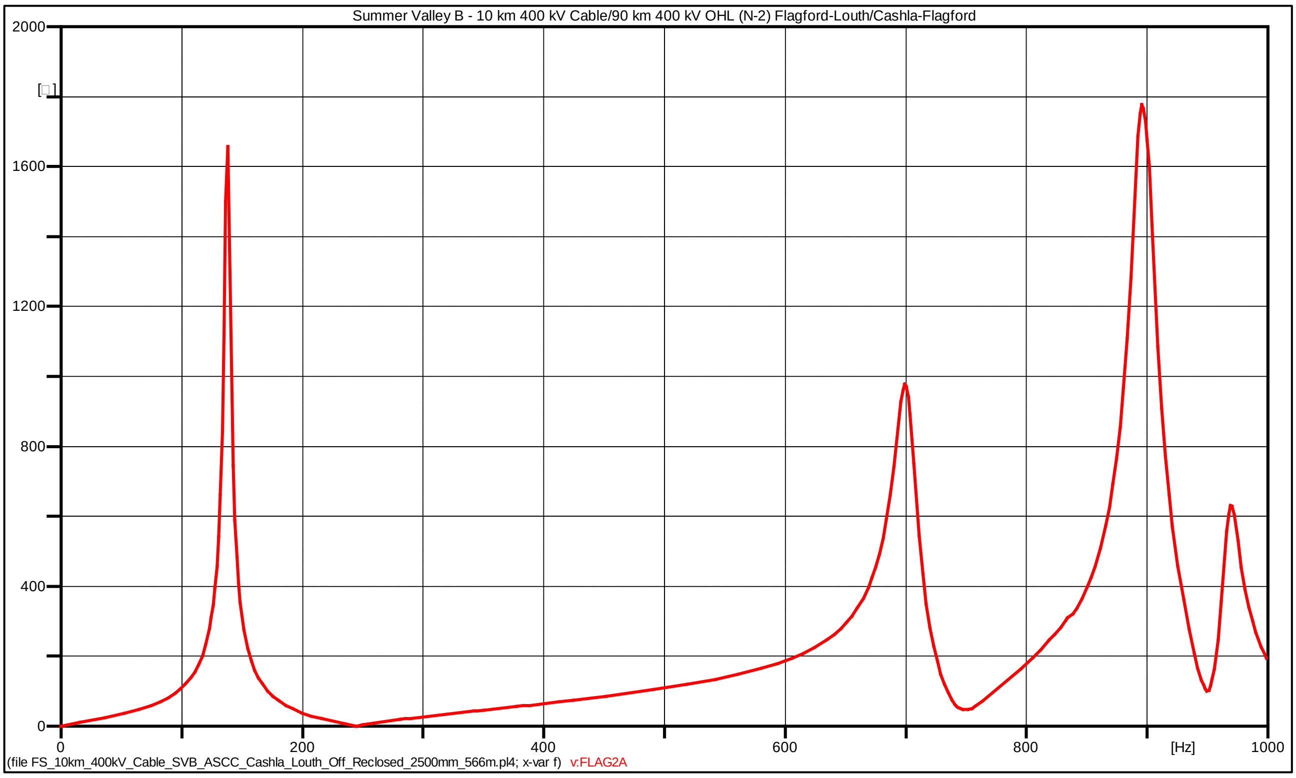

Figure 11: WPA – 90 km OHL/10 km UGC – Flagford – (N-2) Cashla-Flagford/Flagford-Louth Lines Out/With Reactor

<u>Impedance Scan - Resonance points:</u>

Frequency (Hz)	**Impedance (Ω)**
138.01	1656.6
699.01	977.68
895.51	1777.4
969.01	630.98

4.2.2 Time Domain - Length 10 km – Summer Valley B

Conditions for impedance scan:

1. Summer Valley B network
2. North Mayo to Flagford 400 kV Circuit - 10 km Cable/90 km OHL
3. Reactors – North Mayo 20 Mvar/Flagford 125 Mvar
4. LPA 400 kV Cable Model used with 0.566 km PI Sections

Case 1: (N-1-1) Cashla-Flagford Trip/Flagford-Louth Line Out

1. The Flagford – Louth 220 kV line is on an outage i.e. for maintenance. Fault applied on the Flagford side of Cashla-Flagford line at 10 ms, removed Fault at 90ms, opened Flagford-Cashla Line breaker at 90ms, reclosed breaker at 110 ms.

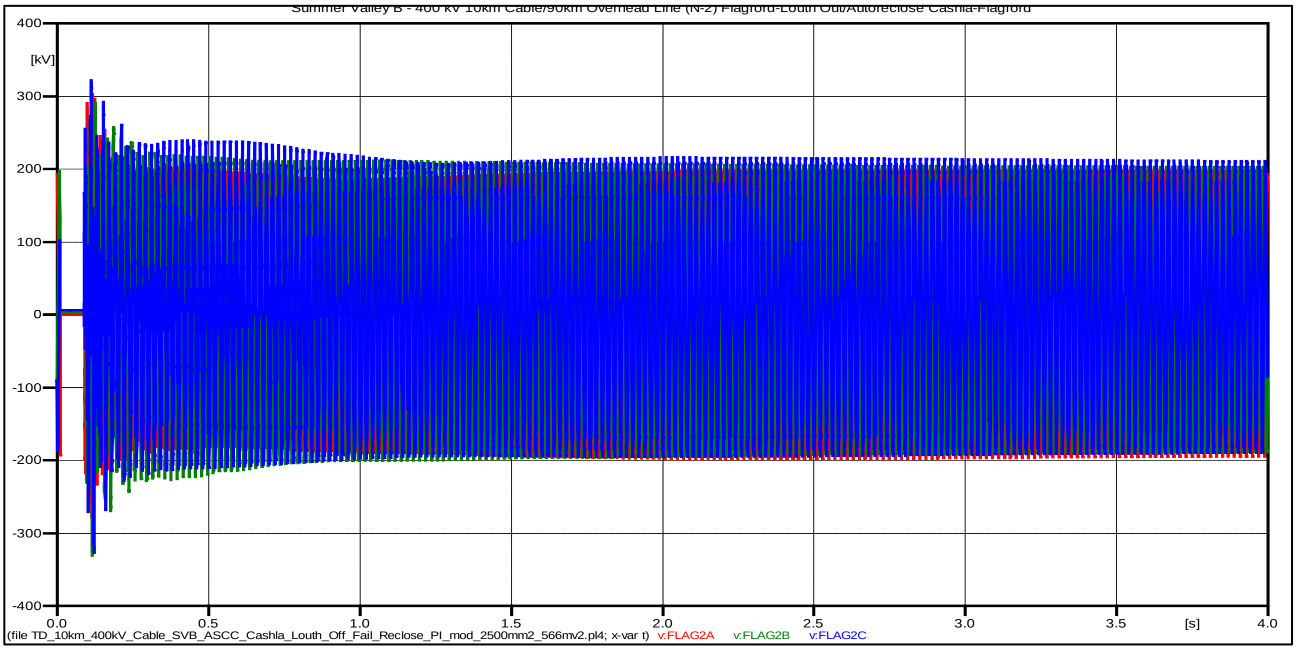

Figure 12: SVB – 90 km OHL/10km UGC – Flagford (220 kV) – (N-1-1) Cashla-Flagford Trip/Flagford-Louth Line Out/With Reactors (0-4s)

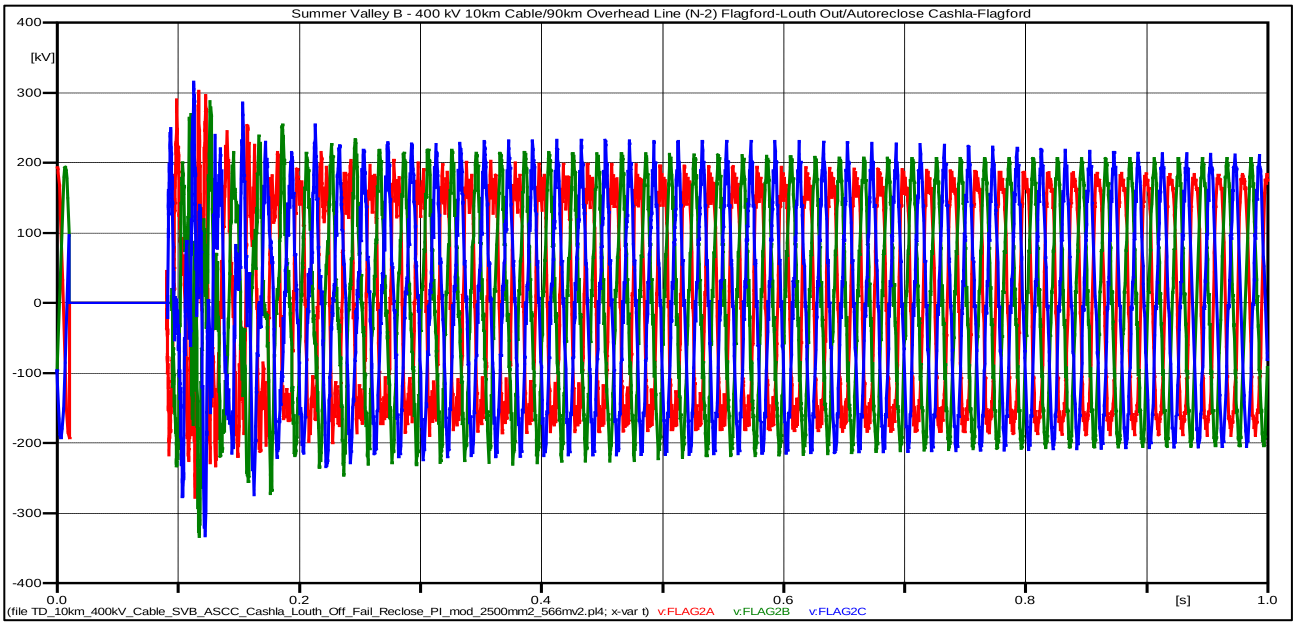

Figure 13: SVB – 90 km OHL/10 km UGC – Flagford (220 kV) – (N-1-1) Cashla-Flagford Trip/Flagford-Louth Line Out/With Reactors (0-1s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	315.39 kV (1.755 pu)	449.07 kV (2.5 pu)	Pass
Temporary Overvoltage	252.67 kV (1.4066 pu)	287.32 kV(1.6 pu)	Pass

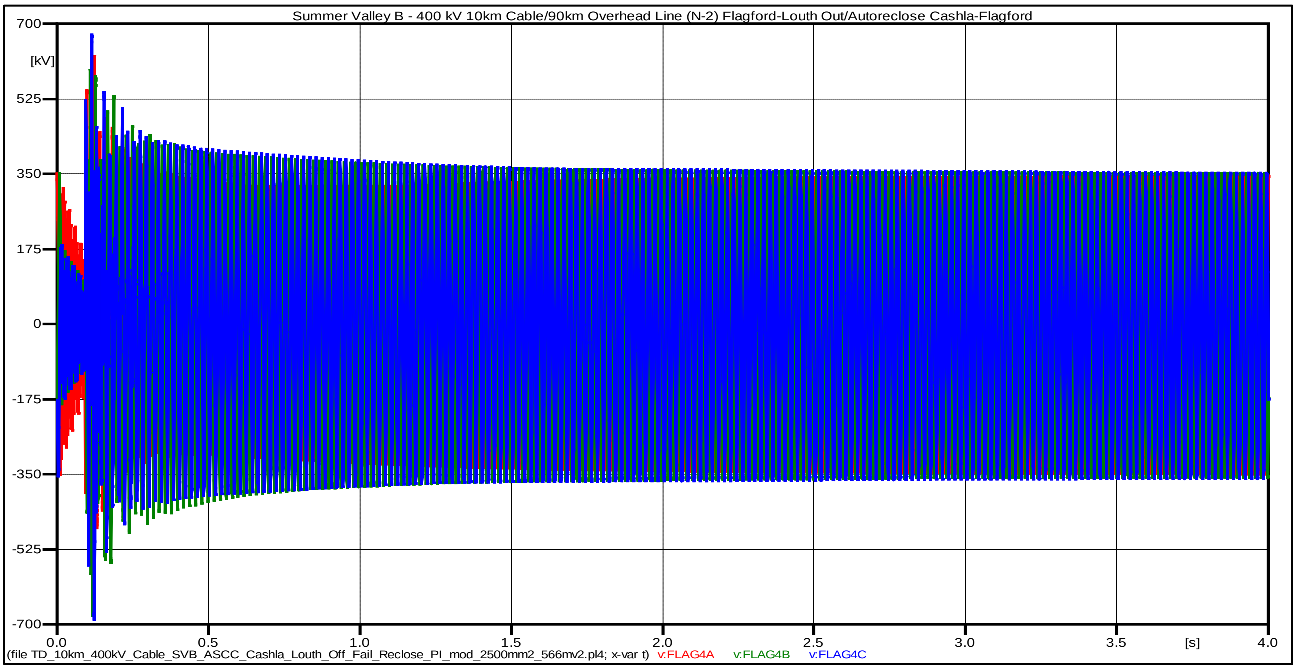

Figure 14: SVB – 90 km OHL/10 km UGC – Flagford (400 kV) – (N-1-1) Cashla-Flagford/Flagford-Louth Line Out/With Reactors (0-4s)

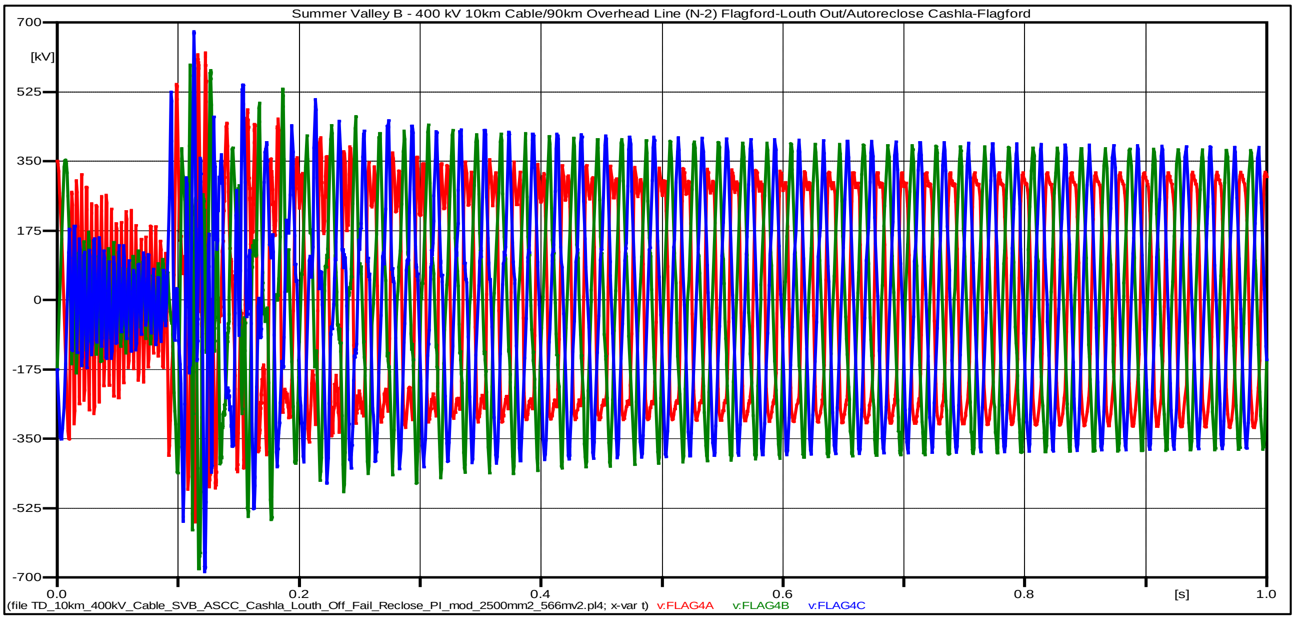

Figure 15: SVB – 90 km OHL/10 km UGC – Flagford (400 kV) – (N-1-1) Cashla-Flagford/Flagford-Louth Line Out/With Reactors (0-1s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	676.9 kV (2.0726 pu)	816.49 kV (2.5 pu)	Pass
Temporary Overvoltage	547.2 kV (1.675 pu)	522.55 kV (1.6 pu)	Fail

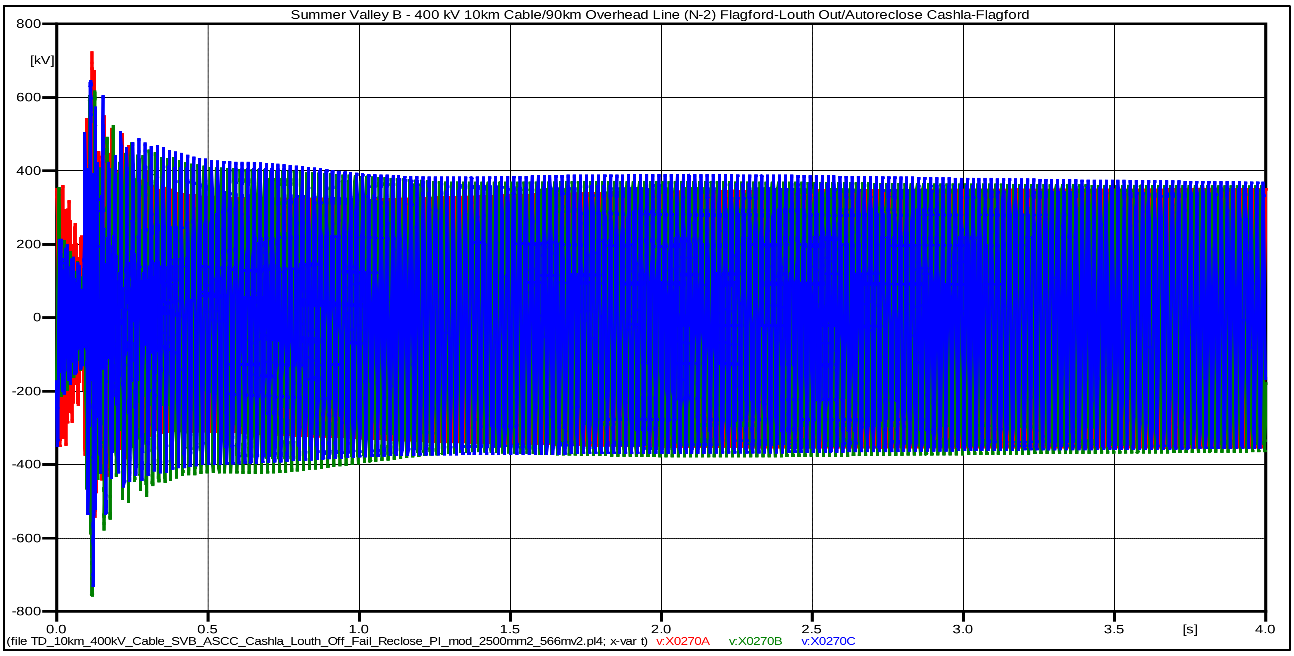

Figure 16: SVB – 90 km OHL/10 km UGC – North Mayo (400 kV) – (N-1-1) Cashla-Flagford/Flagford-Louth Line Out/With Reactors (0-4s)

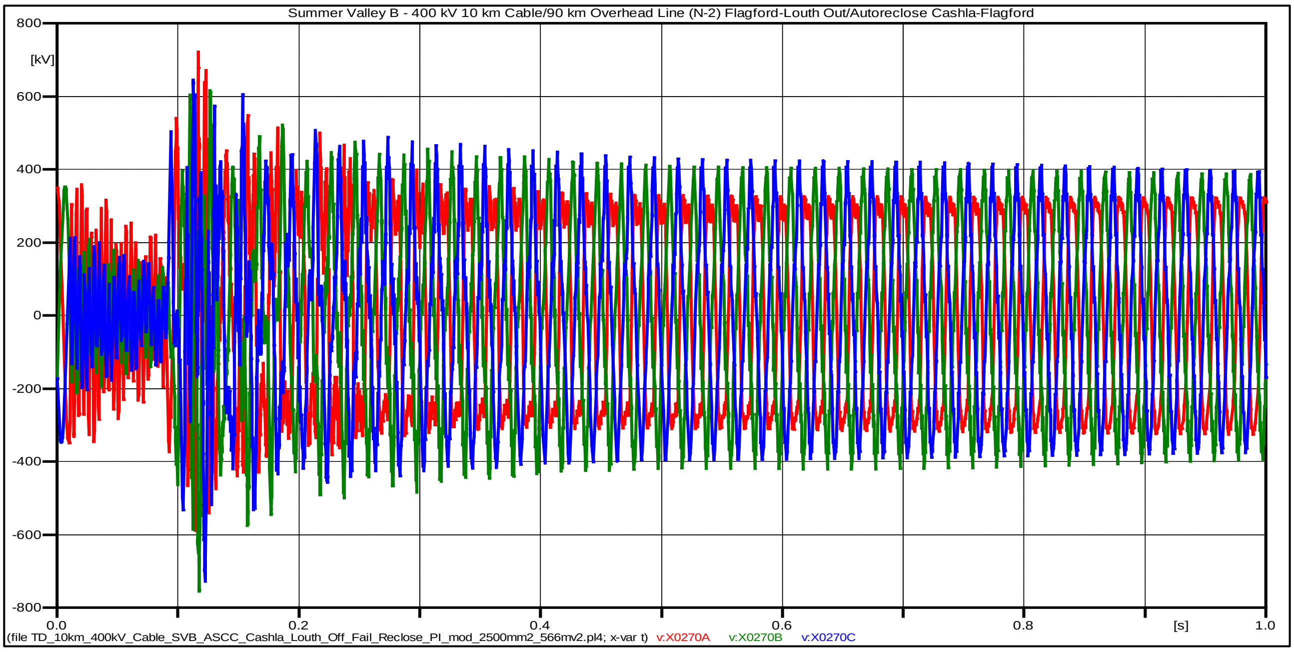

Figure 17: SVB - 90km OHL/10km UGC – North Mayo (400 kV) – (N-1-1) Cashla-Flagford/Flagford-Louth Line Out/With Reactors (0-1s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	754.72 kV (2.3108 pu)	816.49 kV (2.5 pu)	Pass
Temporary Overvoltage	603.25 kV (1.847 pu)	522.55 kV (1.6 pu)	Fail

4.3 Case 2 – Full Cable Solution – 120 km 220 kV Cable

A full cable solution was considered with 120 km of 220 kV Cable for the Summer Valley B configuration. Detailed results are shown in Appendix B.

4.3.1 Impedance Scan – Cable length 120 km – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 120 km 220 kV Cable
4. Reactors – North Mayo 250 Mvar/Flagford 300 Mvar.

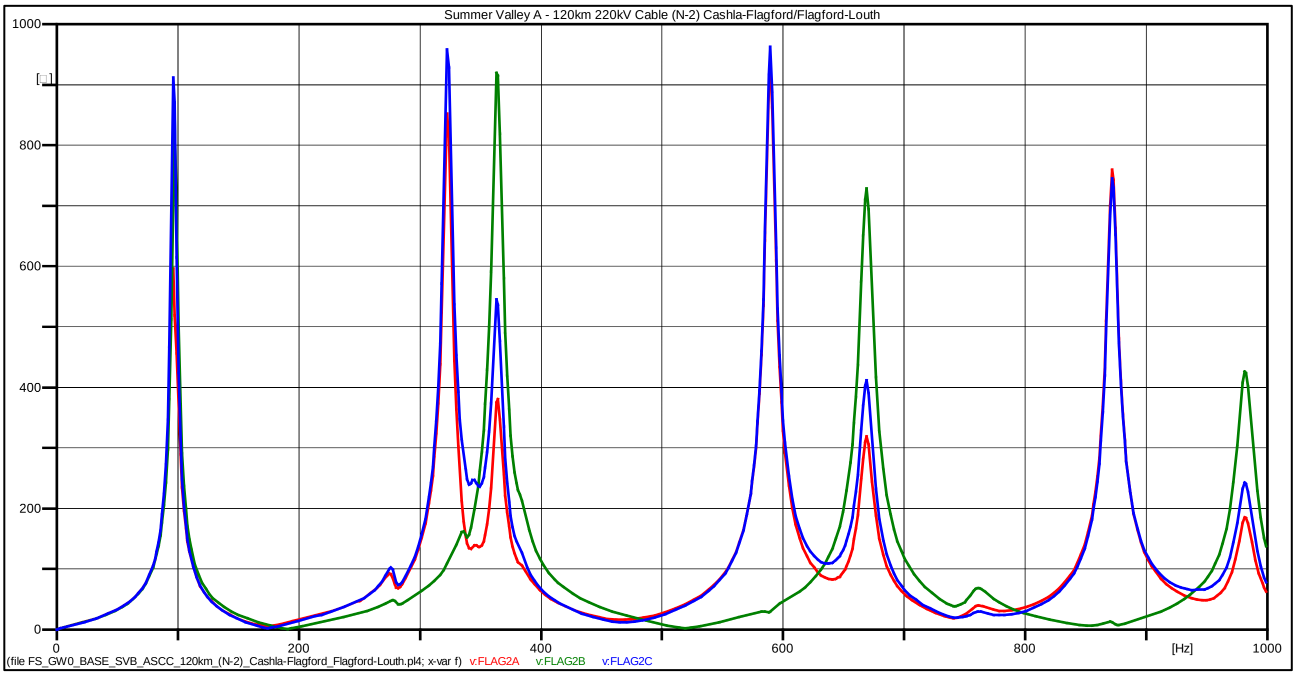

Figure 18: SVB - Length 120 km – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
96.01	912.19
322.51	957.68
364.51	915.22
589.51	962.08
669.01	728.37
871.51	759.82
982.51	424.32

4.3.2 Time Domain – 220 kV Cable length 120 km – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, (N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 120 km 220 kV Cable
4. Reactors – North Mayo 250 Mvar/Flagford 300 Mvar.

Case 2: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.6s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

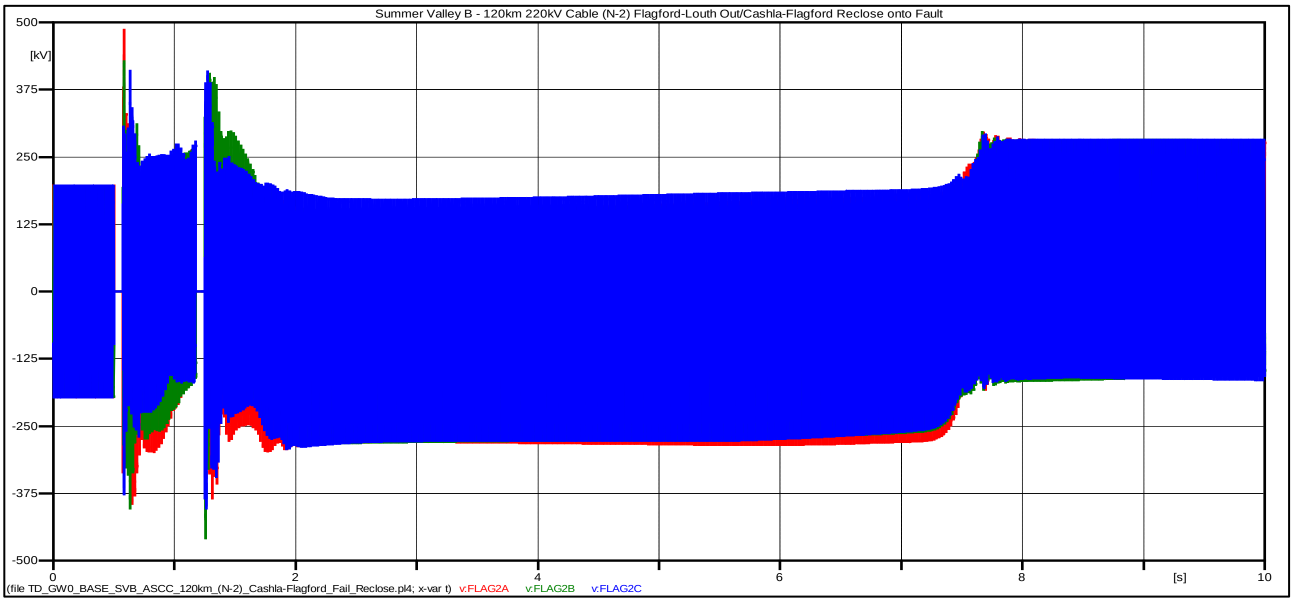

Figure 19: SVB - Length 120 km – Flagford – (N-1-1) Condition – Flagford/Louth line out - Autoreclose of the Cashla/Flagford Line - Permanent Fault (0-10s)

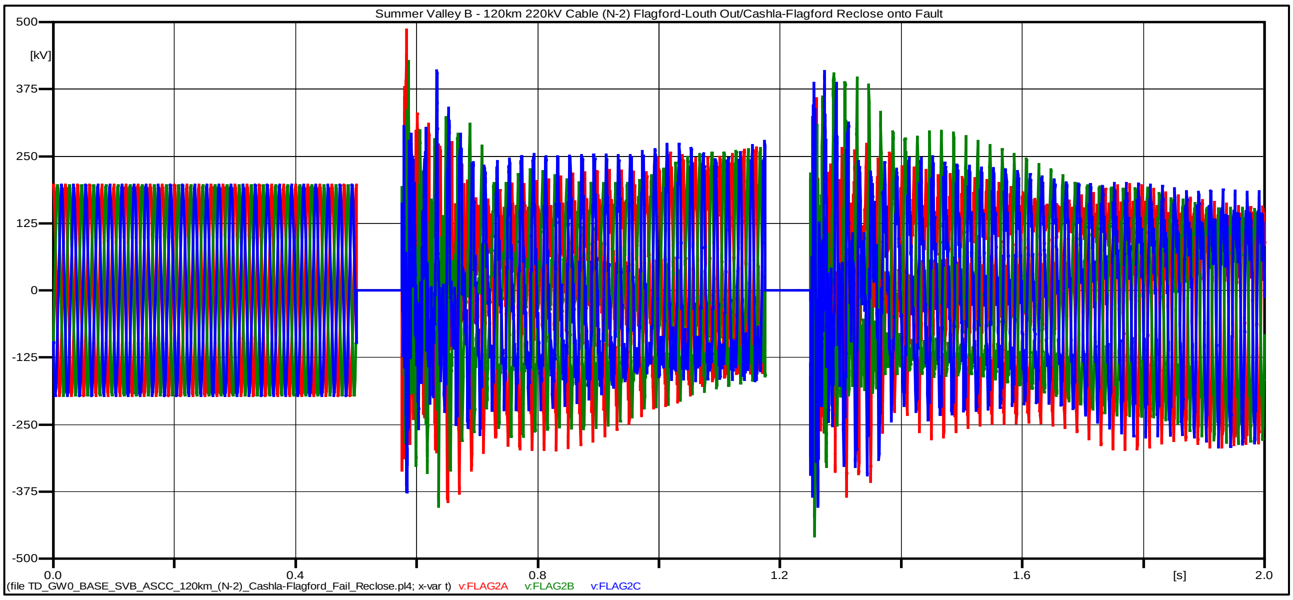

Figure 20: SVB - Length 120 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford Line - Permanent Fault (0-2s)

Condition	Maximum Value	Limit	Result
Switching	482.79 kV (2.6884 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	381.29 kV (1.6777 pu)	287.32 kV (1.6 pu)	Fail
Note: Significant transformer saturation - Fail			

*Pass can be achieved with the application of surge arrestors

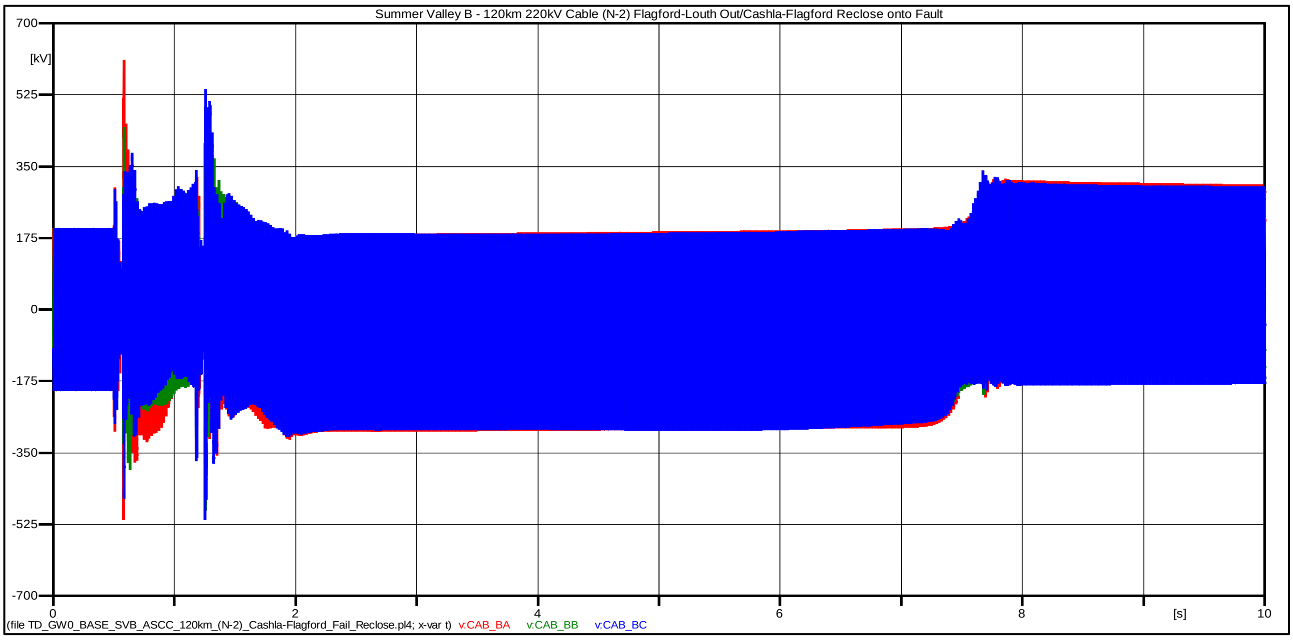

Figure 21: SVB - Length 120 km – North Mayo – (N-1-1) Condition – Flagford/Louth line out - Autoreclose of the Cashla/Flagford - Permanent removal (0-10s)

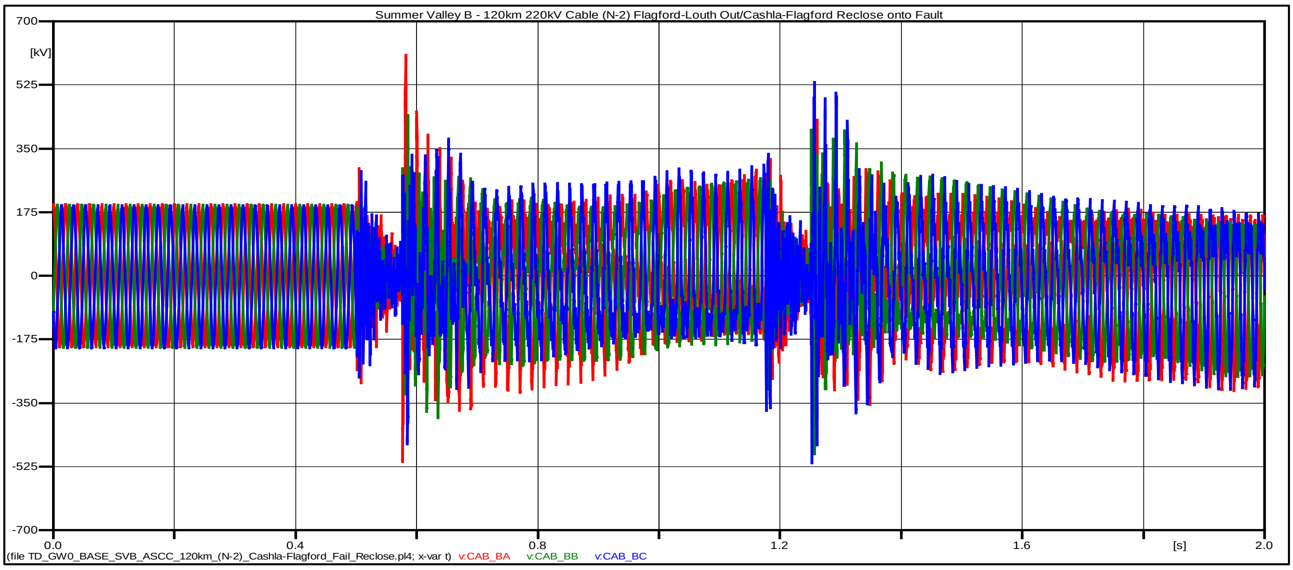

Figure 22: SVB - Length 120 km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent removal (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	605.23 kV (3.3702 pu)	449.07 kV (2.5pu)	Fail*
Temporary Overvoltage	354.56 kV (1.974 pu)	287.32 kV(1.6pu)	Fail
Note: Significant transformer saturation - Fail			

*Pass can be achieved with the application of surge arrestors.

4.4 Case 3 – Partial Cable Solution – 99.7 km Cable/10.8 km 220 kV OHL

A partial cable solution was considered with 99.7 km of 220 kV Cable and 10.8 km Overhead Line for the Summer Valley B configuration. As per EirGrid specification the length was chosen as they fit identified cable routes lengths. Detailed results are shown in Appendix C.

4.4.1 Impedance Scan – Cable length 99.7 km/10.8 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 10.8km OHL/99.7km 220 kV Cable
4. Reactors – North Mayo 75 Mvar/Flagford 225 Mvar.

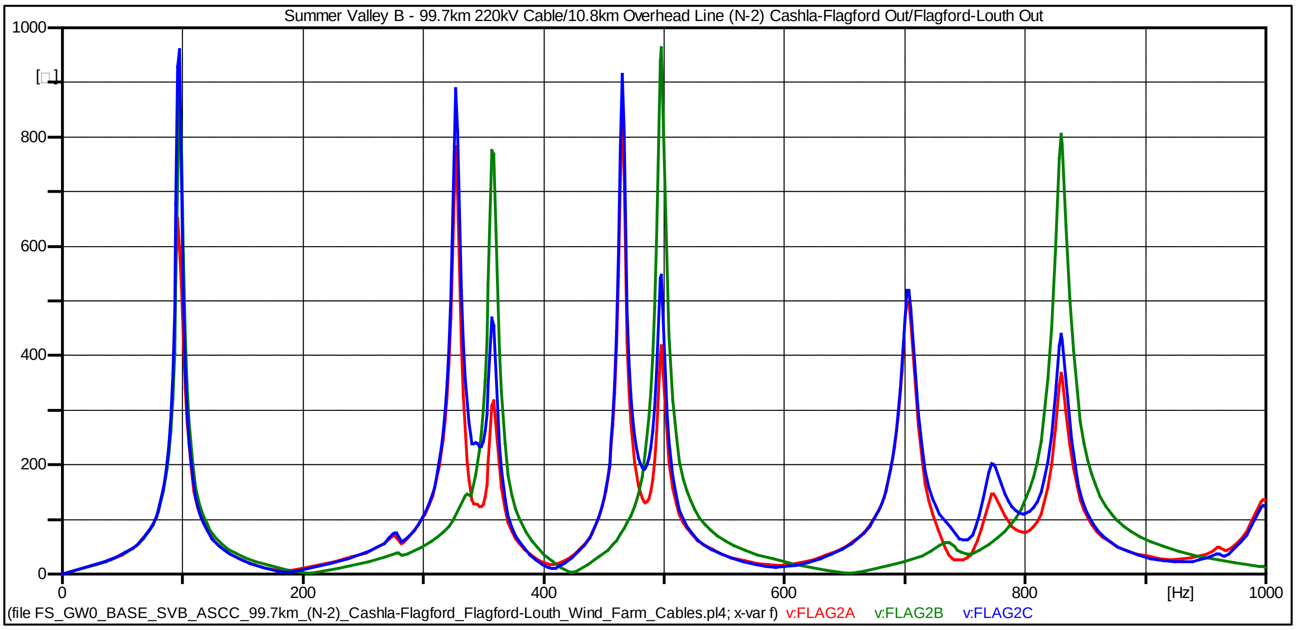

Figure 23: SVB - Length 99.7 km Cable – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
97.51	960.71
327.51	889.12
357.01	775.44
465.01	914.76
498.01	963.29
702.01	518.73
829.51	804.90

4.4.2 Time Domain – 220 kV Cable length 99.7 km – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 10.8 km OHL/99.7 km 220 kV Cable
4. Reactors – North Mayo 75 Mvar/Flagford 225 Mvar.

Case 3: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.7s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

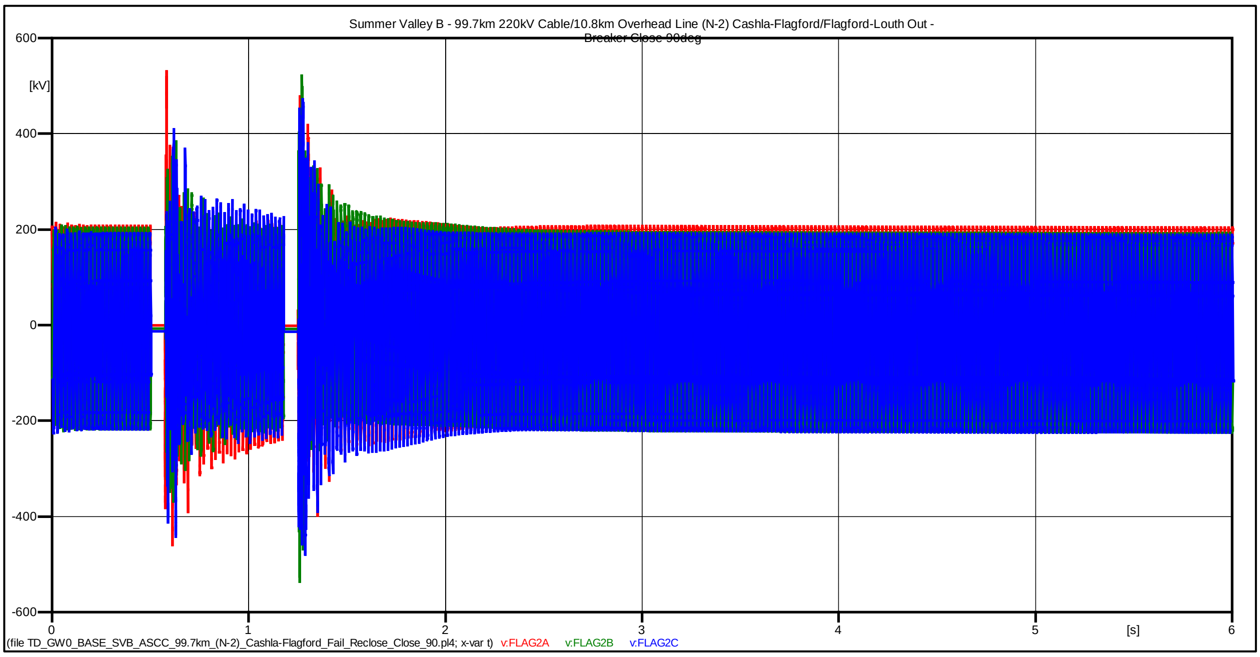

Figure 24: SVB - Length 99.7km cable – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

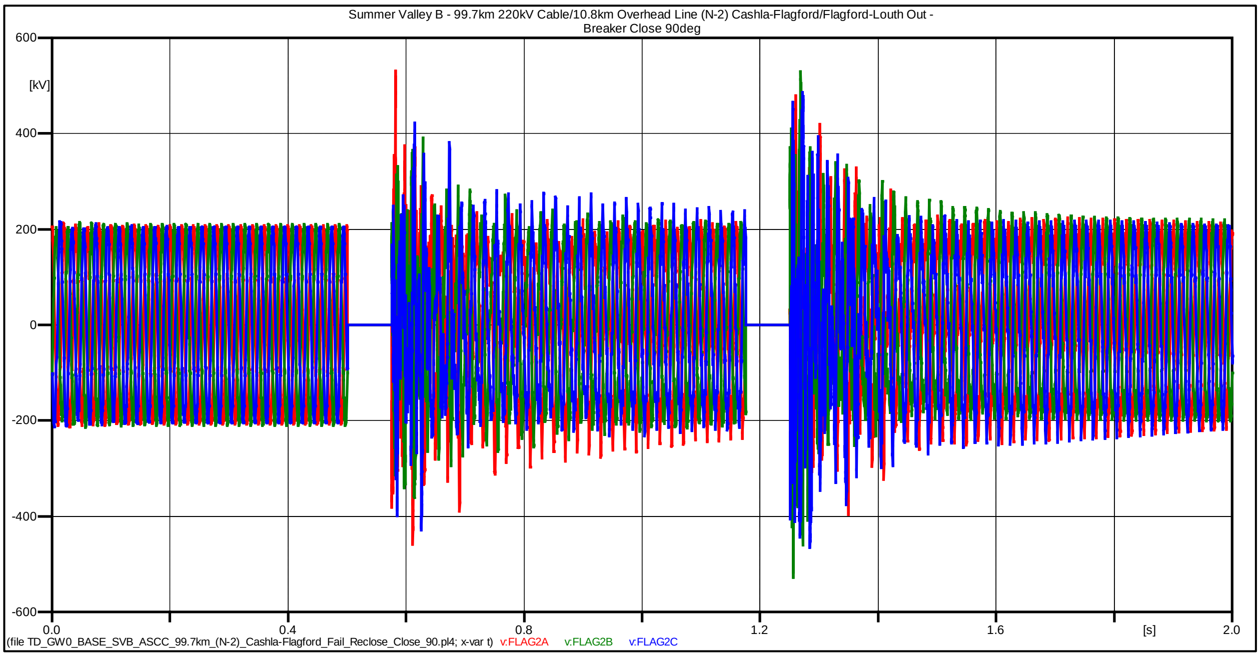

Figure 25: SVB - Length 99.7km cable – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	525.23 kV (2.924 pu)	449.07 kV (2.5 pu)	Fail*
Temporary Overvoltage	435.26 kV (2.423 pu)	287.32 kV(1.6pu)	Fail

*Pass can be achieved with the application of surge arrestors.

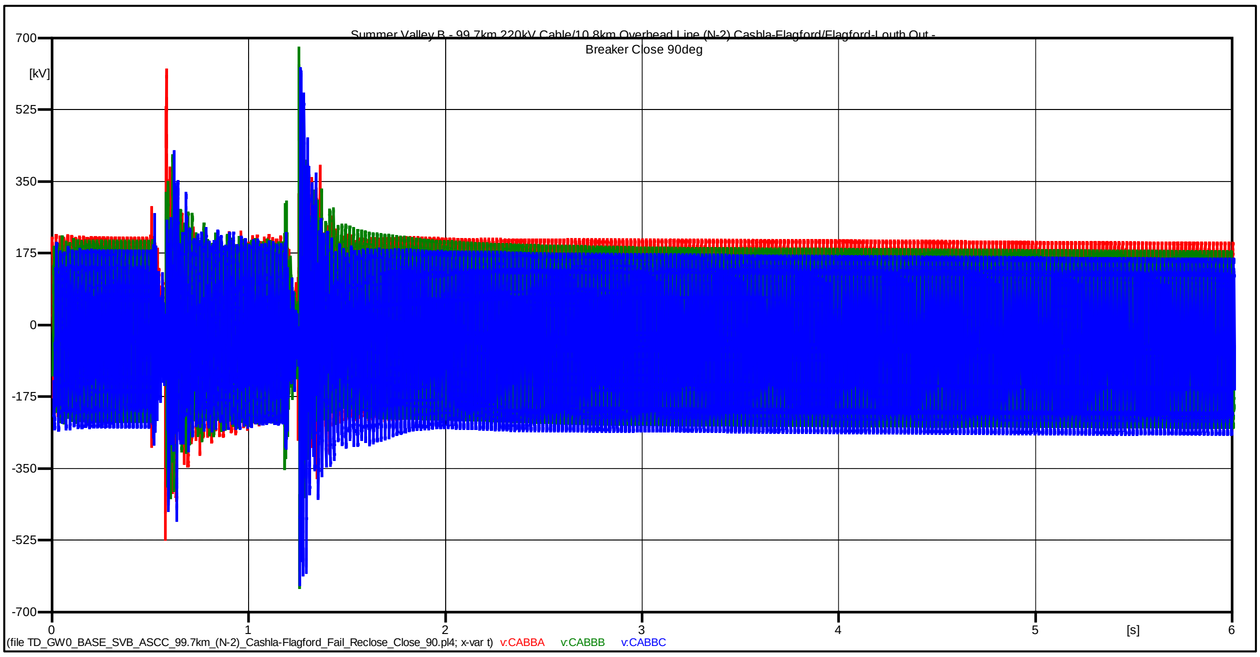

Figure 26: SVB - Length 99.7km cable – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

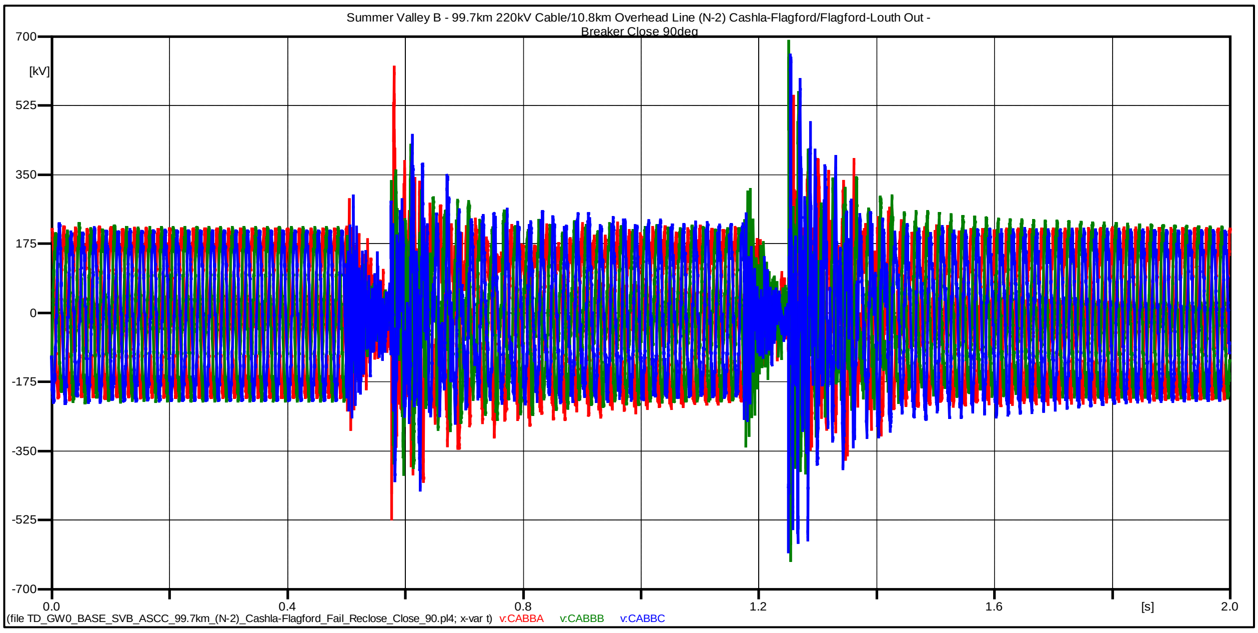

Figure 27: SVB - Length 99.7km cable – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	610.67 kV (3.400 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	495.78 kV (2.760 pu)	287.32 kV (1.6 pu)	Fail

*Pass can be achieved with the application of surge arrestors.

4.5 Case 4 – Partial Cable Solution – 80 km 220 kV Cable/30 km OHL

A partial cable solution was considered with 80 km of 220 kV Cable and 30 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix E.

4.5.1 Impedance Scan – Cable length 80 km/30 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-1-1) scenario with Cashla – Flagford and Flagford – Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – Cable Length 80 km/30 km Overhead Line
4. Reactors – North Mayo 225 Mvar/Flagford 150 Mvar.

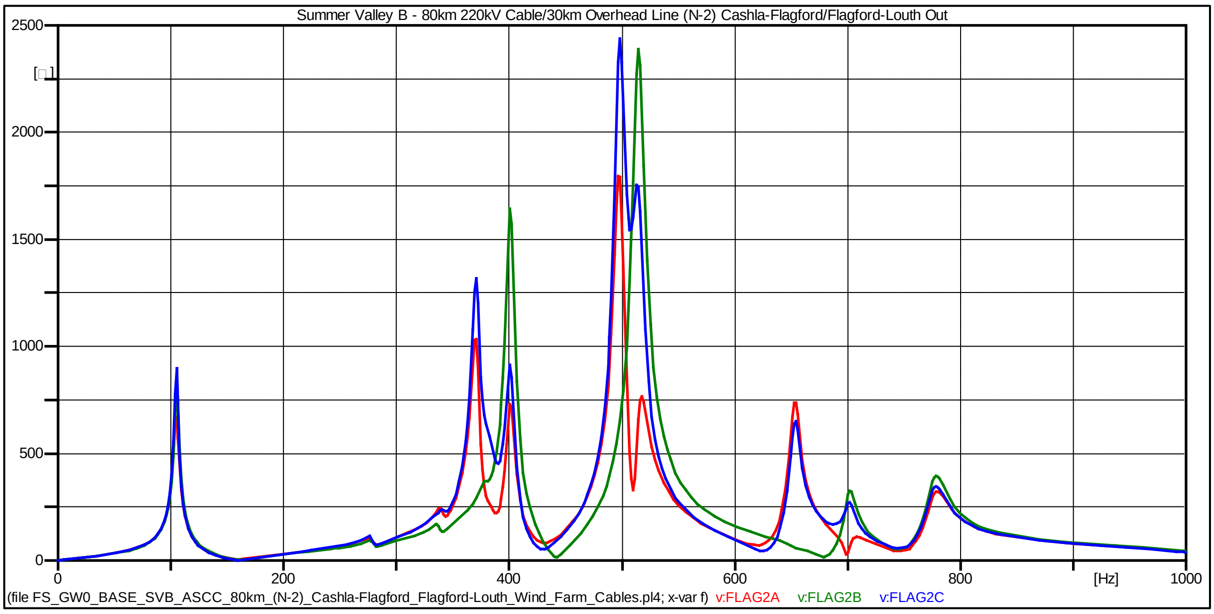

Figure 28: SVB - Length 80 km Cable – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
105.51	739.67
370.51	1317.00
400.51	1641.40
499.51	2327.50
514.51	2390.40
654.01	737.85
778.51	395.30

4.5.2 Time Domain – Cable length 80 km/30 km OHL – Summer Valley B

Conditions for time domain simulation:

1. Consideration of the worst case, **(**N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – Cable Length 80 km/30 km Overhead Line
4. Reactors – North Mayo 225 Mvar/Flagford 150 Mvar.

Case 4: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.7s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

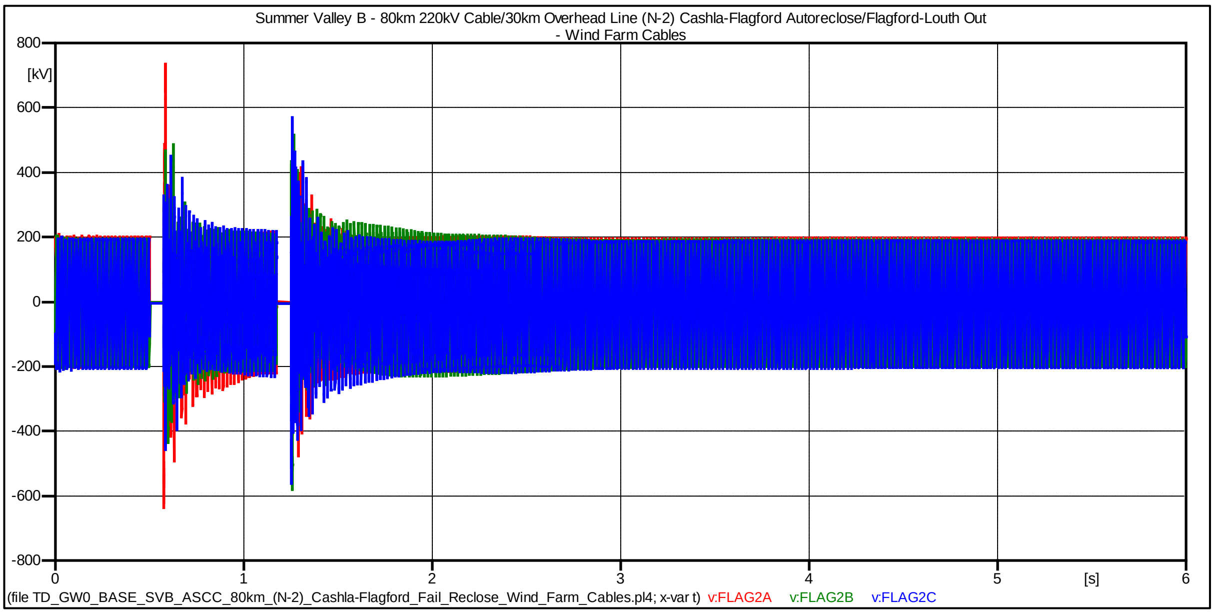

Figure 29: SVB - Length 80 km Cable – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

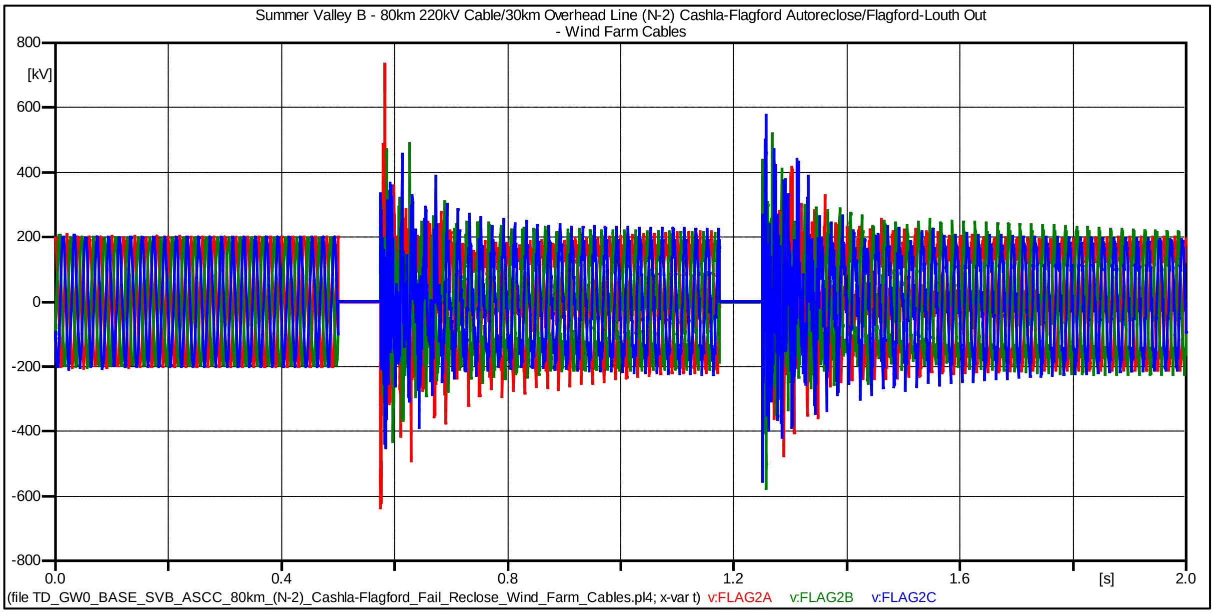

Figure 30: SVB - Length 80 km Cable – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	753.2 kV (4.218 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	496.23 kV (2.7632 pu)	287.32 kV (1.6 pu)	Fail

*Pass can be achieved with the application of surge arrestors.

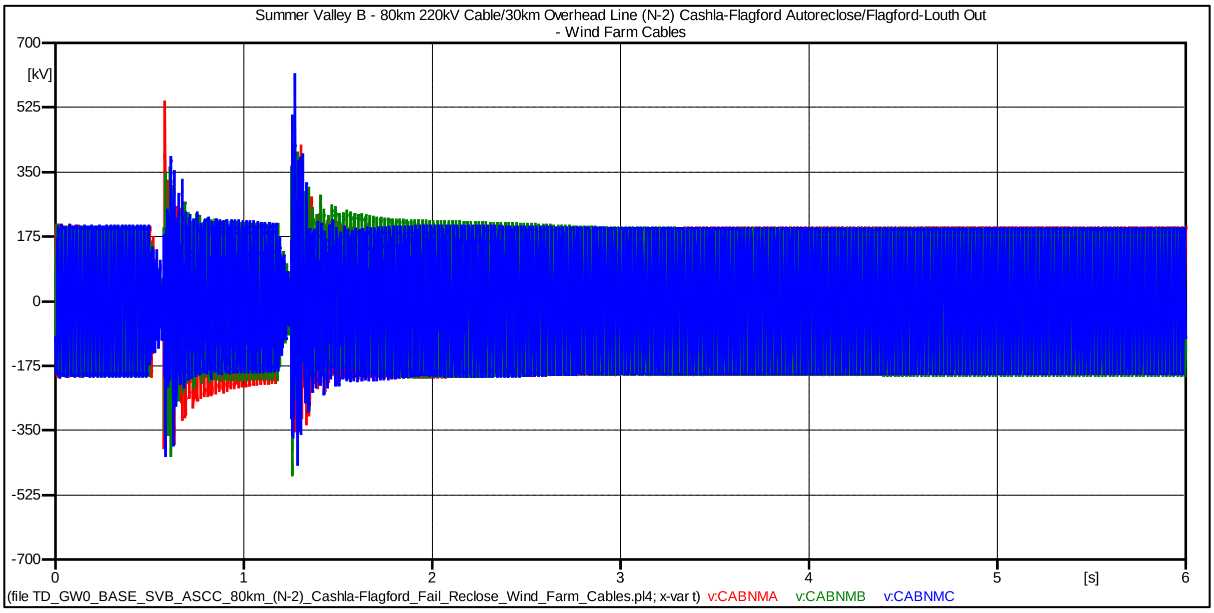

Figure 31: SVB – Length 80 km Cable – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

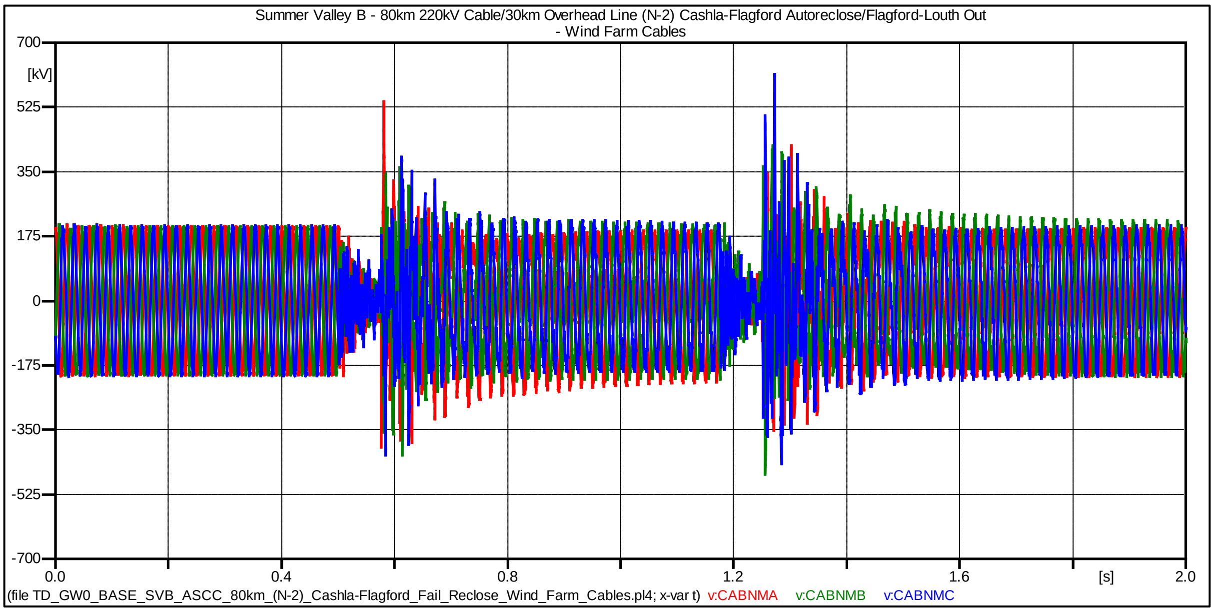

Figure 32: SVB - Length 80 km Cable – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	531.28 kV (2.958 pu)	449.07 kV (2.5 pu)	Fail*
Temporary Overvoltage	423.56 kV (2.358pu)	287.32 kV(1.6pu)	Fail

*Pass can be achieved with the application of surge arrestors.

4.6 Case 5 – Partial Cable Solution – 70 km 220 kV Cable/40 km OHL

A partial cable solution was considered with 70 km of 220 kV Cable and 40 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix E.

4.6.1 Impedance Scan – Cable length 70 km/40 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 62 km 220 kV Cable/40 km OHL/8 km Cable
4. Reactors – North Mayo 200 Mvar/Flagford 125 Mvar.

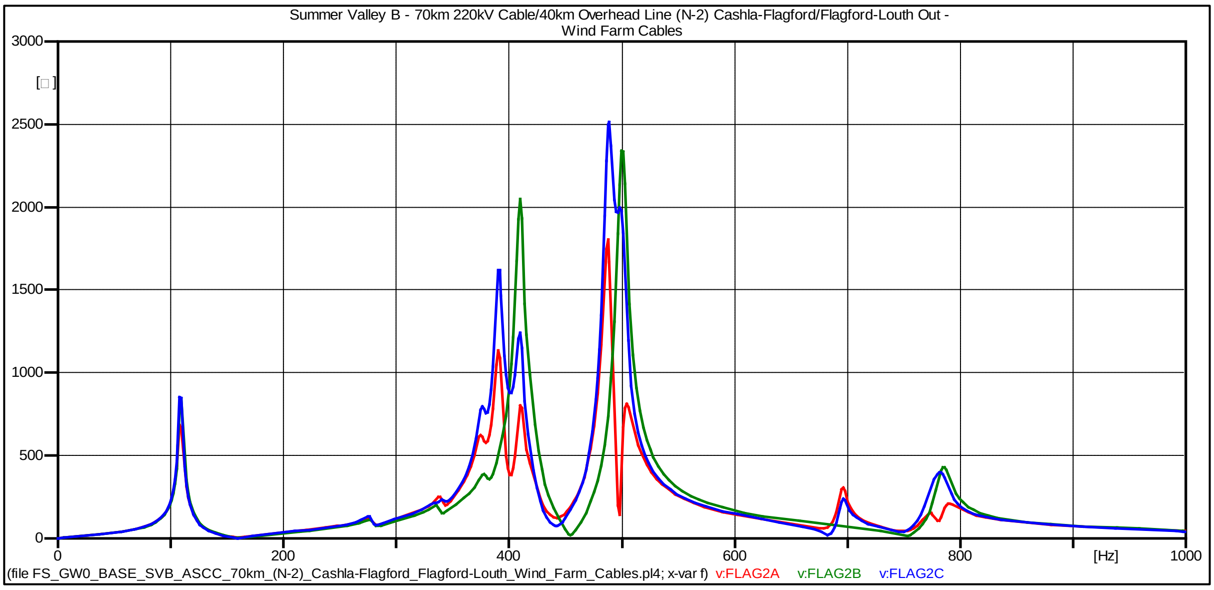

Figure 33: SVB - Length 70 km Cable – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

<u>**Impedance scan results**</u>

Frequency (Hz)	Impedance (Ω)
109.51	847.09
391.51	1620.00
411.01	1933.30
489.01	2414.40
501.01	2337.90

4.6.2 Time Domain – Cable length 70 km 220 kV Cable/40 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 62 km 220 kV Cable/40 km OHL/8 km 220 kV Cable
4. Reactors – North Mayo 200 Mvar/Flagford 125 Mvar.

Case 5: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.7s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

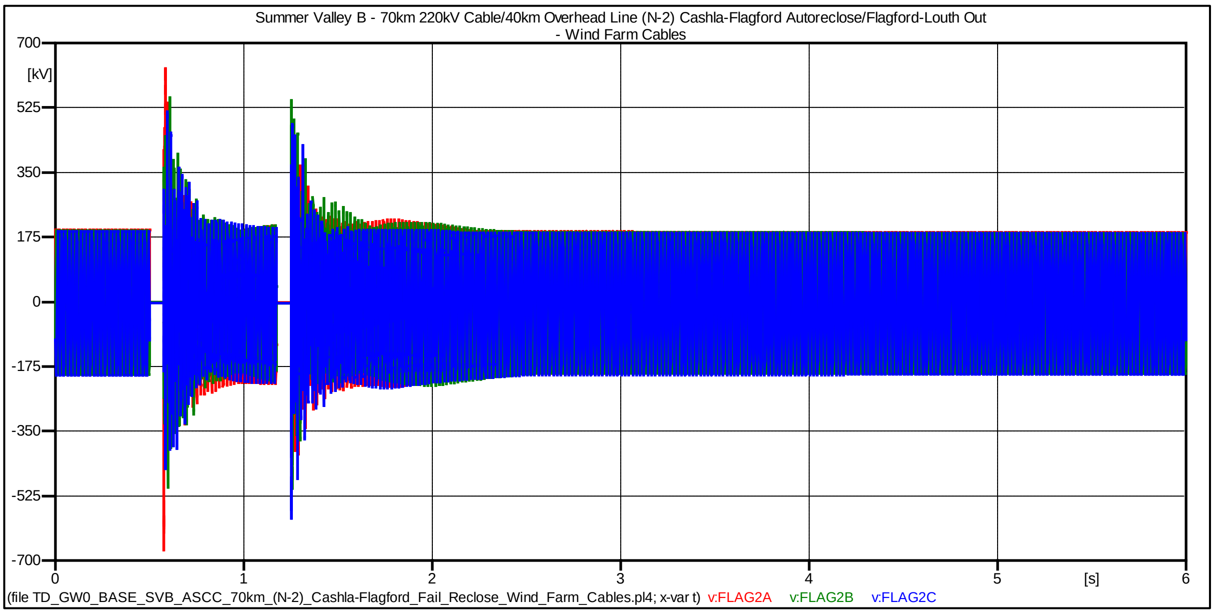

Figure 34: SVB - Length 70 km Cable – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

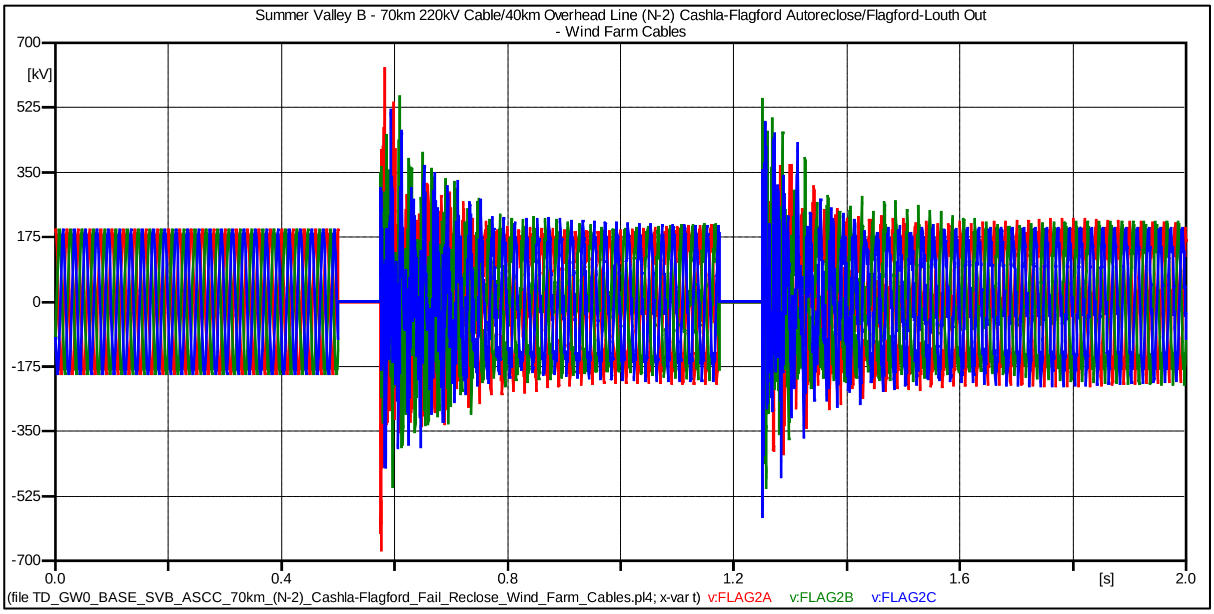

Figure 35: SVB - Length 70 km Cable – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	642.12 kV (3.5961 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	380.12 kV (2.128 pu)	287.32 kV (1.6 pu)	Fail

*Pass can be achieved with the application of surge arrestors.

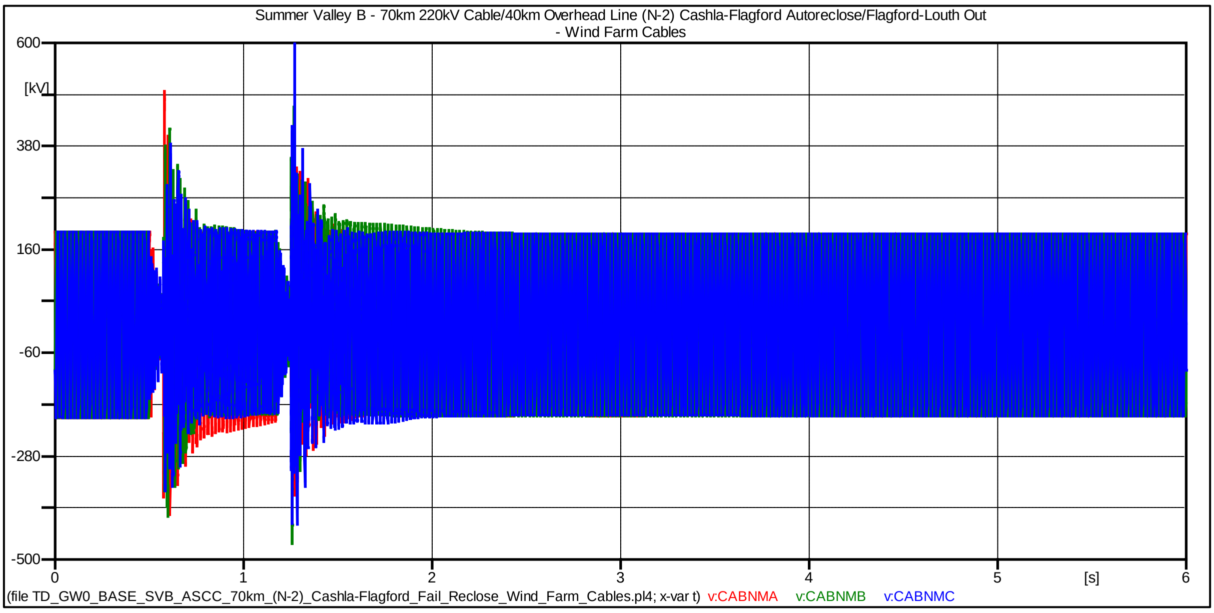

Figure 36: SVB - Length 70 km cable / 40 km OHL – Cable End - North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-6s)

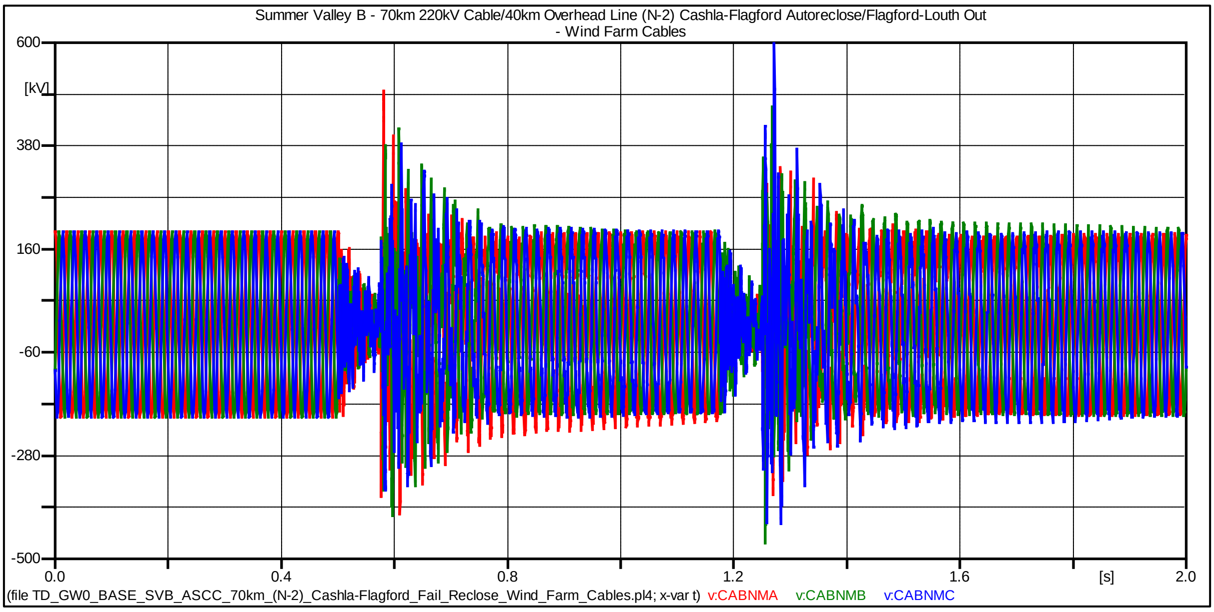

Figure 37: SVB - Length 70 km cable / 40 km OHL – Cable End - North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	601.12 kV (3.3665 pu)	449.073 kV (2.5pu)	Fail
Temporary Overvoltage	330.12 kV (1.844 pu)	287.32 kV (1.6 pu)	Fail

4.7 Case 6 – Partial Cable Solution – 58 km 220 kV Cable/52 km OHL

A partial cable solution was considered with 58 km of 220 kV Cable and 52 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix D.

4.7.1 Impedance Scan – Cable length 58 km/52 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 50 km 220 kV Cable/52 km OHL/8 km Cable
4. Reactors – North Mayo 175 Mvar/Flagford 50 Mvar.

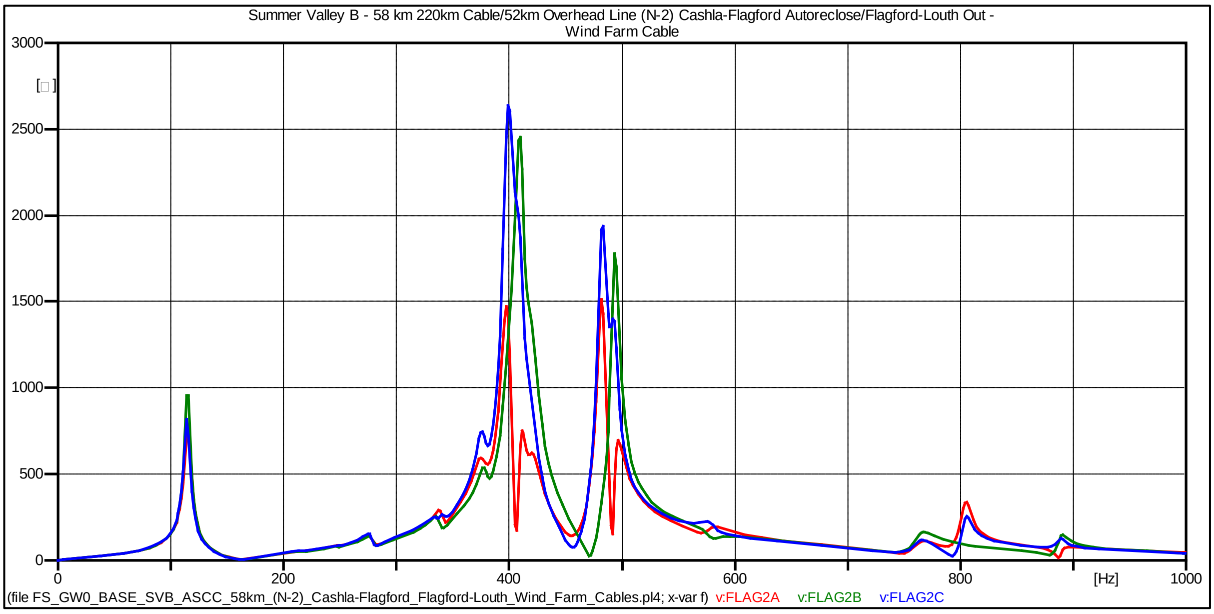

Figure 38: SVB - Length 58km Cable – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
114.01	957.51
399.01	2638.90
483.01	1936.70

4.7.2 Time Domain – Cable length 58km 220 kV Cable/52km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 50 km 220 kV Cable/52 km OHL/8 km 220 kV Cable
4. Reactors – North Mayo 175 Mvar/Flagford 50 Mvar.

Case 6: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.7s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

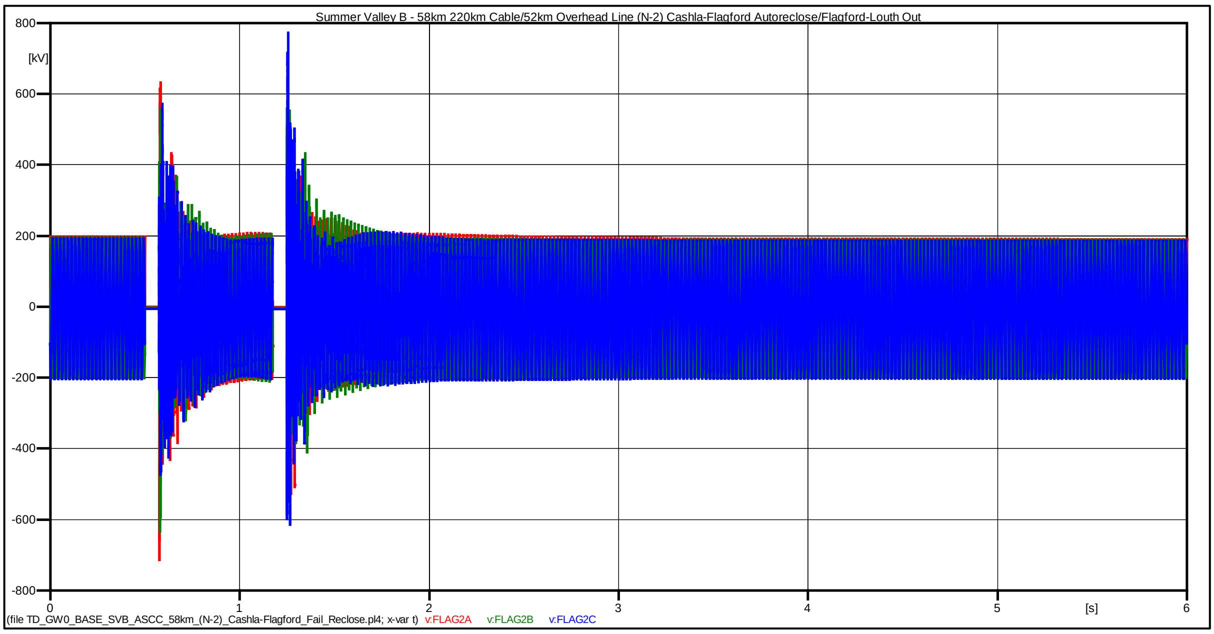

Figure 39: SVB - Length 58 km cable / 52 km OHL - Flagford – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-6s)

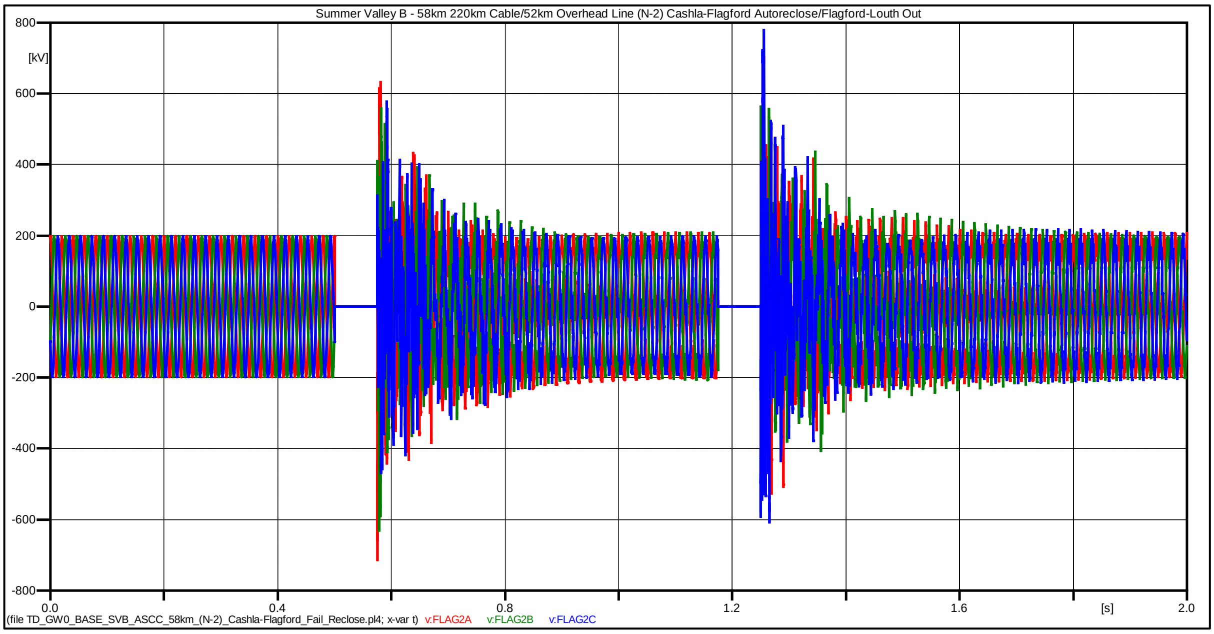

Figure 40: SVB - Length 58 km cable / 52 km OHL - Flagford – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	780.26 kV (4.344 pu)	446.375 kV (2.5 pu)	Fail*
Temporary Overvoltage	410.97 kV (2.288pu)	287.32 kV (1.6pu)	Fail

*Pass can be achieved with the application of surge arrestors.

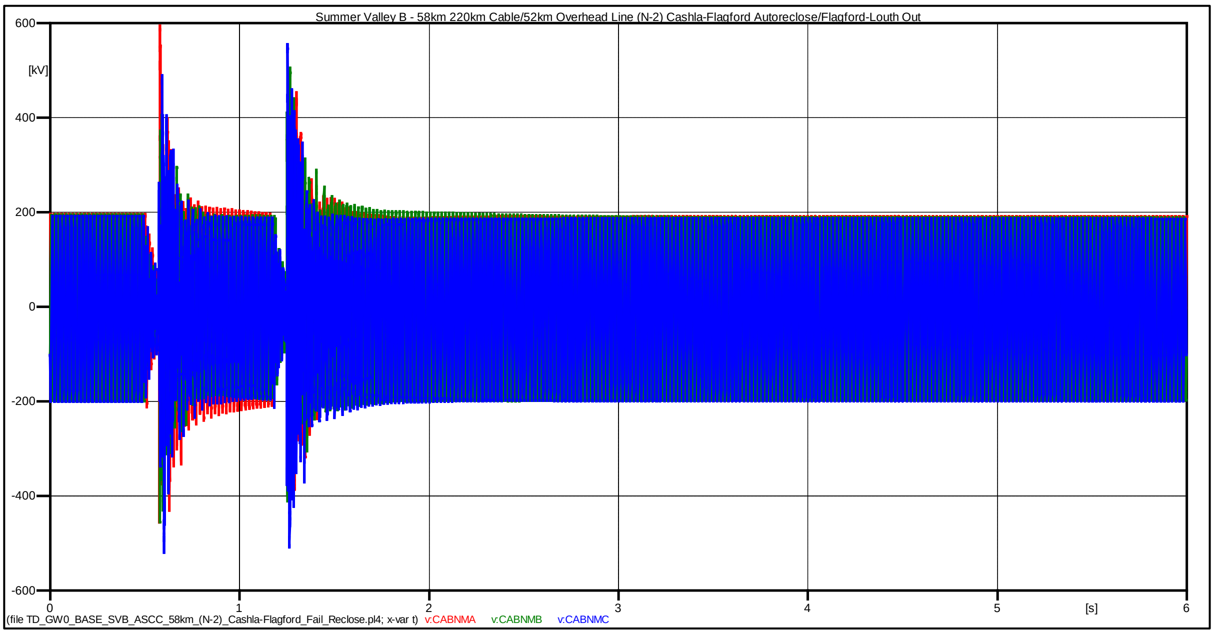

Figure 41: SVB - Length 58 km cable / 52 km OHL –North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-6s)

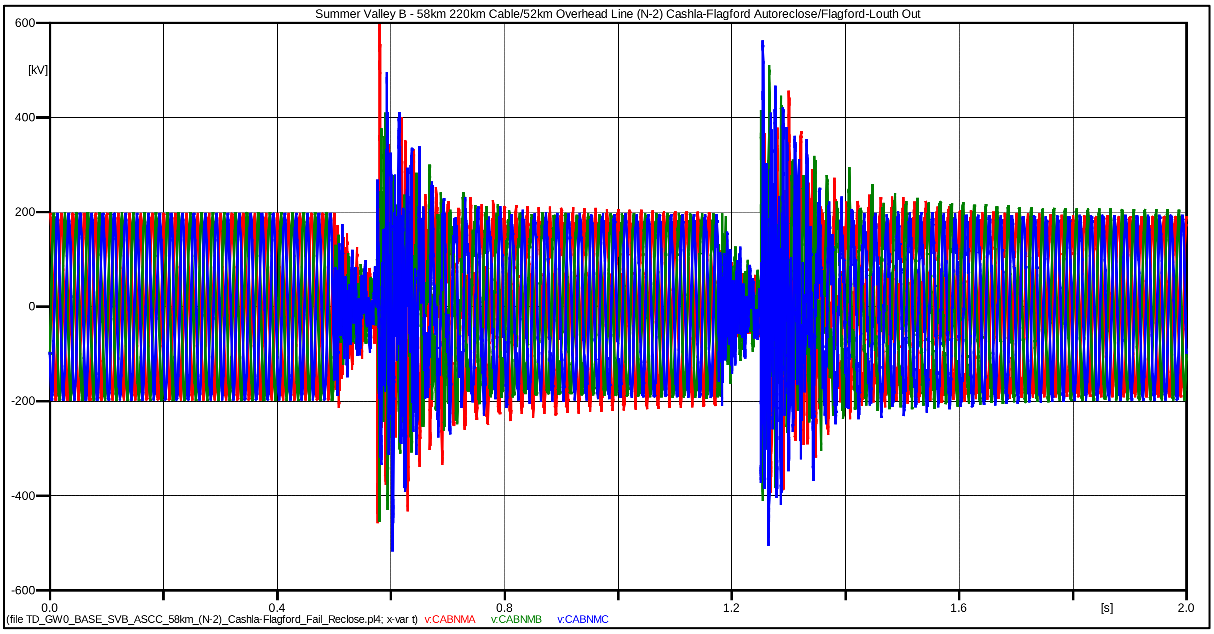

Figure 42: SVB - Length 58 km cable / 52 km OHL – Cable End - North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-2s)

Condition	Maximum Value	Limit	Result
Switching	600.05 kV (3.341 pu)	446.375 kV (2.5 pu)	Fail
Temporary Overvoltage	400.56 kV (2.230 pu)	287.32 kV (1.6pu)	Fail

4.8 Case 7 – Partial Cable Solution – 40 km 220 kV Cable/70 km OHL

A partial cable solution was considered with 40 km of 220 kV Cable and 70 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix E.

4.8.1 Impedance Scan – Cable length 40 km/70 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 32 km 220 kV Cable/70 km OHL/8 km Cable
4. Reactors – North Mayo 100 Mvar/Flagford 75 Mvar.

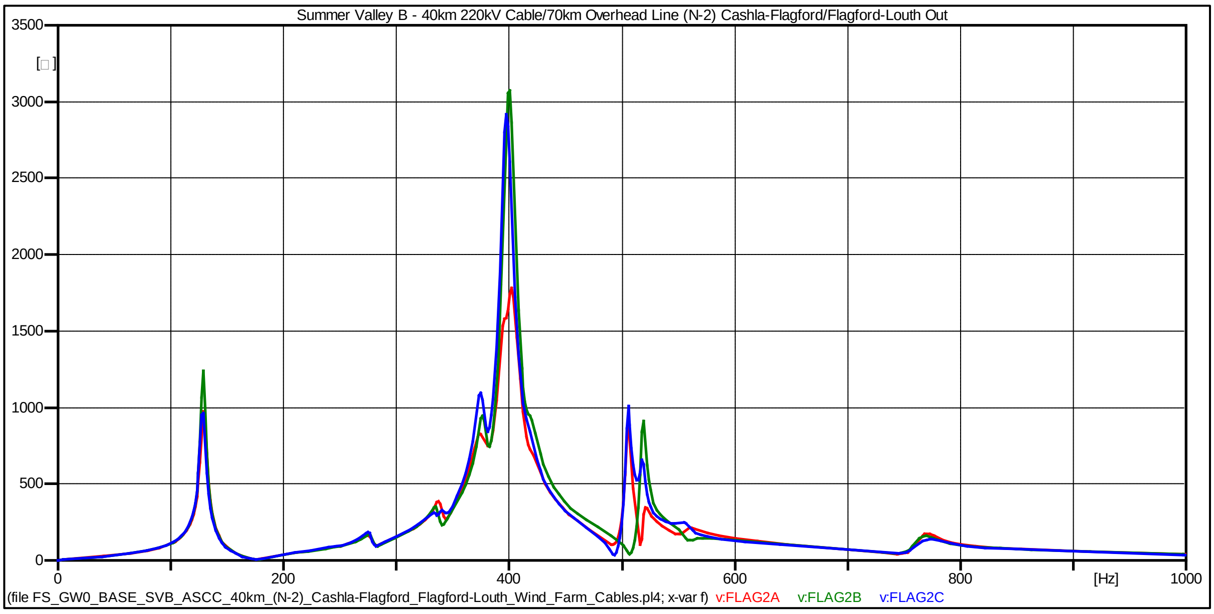

Figure 43: SVB - Length 40 km – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
129.01	1238.80
399.01	3057.00
505.51	1006.90
520.51	761.29

4.8.2 Time Domain – Cable length 40 km 220 kV Cable/70 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, (N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 32 km 220 kV Cable/70 km OHL/8 km 220 kV Cable
4. Reactors – North Mayo 100 Mvar/Flagford 75 Mvar.

Case 7: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.6s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

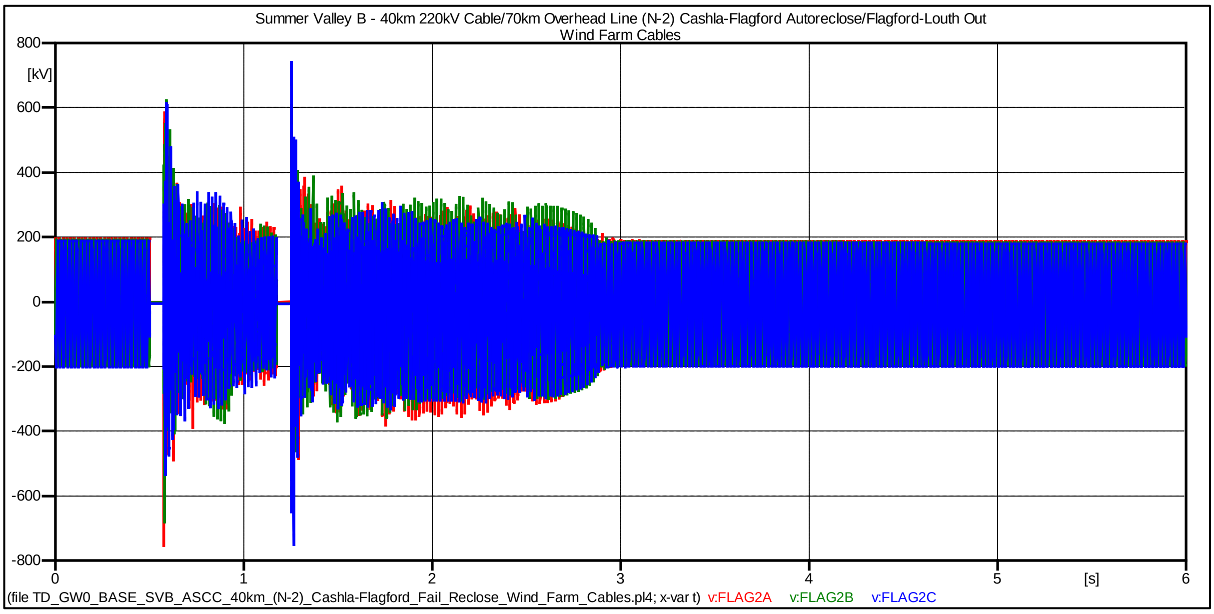

Figure 44: SVB - Length 40 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

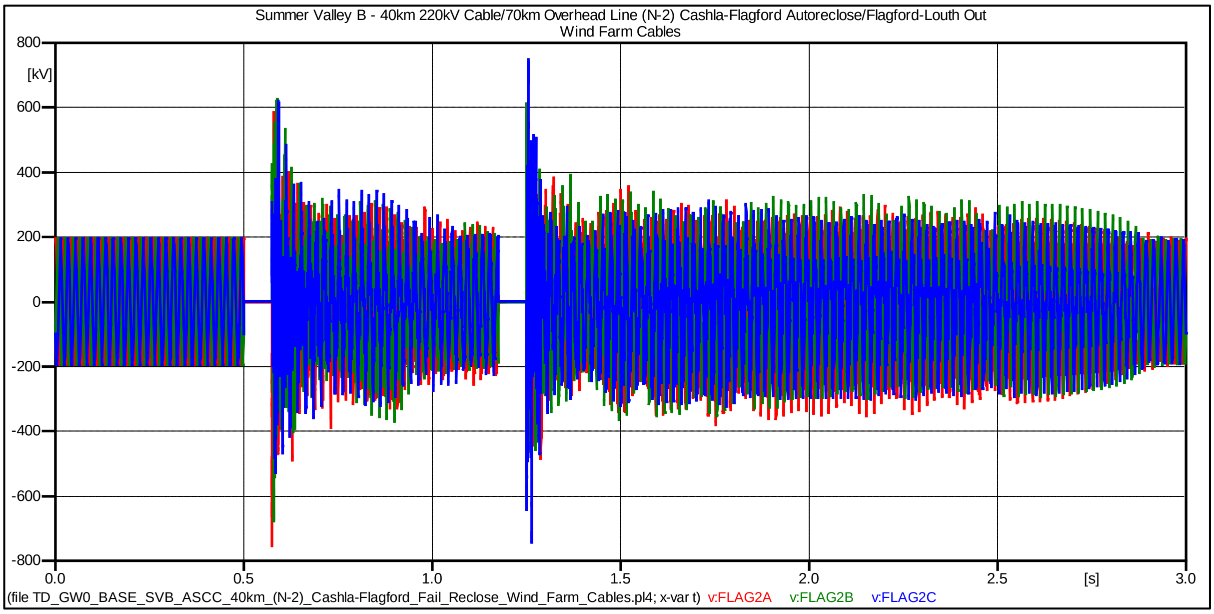

Figure 45: SVB - Length 40 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	Maximum Value	Limit	Result
Switching	770.51 kV (4.3155 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	399.56 kV (2.2371 pu)	287.32 kV (1.6 pu)	Fail

*Pass can be achieved with the application of surge arrestors.

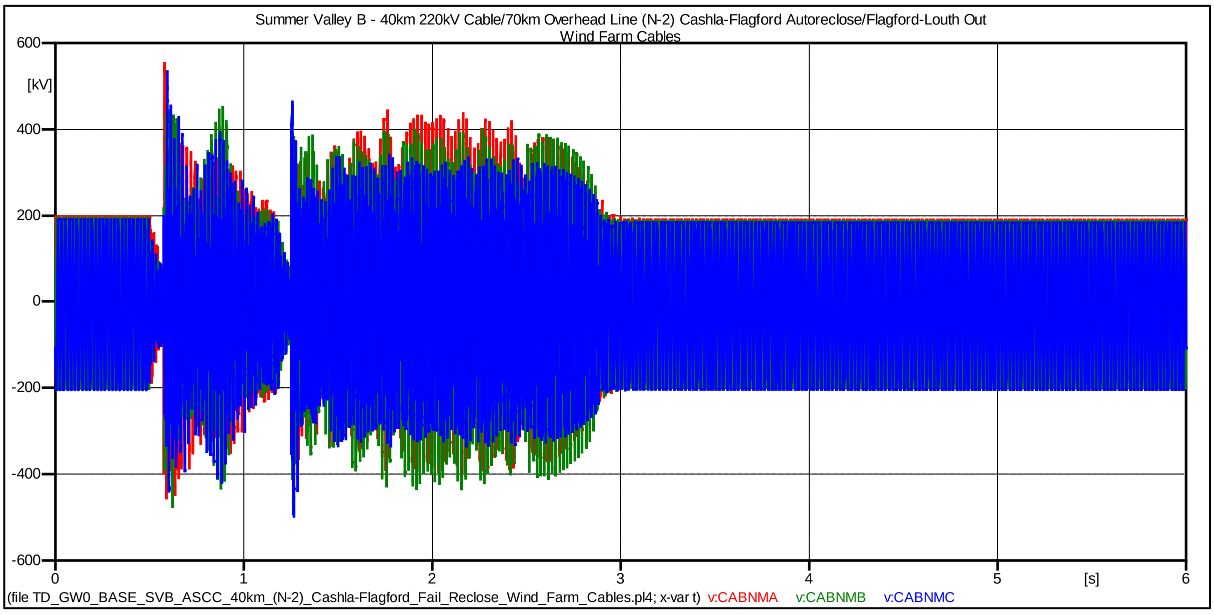

Figure 46: SVB - Length 40 km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

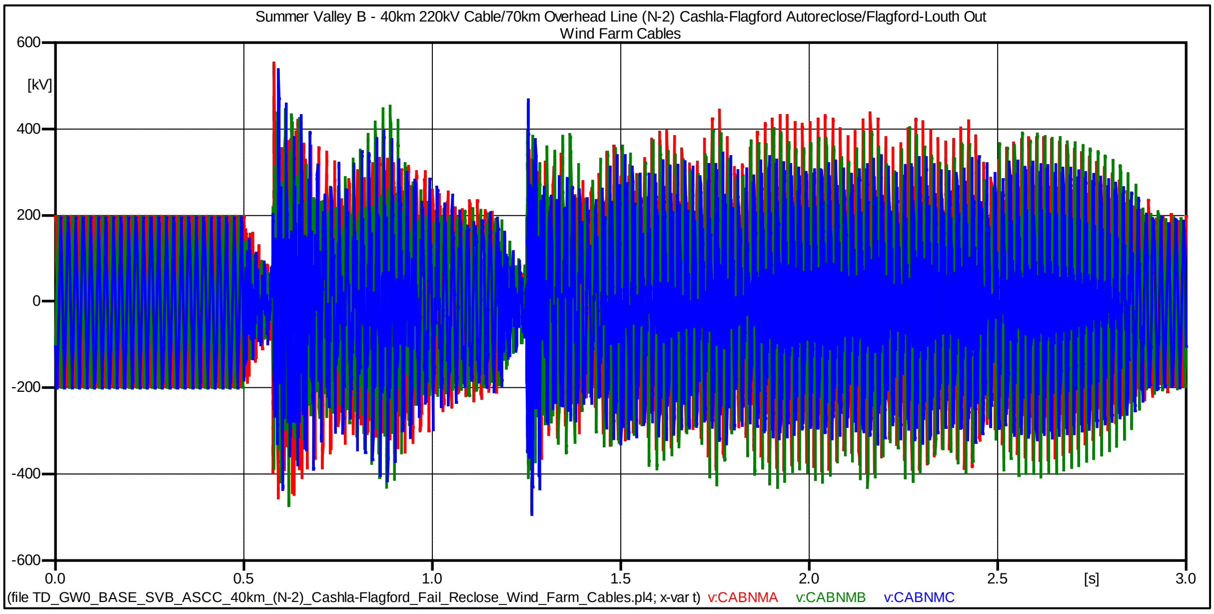

Figure 47: SVB - Length 40 km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	565.23 kV (3.147 pu)	449.073 kV (2.5pu)	Fail
Temporary Overvoltage	461.93 kV (2.572 pu)	287.32 kV (1.6 pu)	Fail

4.9 Case 8 – Partial Cable Solution – 30 km 220 kV Cable/80 km OHL

A partial cable solution was considered with 30 km of 220 kV Cable and 80 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix E.

4.9.1 Impedance Scan – Cable length 30 km/80 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 22 km 220 kV Cable/80 km OHL/8 km Cable
4. Reactors – North Mayo 60 Mvar/Flagford 50 Mvar.

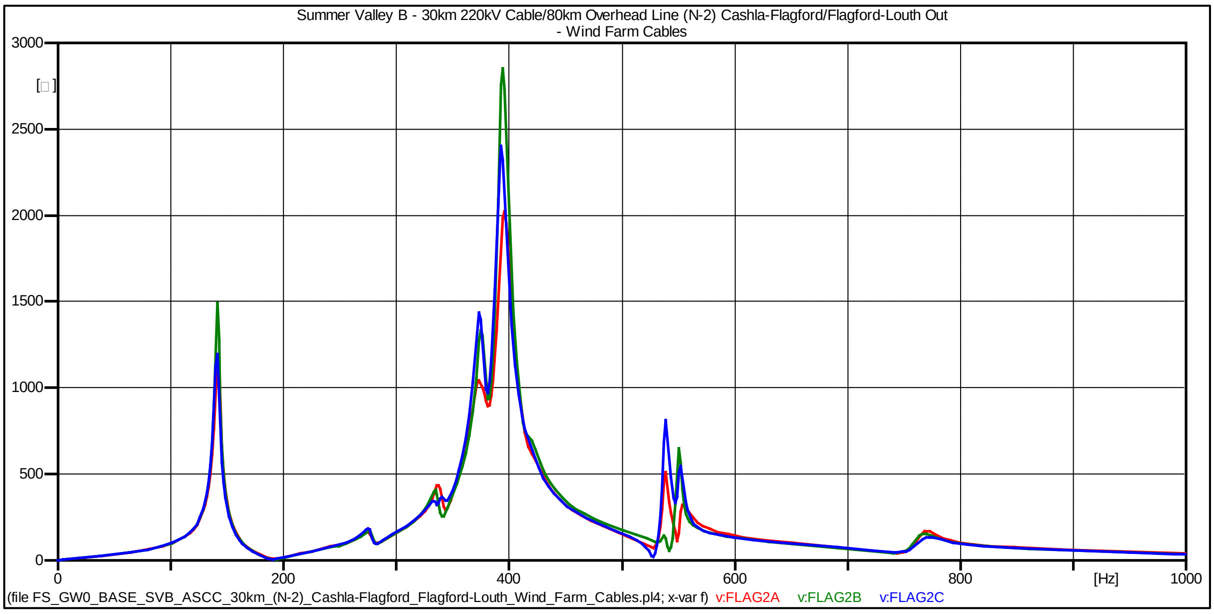

Figure 48: SVB - Length 30 km – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
142.51	1281.90
393.01	2755.50
540.01	697.64

4.9.2 Time Domain – Cable length 30 km 220 kV Cable/80 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 22 km 220 kV Cable/80 km OHL/8km 220 kV Cable
4. Reactors – North Mayo 60 Mvar/Flagford 50 Mvar.

Case 8: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.6s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

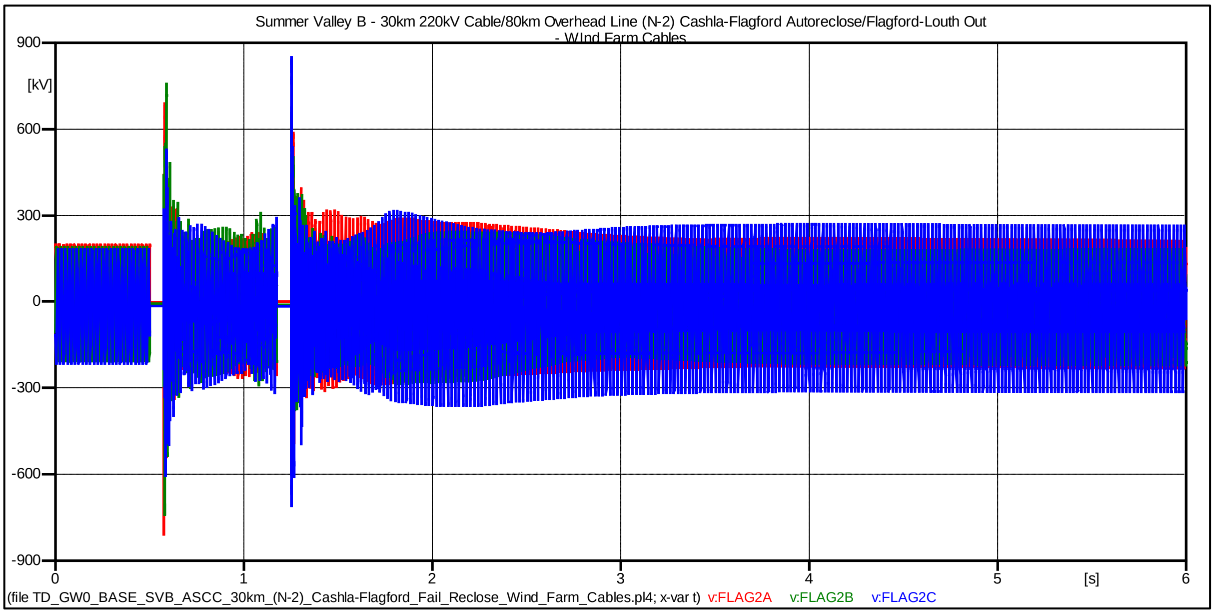

Figure 49: SVB - Length 30 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

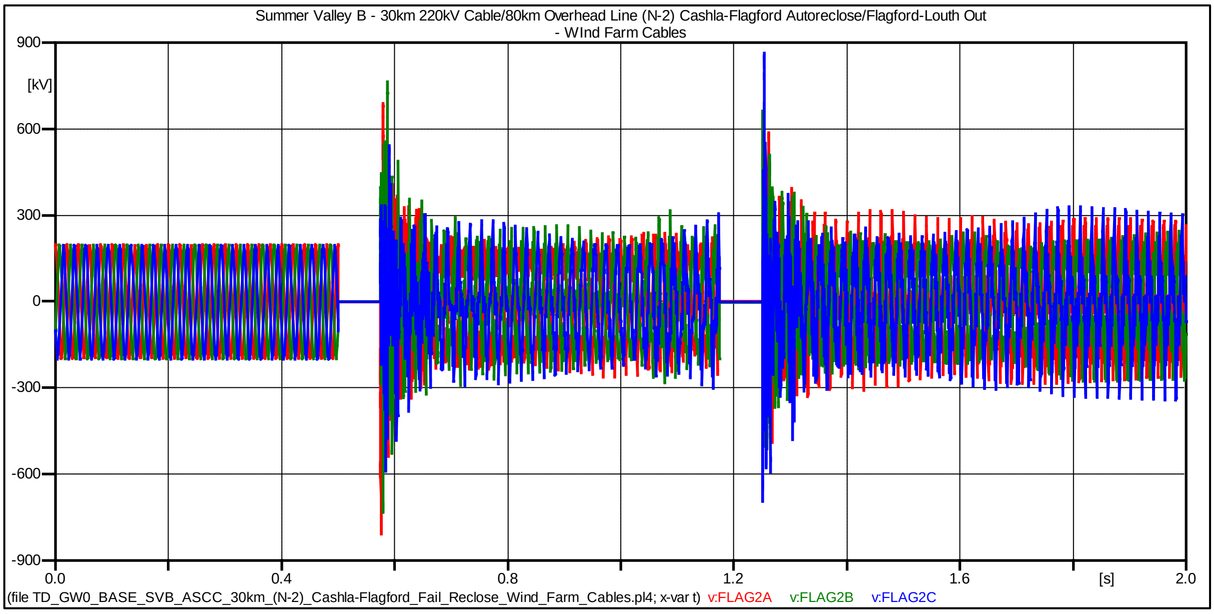

Figure 50: SVB - Length 30 km –Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	880.51 kV (4.9312 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	341.23 kV (1.9110 pu)	287.32 kV (1.6 pu)	Fail

*Pass can be achieved with the application of surge arrestors.

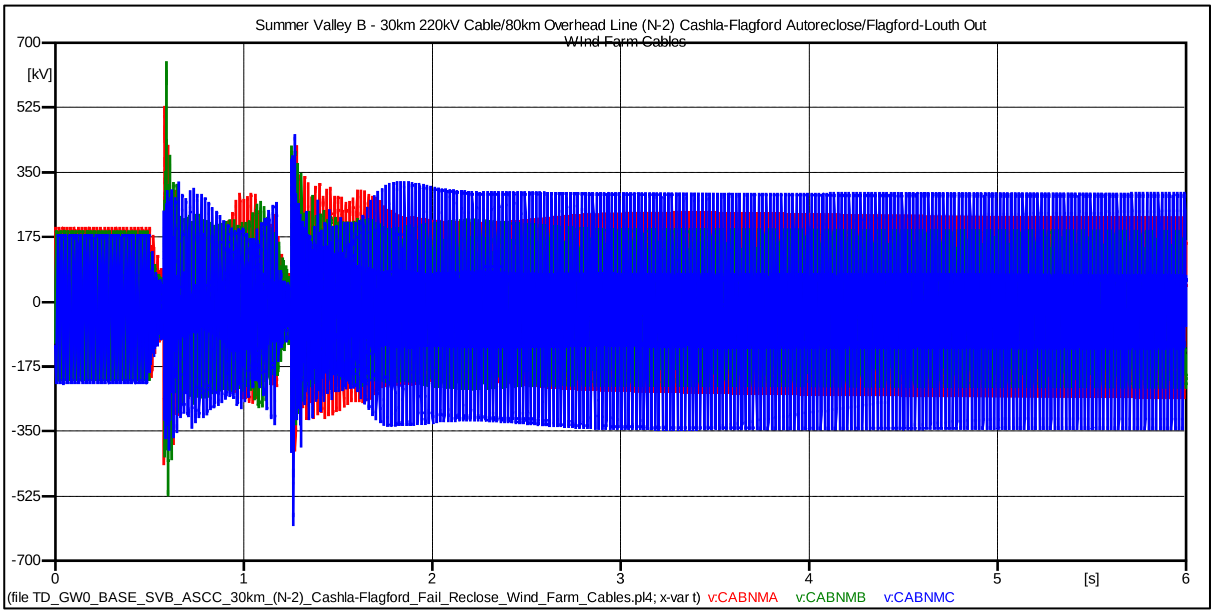

Figure 51: SVB - Length 30 km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

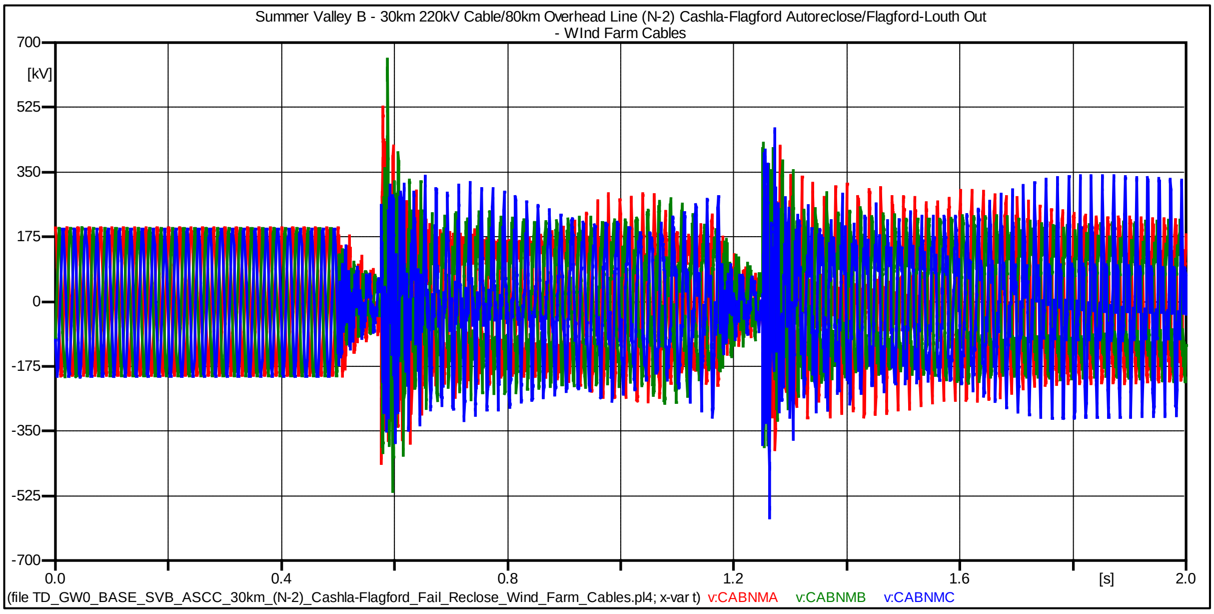

Figure 52: SVB - Length 30 km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	660.58 kV (3.6784 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	370.89 kV (2.065 pu)	287.32 kV (1.6 pu)	Fail

*Pass can be achieved with the application of surge arrestors.

4.10 Case 9 – Partial Cable Solution – 20 km 220 kV Cable/90 km OHL

A partial cable solution was considered with 20 km of 220 kV Cable and 90 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix E.

4.10.1 Impedance Scan – Cable length 20 km/90 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 12 km 220 kV Cable/90 km OHL/8 km Cable
4. Reactors – North Mayo 40 Mvar/Flagford 30 Mvar.

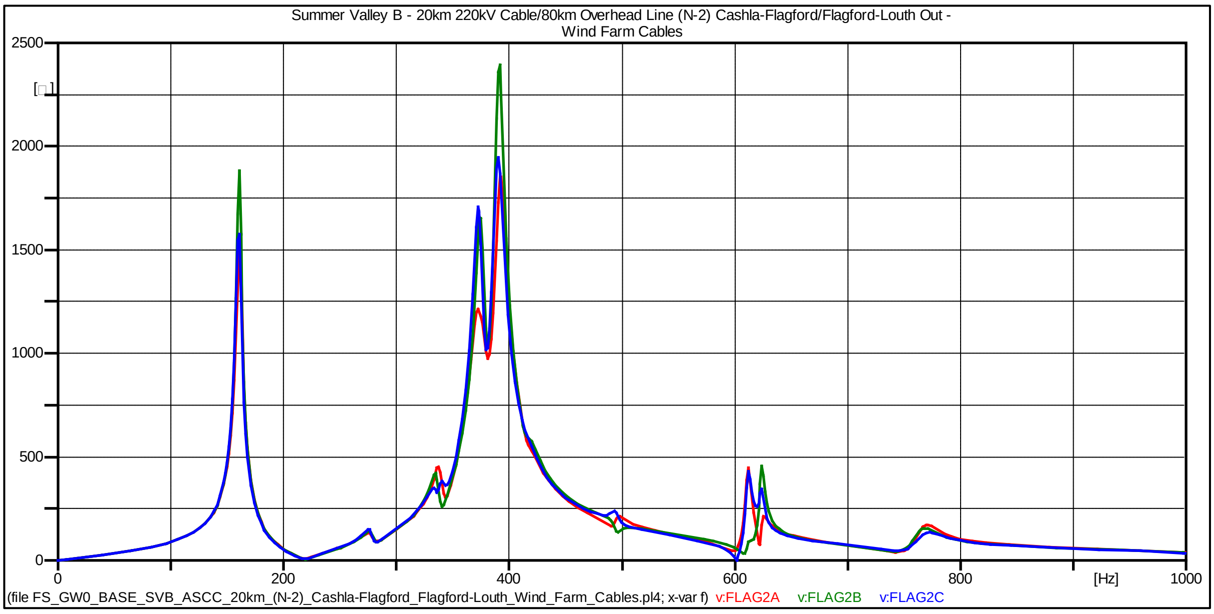

Figure 53: SVB - Length 20 km – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
162.01	1575.00
373.50	1684.60
391.51	2392.60
613.51	391.54

4.10.2 Time Domain – Cable length 20 km 220 kV Cable/90 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, (N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit - 12km 220 kV Cable/90 km OHL/8 km 220 kV Cable
4. Reactors – North Mayo 40 Mvar/Flagford 30 Mvar.

Case 9: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.6s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

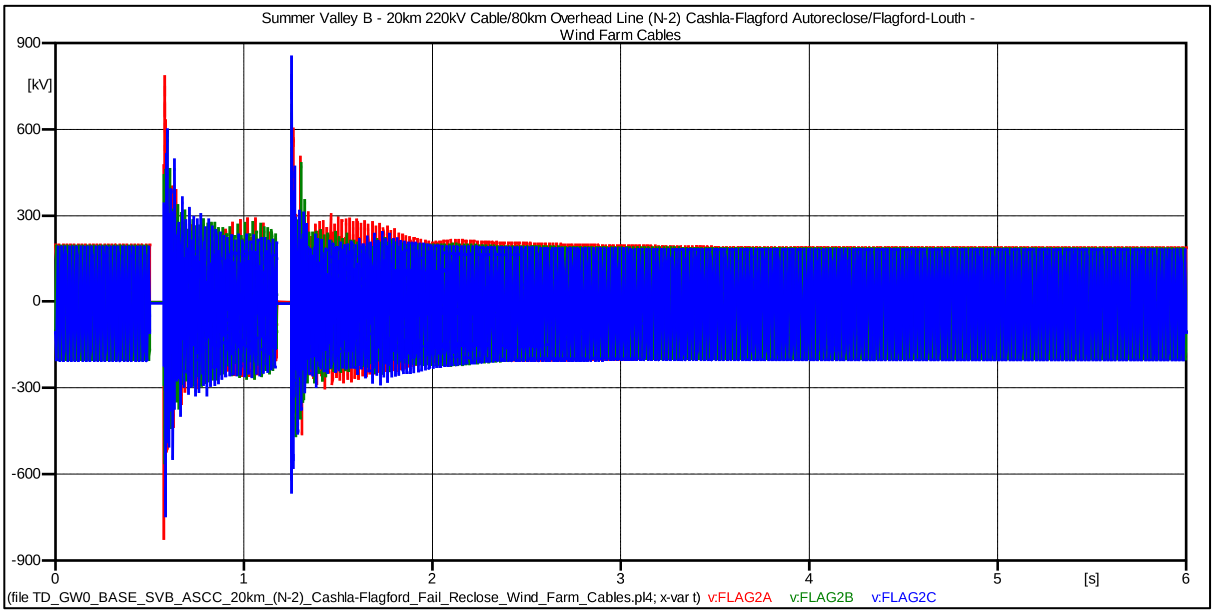

Figure 54: SVB - Length 20 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

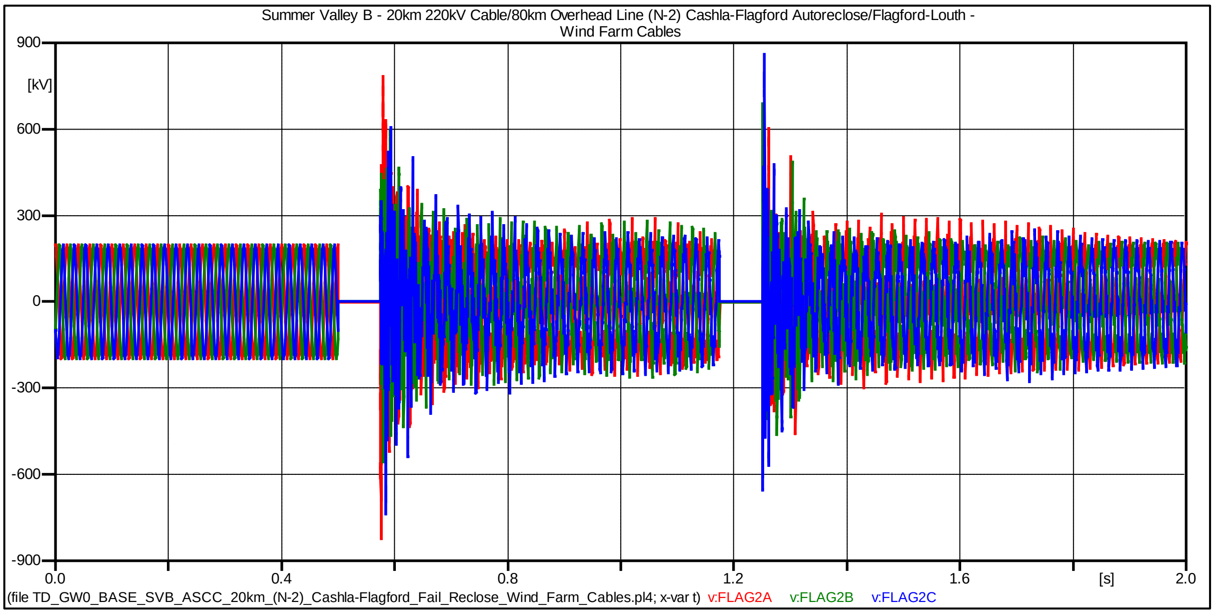

Figure 55: SVB - Length 20 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	781.26 kV (4.350pu)	449.073 kV (2.5pu)	Fail[1]
Temporary Overvoltage	560.28 kV (3.119 pu)	287.32 kV (1.6 pu)	Fail[2]

[1]Pass can be achieved with the application of surge arrestors.
[2]Short duration TOV.

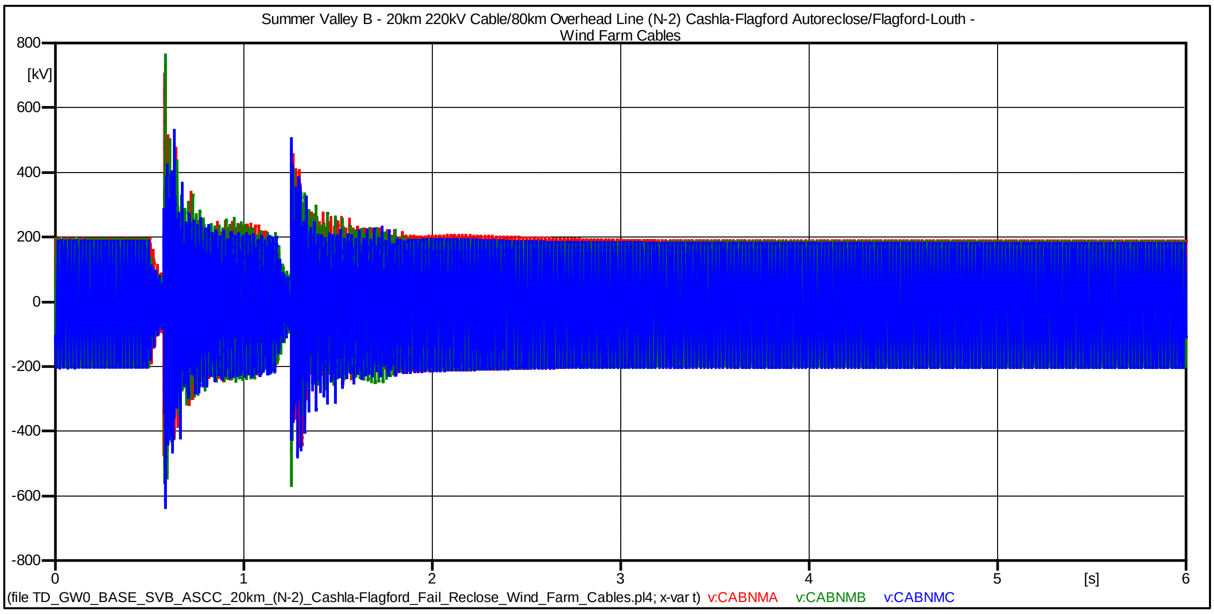

Figure 56: SVB - Length 20 km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

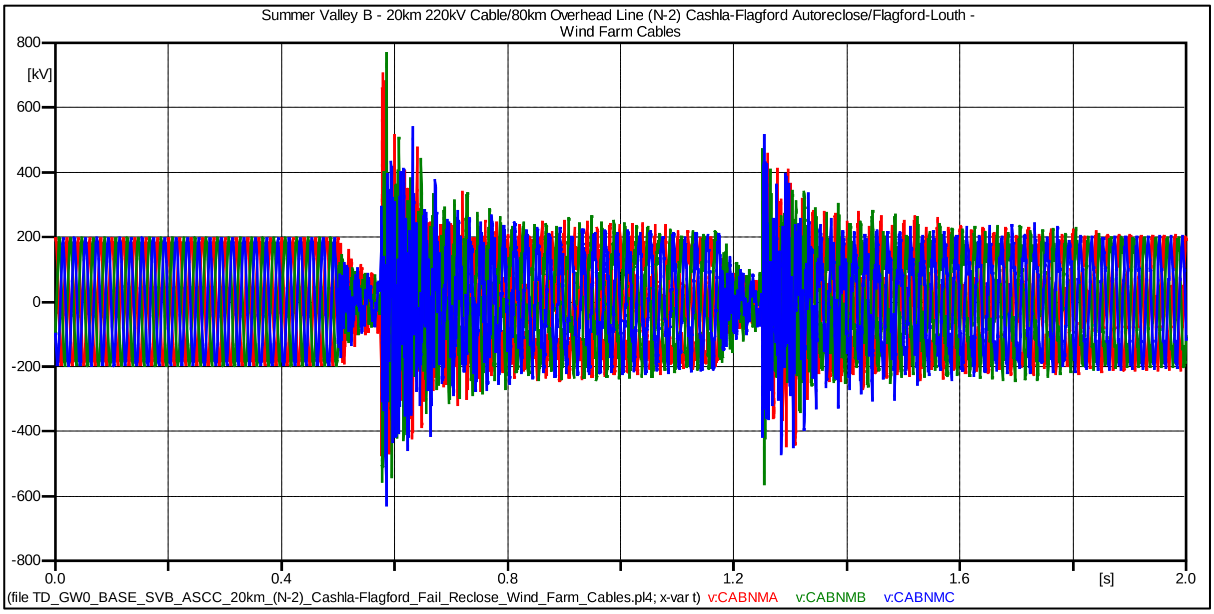

Figure 57: SVB - Length 20 km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	715.45 kV (3.984 pu)	449.073 kV (2.5pu)	Fail[1]
Temporary Overvoltage	487.67 kV (2.715 pu)	287.32 kV (1.6 pu)	Fail[2]

[1]Pass can be achieved with the application of surge arrestors.
[2]Short duration TOV.

4.11 Case 10– Split Cable Solution – 30 km 220kV Cable/75 km OHL

A partial cable solution was considered with 30 km of 220 kV Cable and 75 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix F.

4.11.1 Impedance Scan – Cable length 30 km/75 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 2 km Cable/11 km OHL/20 km Cable/64 km OHL/8 km Cable.
4. Reactors – North Mayo 125 Mvar/Flagford 45 Mvar.

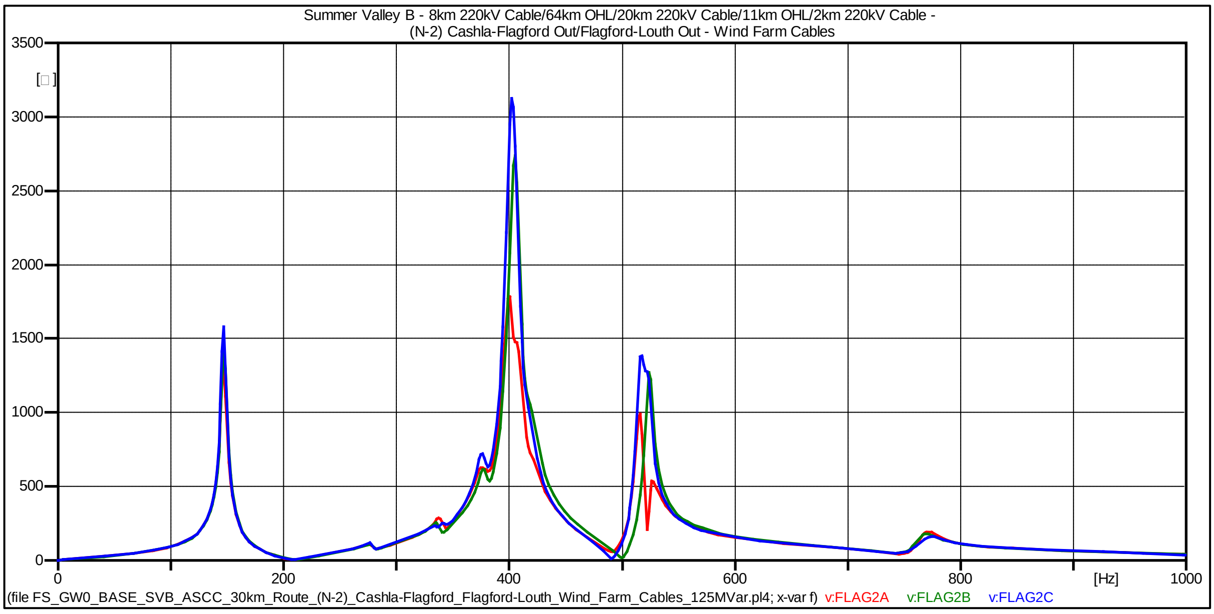

Figure 58: SVB – Split Length 30 km – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
147.01	1578.90
402.01	3126.80
517.51	1384.90

4.11.2 Time Domain – Cable length 30 km 220 kV Cable/75 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 2 km Cable/11 km OHL/20 km Cable/64 km OHL/8 km Cable.
4. Reactors – North Mayo 125 Mvar/Flagford 25 Mvar.

Case 10: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.6s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

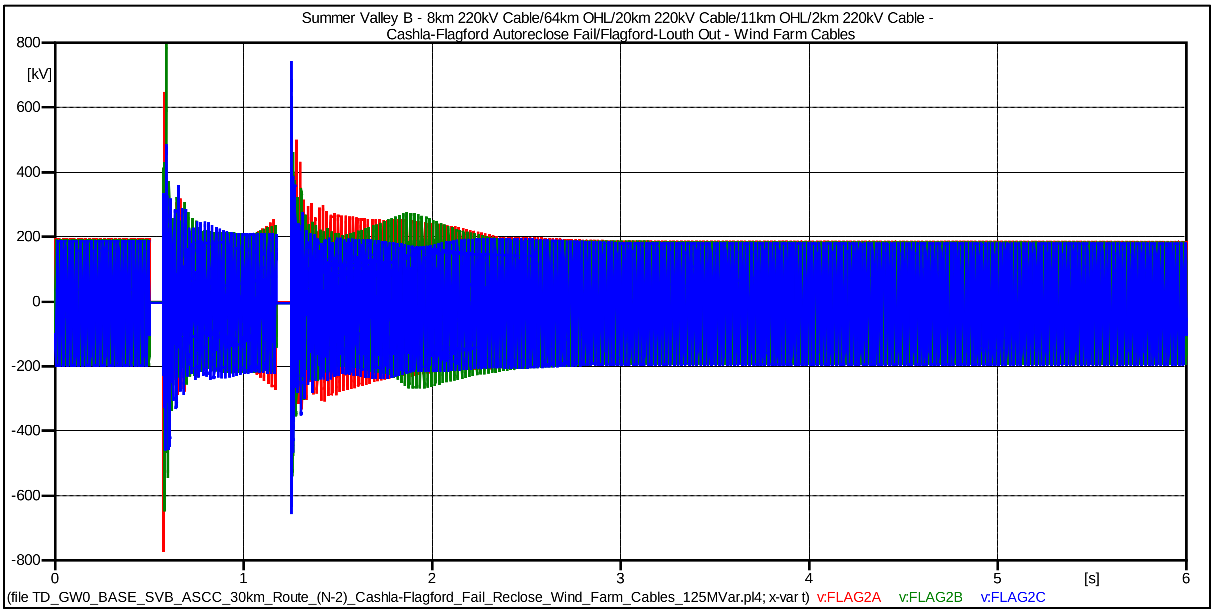

Figure 59: SVB – Split Length 30 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

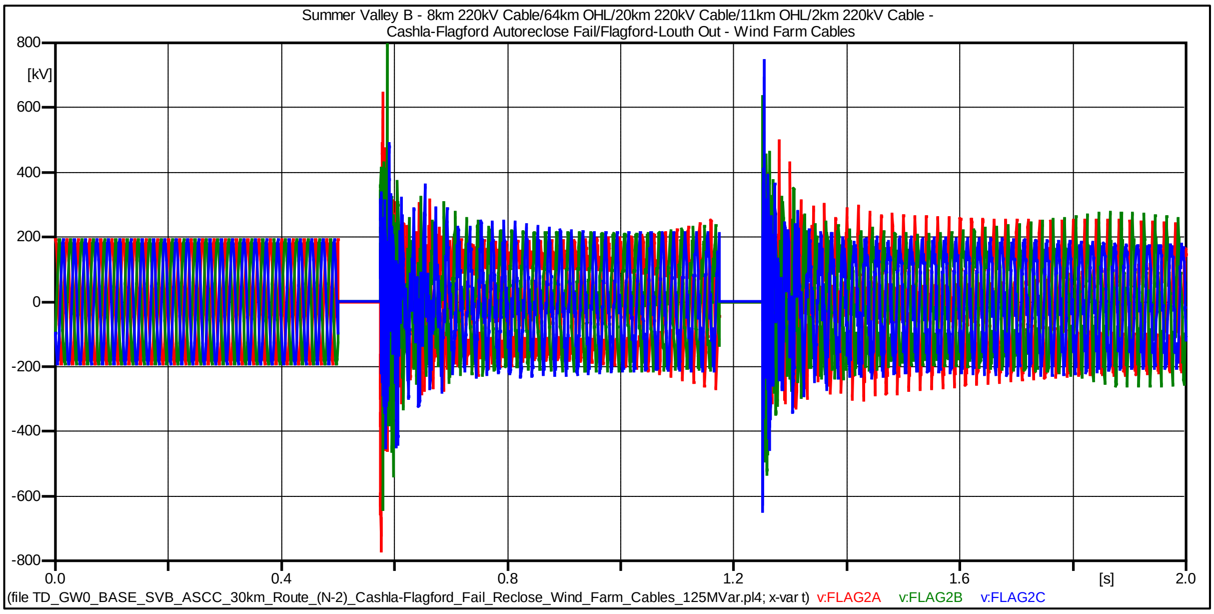

Figure 60: SVB – Split Length 30km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	790.12 kV (4.3998 pu)	449.073 kV (2.5pu)	Fail[1]
Temporary Overvoltage	355.21 kV (1.9780 pu)	287.32 kV (1.6 pu)	Fail[2]

[1]Pass can be achieved with the application of surge arrestors.
[2]TOV short duration.

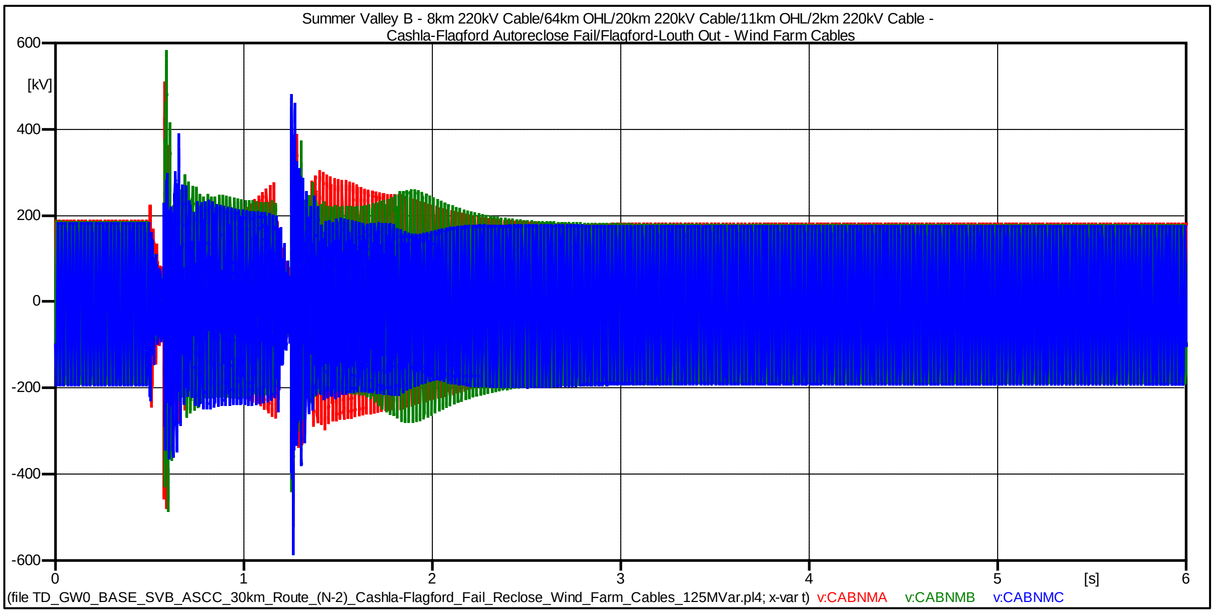

Figure 61: SVB – Split Length 30 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

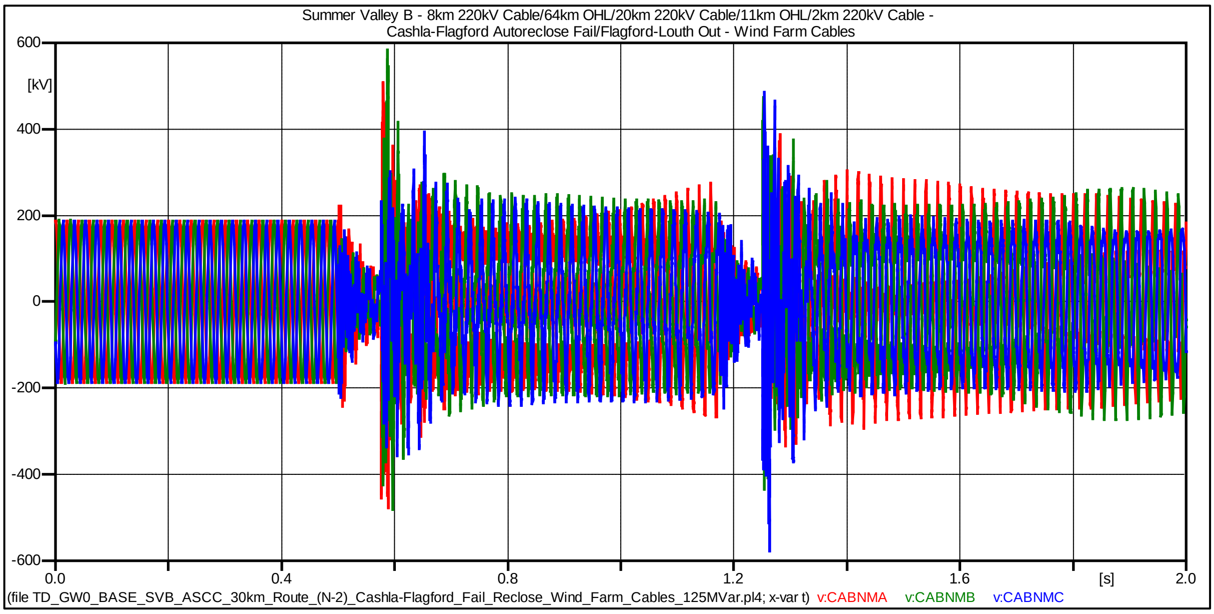

Figure 62: SVB – Split Length 30 km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	595.56 kV (3.3164 pu)	449.073 kV (2.5pu)	Pass[1]
Temporary Overvoltage	400.23 kV (2.2287 pu)	287.32 kV (1.6 pu)	Fail[2]

[1]Pass can be achieved with the application of surge arrestors.
[2] TOV short duration.

4.12 Case 11 – Split Cable Solution – 23 km 220 kV Cable/82 km OHL

A partial cable solution was considered with 23km of 220 kV Cable and 82 km Overhead Line for the Summer Valley B configuration. Detailed results are shown in Appendix F.

4.12.1 Impedance Scan – Cable length 23 km/82 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, **(**N-2) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 2 km Cable/18 km OHL/13 km Cable/64 km OHL/8 km Cable.
4. Reactors – North Mayo 100 Mvar/Flagford 25 Mvar.

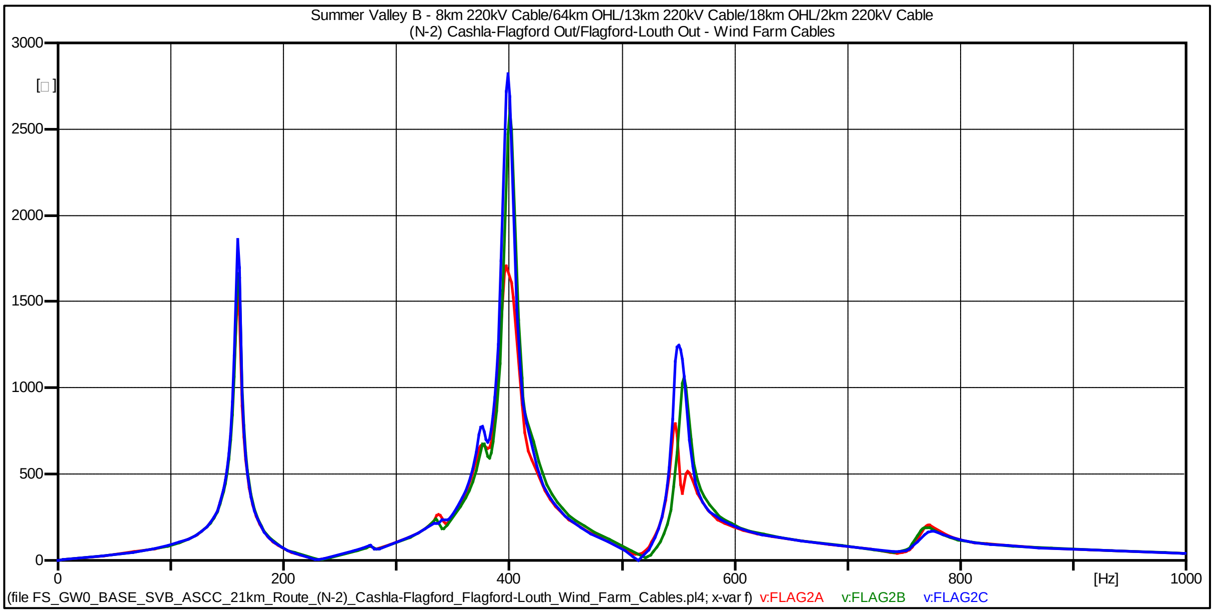

Figure 63: SVB – Split Length 23km – (N-2) Flagford-Louth & Cashla-Flagford Lines Out

Impedance scan results

Frequency (Hz)	Impedance (Ω)
160.51	1696.50
399.01	2823.50
550.51	1246.70

4.12.2 Time Domain – Split cable length 23 km 220 kV Cable/82 km OHL – Summer Valley B

Conditions for impedance scan:

1. Consideration of the worst case, (N-1-1) scenario with Cashla-Flagford and Flagford-Louth 220 kV lines out of service.
2. Summer Valley B network.
3. North Mayo to Flagford Circuit – 2 km Cable/18 km OHL/13 km Cable/64 km OHL/8 km Cable
4. Reactors – North Mayo 100 Mvar/Flagford 25 Mvar.

Case 11: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

4. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
5. Reclose sequence at 0.575s, dead time 0.7s, circuit breaker closes 1.185s, point on wave closes at 90°.
6. Breaker opens at again at 1.25s.

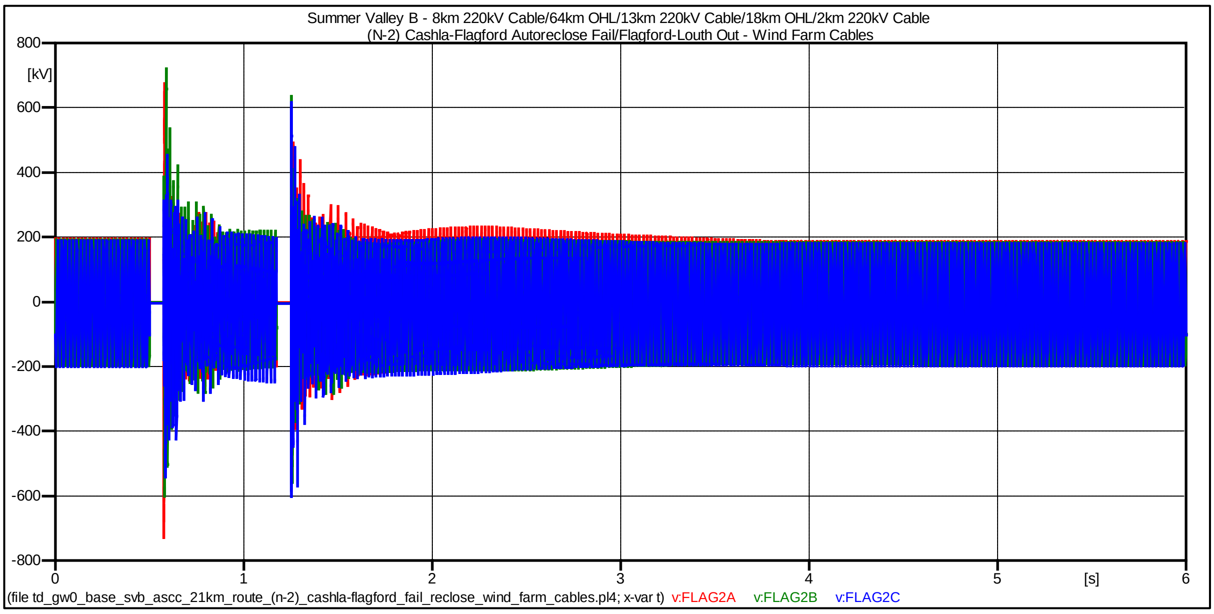

Figure 64: SVB – Split Length 23km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

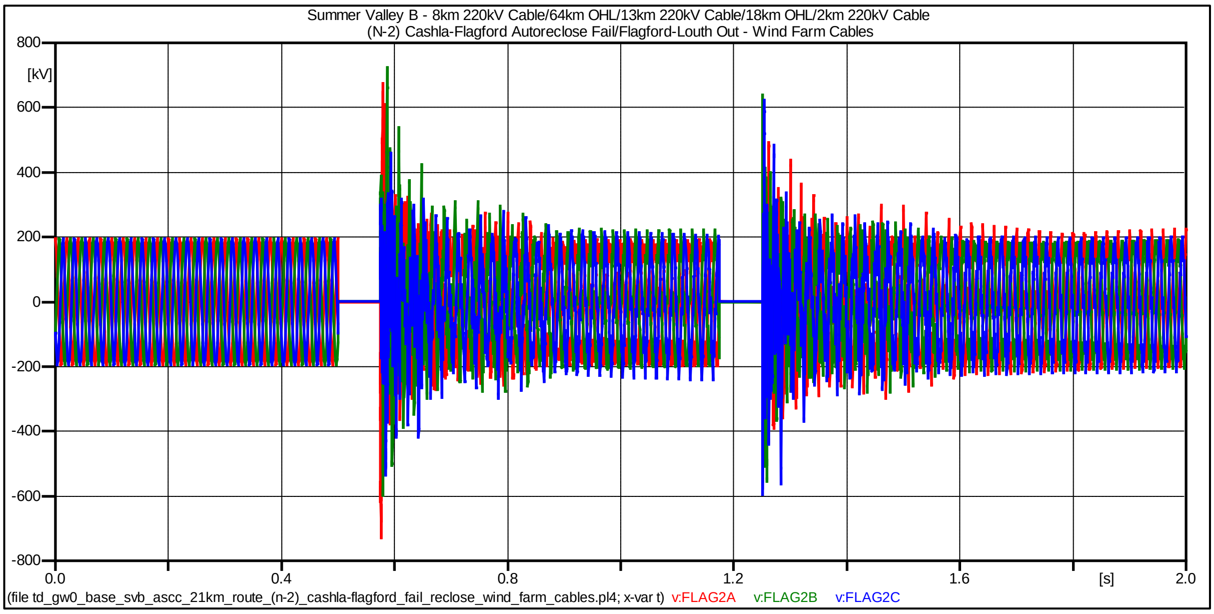

Figure 65: SVB – Split Length 23km – Flagford – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	723.56 kV (4.029 pu)	449.073 kV (2.5pu)	Fail[1]
Temporary Overvoltage	405.25 kV (2.2566 pu)	287.32 kV (1.6 pu)	Fail[2]

[1]Pass can be achieved with the application of surge arrestors.
[2] TOV short duration.

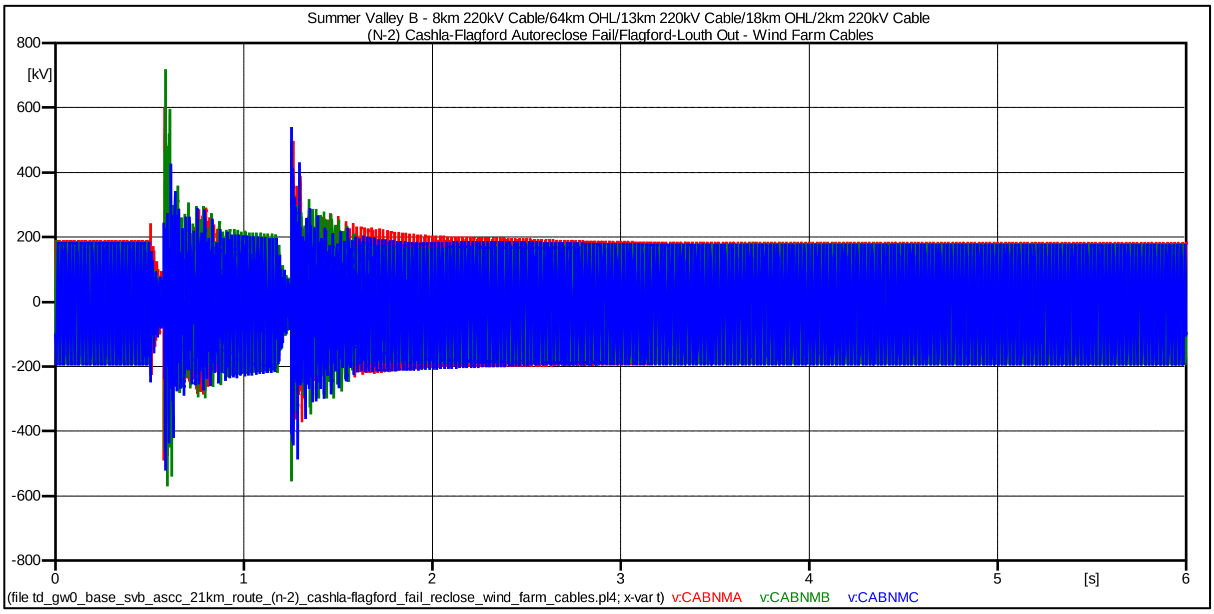

Figure 66: SVB – Split Length 23km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-6s)

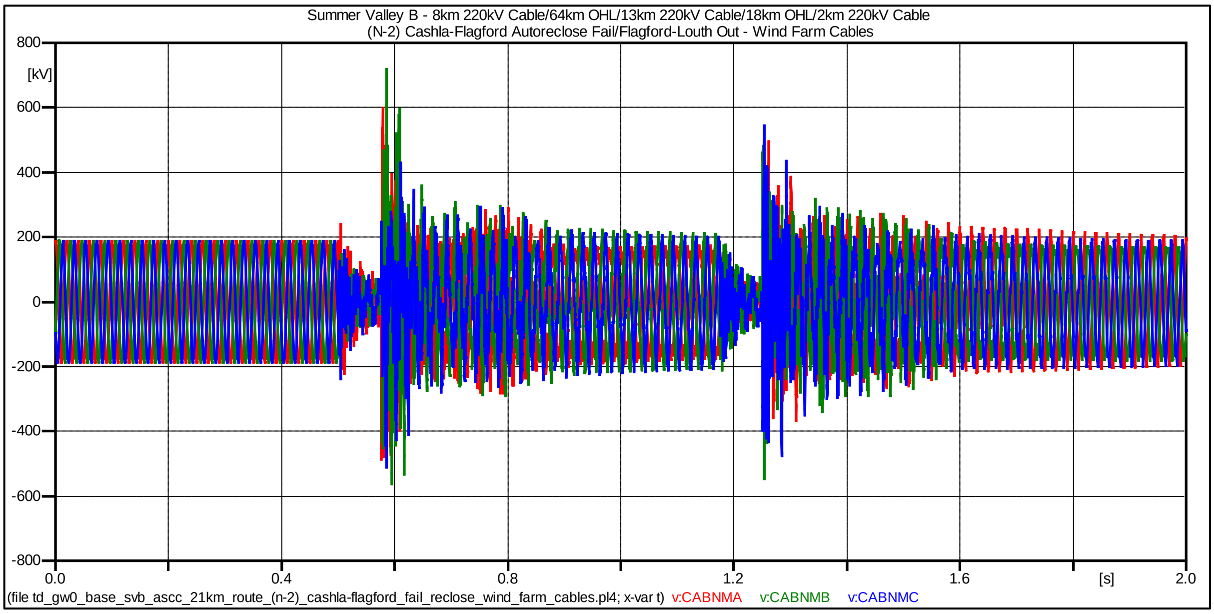

Figure 67: SVB – Split Length 23km – North Mayo – (N-1-1) Condition – Flagford-Louth line out - Autoreclose of the Cashla-Flagford - Permanent Fault (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	710.23 kV (3.954 pu)	449.073 kV (2.5pu)	Fail[1]
Temporary Overvoltage	345.23 kV (1.922 pu)	287.32 kV (1.6 pu)	Fail[2]

[1]Pass can be achieved with the application of surge arrestors.
[2] TOV short duration.

4.13 Case 12 – Cable length 30 km + HP Filter – Summer Valley B

Cable length of 30 km using high pass filter mitigation, 22 km of cable between North Mayo and Flagford and 8 km of cable between Srananagh and Flagford. An impedance scan and time domain simulations are considered below for the Summer Valley B configuration. Detailed results are shown in Appendix G.

4.13.1 Impedance Scans - Length 30 km – Summer Valley B – Case 12

Conditions for impedance scan:

1. Summer Valley B network
2. North Mayo to Flagford Circuit – 2 km Cable/11 km OHL/20 km Cable/72 km OHL/2 km Double Circuit OHL.
3. Flagford to Srananagh Circuit – 8 km Cable/45 km OHL
4. Reactors – North Mayo 100 Mvar/Flagford 50 Mvar
5. Filter – High Pass Filter – 3.29 uF, 372 mH, 500 Ω

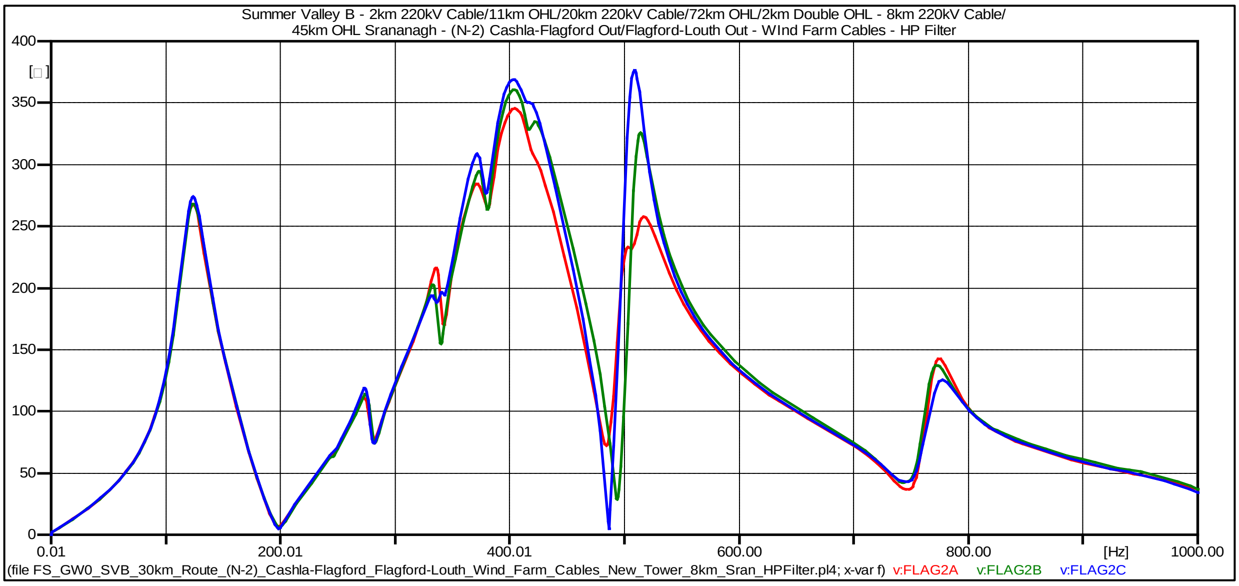

Figure 68: SVB - Length 30 km - (N-2) Cashla-Flagford/Flagford-Louth Lines Out

Impedance Scan - Resonance points

Frequency (Hz)	Impedance (Ω)
123.91	273.61
403.51	368.59
509.41	375.68
774.31	142.73

4.13.2 Time Domain Simulation - Length 30 km – Summer Valley B – Case 12

Conditions for time domain simulation:

1. Summer Valley B network
2. North Mayo to Flagford Circuit - 2km Cable/11km OHL/20km Cable/72km OHL/2km Double Circuit OHL.
3. Flagford to Sranangh Circuit – 8 km Cable/45 km OHL
4. Reactors – North Mayo 100 Mvar/Flagford 50 Mvar
5. Filter – High Pass Filter – 3.29 uF, 372 mH, 500 Ω
6. Plots only shown for the Flagford and North Mayo busbars, other results are shown in Appendix G.

Case 12: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.6s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

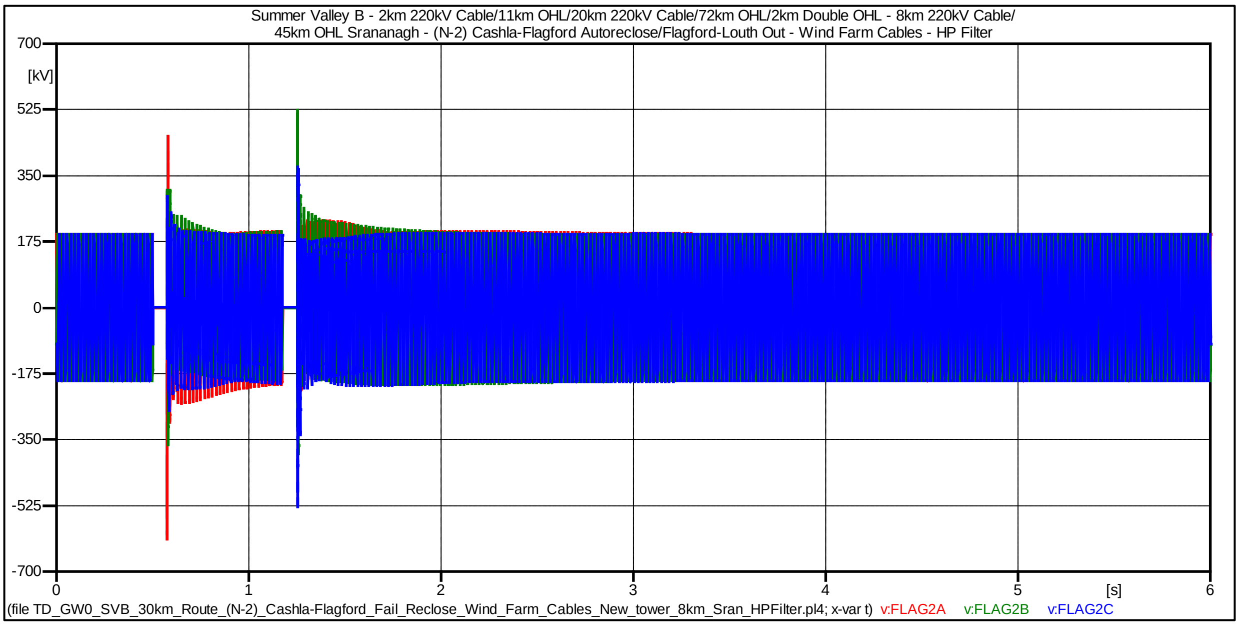

Figure 69: SVB - Length 30 km – North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-6s)

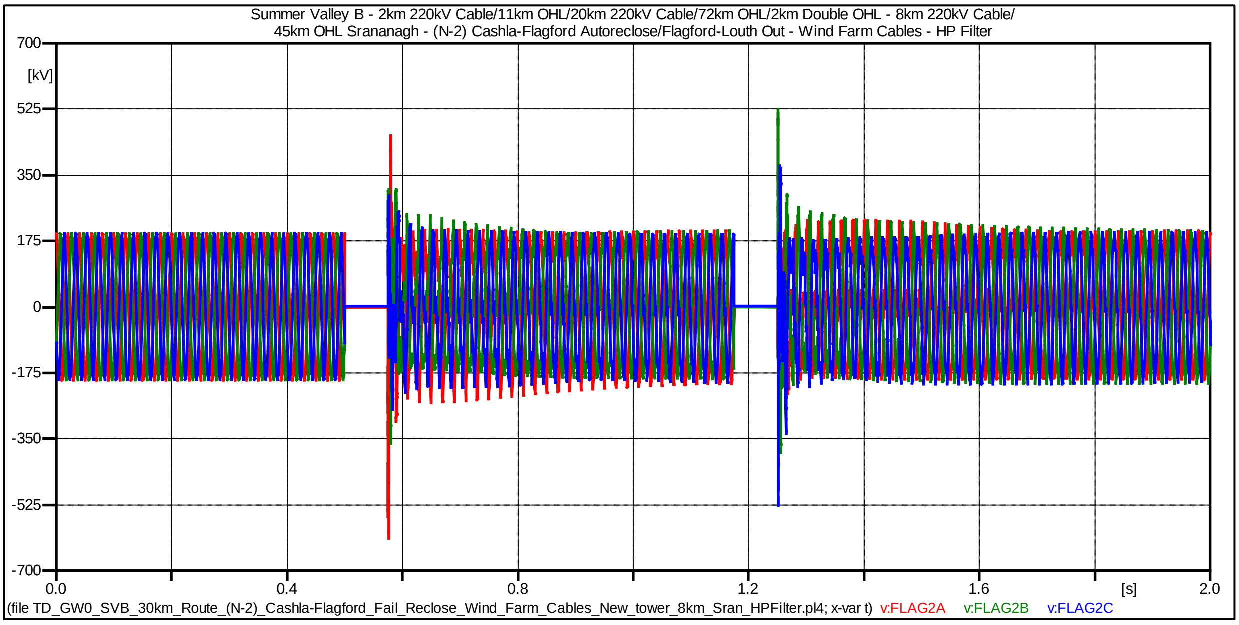

Figure 70: SVB - Length 30 km – North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	525 kV (2.923 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	264.52 kV (1.4729 pu)	287.32 kV (1.6 pu)	Pass

*Pass can be achieved with surge arrestors

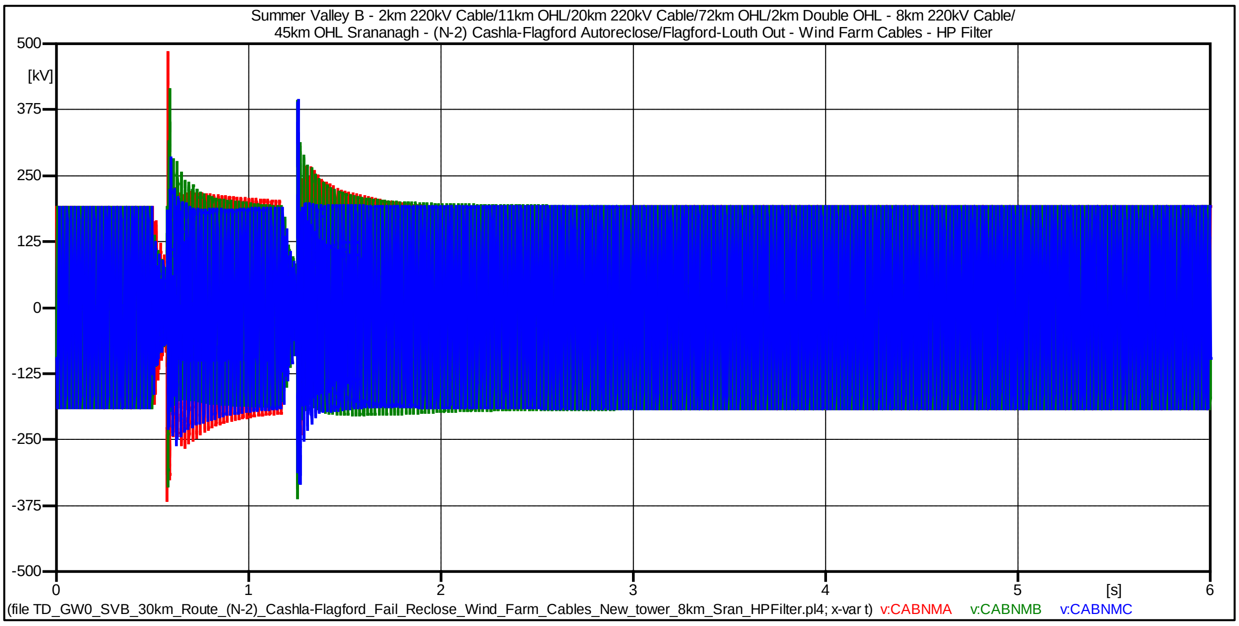

Figure 71: SVB - Length 30 km – North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-6s)

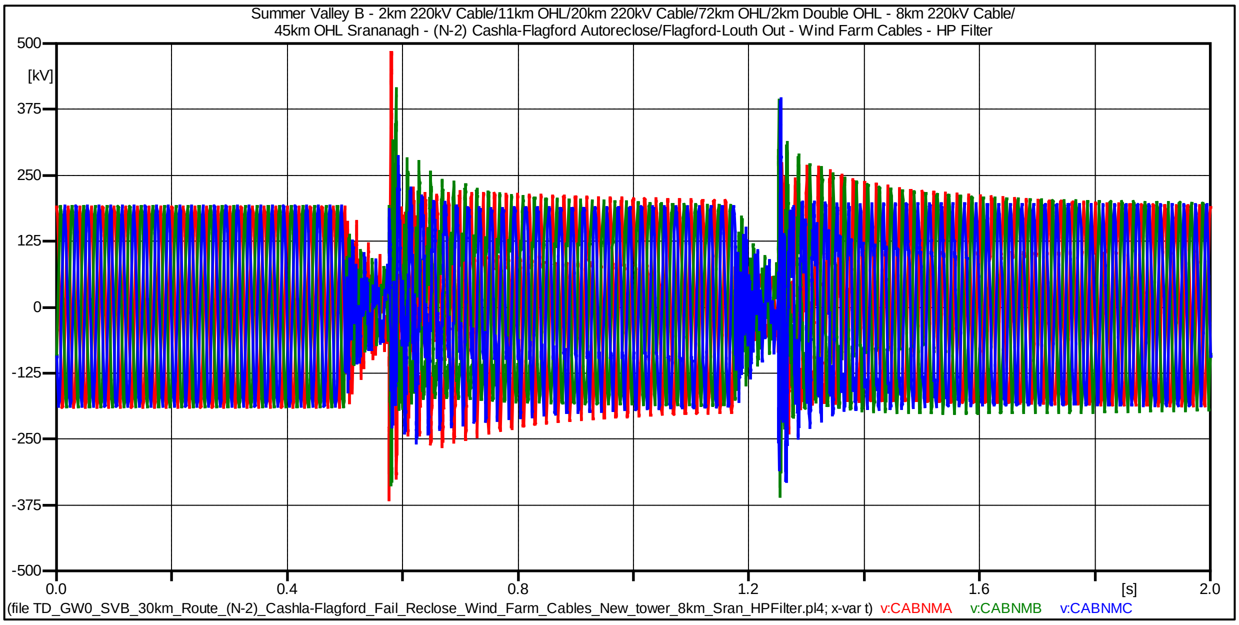

Figure 72: SVB - Length 30 km –North Mayo– (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	480.02 kV (2.6730 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	286.10 kV (1.593 pu)	287.32 kV (1.6 pu)	Pass

*Pass can be achieved with surge arrestors

4.14 Case 13 – Cable length 30km + HP Filter – Winter Peak A

Cable length of 30 km using high pass filter mitigation, 22 km of cable between North Mayo and Flagford and 8km of cable between Sranangh and Flagford. An impedance scan and time domain simulations are considered below for the Winter Peak A configuration. Detailed results are shown in Appendix H.

4.14.1 Impedance Scans - Length 30 km – Winter Peak A – Case 13

Conditions for impedance scan:

1. Winter Peak A Network
2. North Mayo to Flagford Circuit – 2 km Cable/11 km OHL/20 km Cable/72 km OHL/2 km Double Circuit OHL.
3. Flagford to Srananagh Circuit – 8 km Cable/45 km OHL
4. Reactors – North Mayo 100 Mvar/Flagford 50 Mvar
5. Filter – High Pass Filter – 3.29 uF, 372 mH, 500 Ω
6. Plots only shown for the Flagford and North Mayo busbars, other results are shown in Appendix H.

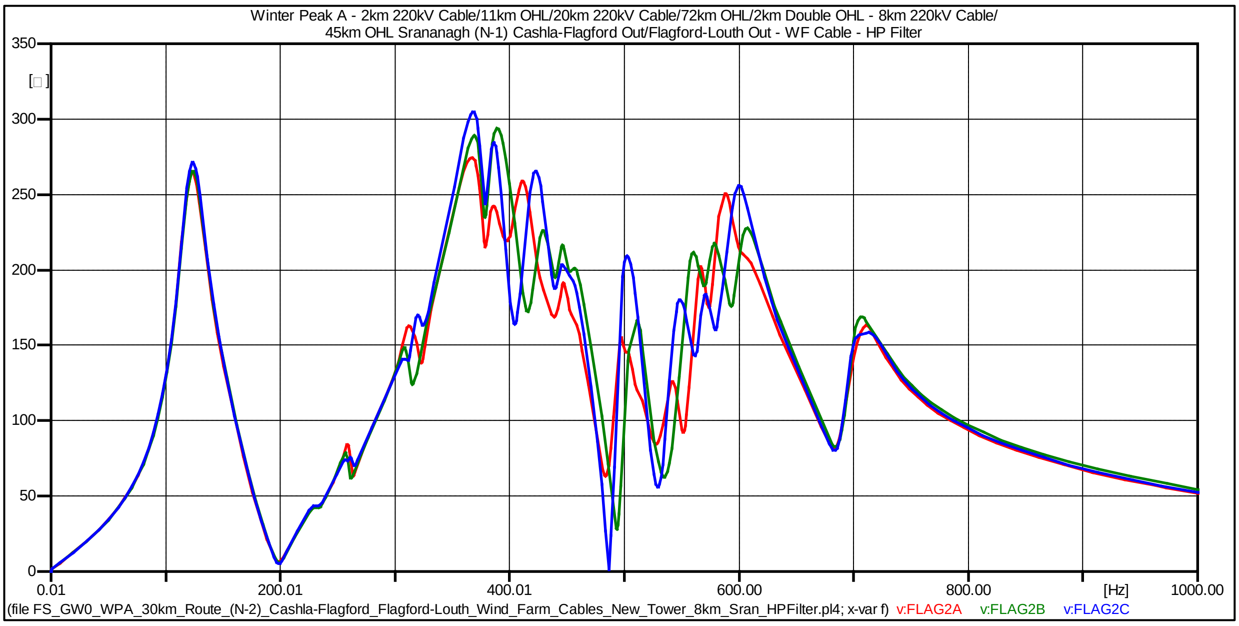

Figure 73: WPA - Length 30 km - (N-2) Cashla-Flagford/Flagford-Louth Lines Out

Impedance Scan - Resonance points

Frequency (Hz)	Impedance (Ω)
123.91	271.12
369.91	303.12
502.21	209.25
601.81	254.91
709.21	167.69

4.14.2 Time Domain Simulation - Length 30 km – Winter Peak A – Case 13

Conditions for time domain simulation:

1. Winter Peak A Network
2. North Mayo to Flagford Circuit – 2 km Cable/11 km OHL/20 km Cable/72 km OHL/2 km Double Circuit OHL.
3. Flagford to Srananagh Circuit – 8 km Cable/45 km OHL
4. Reactors – North Mayo 100 Mvar/Flagford 50 Mvar
5. Filter – High Pass Filter – 3.29 uF, 372 mH, 500 Ω
6. Plots only shown for the Flagford and North Mayo busbars, other results are shown in Appendix G.

Case 13: (N-1-1) Condition – Flagford-Louth line outage - Autoreclose of the Cashla-Flagford – Fault not removed.

1. Fault on Flagford side of Flagford-Cashla line, applied at 0.5s.
2. Reclose sequence at 0.575s, dead time 0.6s, circuit breaker closes 1.175s, point on wave closes at 90°.
3. Breaker opens at again at 1.25s.

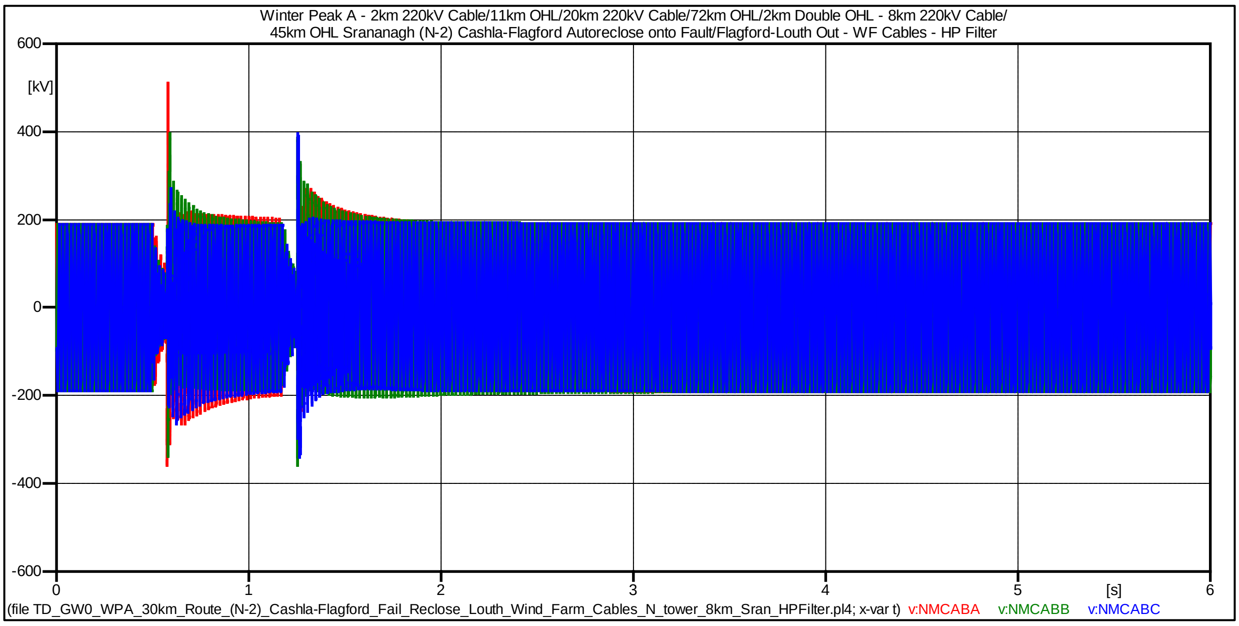

Figure 74: WPA - Length 30 km – North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-6s)

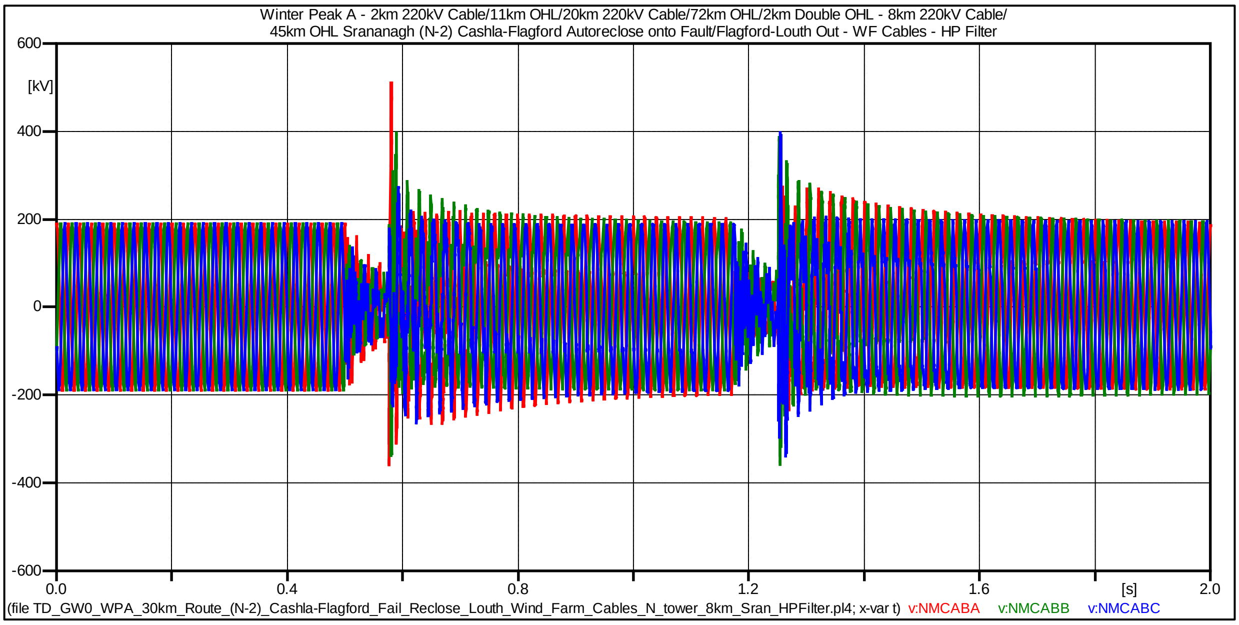

Figure 75: WPA - Length 30 km – North Mayo – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	487.69 kV (2.7157 pu)	449.073 kV (2.5pu)	Fail*
Temporary Overvoltage	270.97 kV (1.5089 pu)	287.32 kV (1.6 pu)	Pass

*Pass can be achieved with surge arrestors

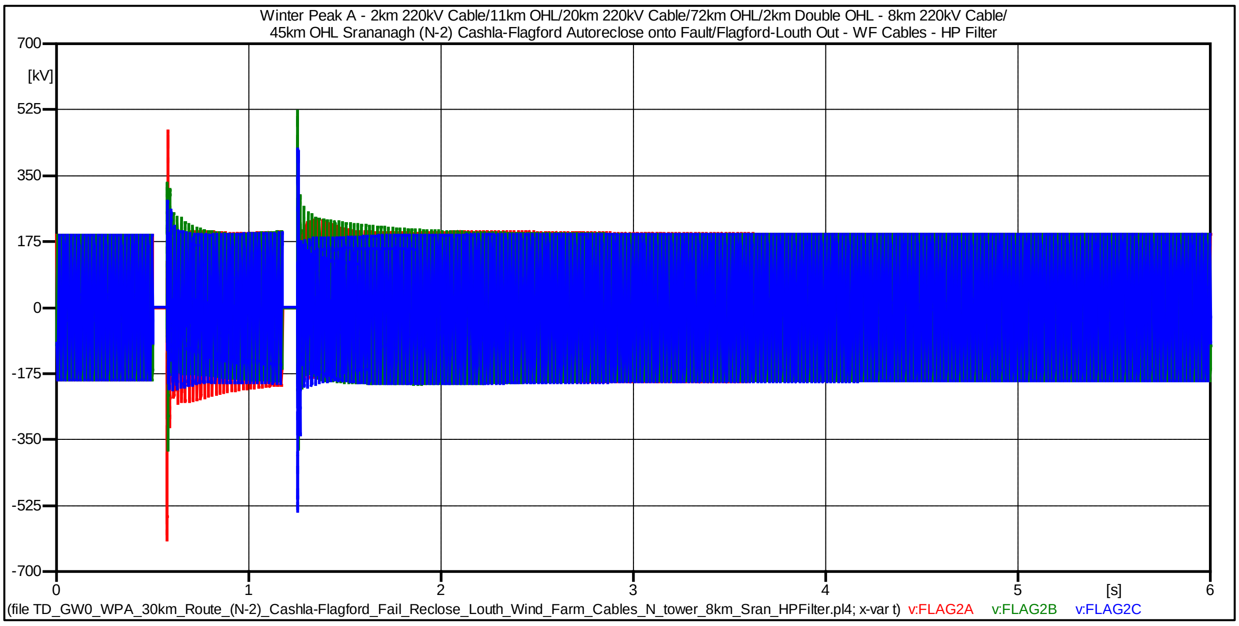

Figure 76: WPA - Length 30 km – Flagford – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-6s)

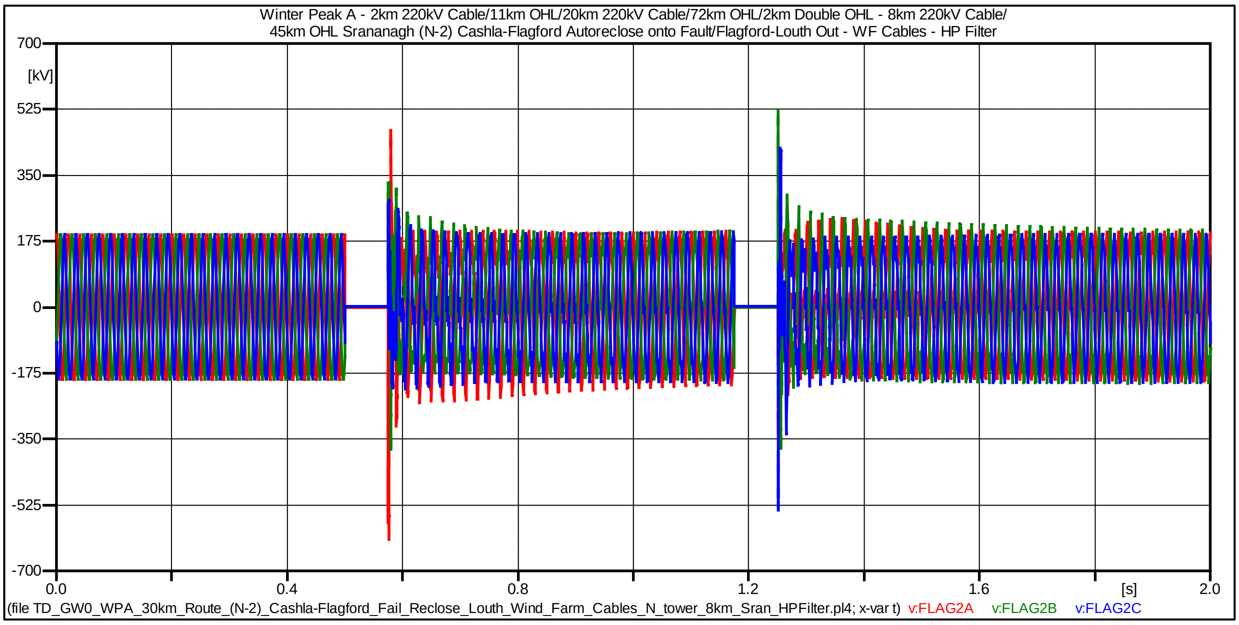

Figure 77: WPA - Length 30 km – Flagford – (N-1-1) Cashla-Flagford Auto Reclose onto Fault/Flagford-Louth Lines Out (0-2s)

Condition	**Maximum Value**	**Limit**	**Result**
Switching	329.99 kV (1.8375 pu)	449.073 kV (2.5pu)	Pass
Temporary Overvoltage	259.22 kV (1.4434 pu)	287.32 kV (1.6 pu)	Pass

5 DISCUSSION OF RESULTS

This section discusses the performance of each of the options and/or configurations studies. Summary tables are provided at the end of the chapter. The Grid West Partial AC Underground Solution studies initially focused on a hybrid overhead line and cable 400 kV solution between Flagford and North Mayo. This configuration produced resonance points below the third harmonic above the 1000 Ω threshold and the TOVs recorded were also above the limit. Therefore this configuration at 400 kV was considered as a fail.

As the Grid West circuit with a partial cable solution greater than 10 km at 400 kV had failed, and any possible shorter length at 400 kV was considered impractical with little material benefit[1], the studies focused on finding a more achievable 220 kV underground option. This was done by initially considering a 120 km 220 kV full cable solution (rounded up to the next 10 km from the length of 112.5km that had been identified for a fully undergrounded HVDC solution for Grid West in a separate study). A large number of studies were completed, including verification for both the Winter Peak A and Summer Valley B scenarios with the varying operating conditions, these included various (N-1) and (N-1-1) outages. The worst case from a system point of view was the (N-1-1) autoreclosure of the Cashla – Flagford 220 kV line onto a permanent fault during the outage of the Flagford-Louth 220 kV Line.

In order to comply with the EirGrid planning standard voltage limits, significant reactive power compensation was required in the order of 300 Mvar at North Mayo and 250 Mvar at Flagford.

With this network configuration, frequency scans showed that the first resonant point was below the second harmonic, which had a magnitude just below the 1000 Ω limit of concern. Consequently, time domain simulations were carried out to determine the magnitude of switching overvoltages and temporary overvoltages. The analysis found both the switching and temporary overvoltages were exceeding the predefined limits. Also a significant amount of reactive power was generated by the cable, producing a significant voltage increase at North Mayo, which lead to transformer saturation. Therefore, the full 220 kV underground cable solution was considered as a fail.

To streamline the examination of other shorter lengths of cable on the circuit, the most onerous network scenario, an (N-1-1) autoreclosure of the Cashla-Flagford 220 kV line onto a permanent fault during the outage of the Flagford-Louth 220 kV Line, was used. Additionally, wind farms at North Mayo, due to be connected by the project, were assumed to use 110 kV cables which were modelled using available planning data. It was shown in the full cable solution that the results were influenced significantly by small changes at North Mayo; therefore the wind farm connection configurations were added.

A 99.7 km cable and a 10.8 km overhead line Grid West circuit was then evaluated, with 175 Mvar reactor at North Mayo and 50 Mvar at Flagford substation. The frequency scan showed that the first resonance point was just below the second harmonic and a small amount below the 1000 Ω limit. Further investigation in the time domain simulation demonstrated that the switching overvoltages were above limits, together with the temporary overvoltages. These overvoltages were worst at North Mayo which was the weakest part of the studied network as this node is a radial circuit connected to the North Mayo wind farms. Therefore this configuration was considered as a fail.

[1] Given that 8 km of consequential undergrounding of the nearby Flagford – Srananagh 220 kV circuit was possible

Temporary overvoltages are partly dependent on the capacitance of the cable, therefore a reduced cable length of 80 km was evaluated. This was a split configuration with 72 km of cable from North Mayo, connected to a 30 km overhead line and finally a 8 km cable to Flagford. No mid point compensation was considered in these schemes due to the additional cost that would be driven with the associated requirement of a remote substation. It was also considered that it would not significantly affect the results, as compensation is provided at Flagford and North Mayo. Reactive power compensation of the order of 225Mvar was supplied at North Mayo and 150 Mvar at Flagford. The frequency scan shows that the first resonant point is just above the 2nd harmonic, showing that the first resonance frequency increases as the cable shortens. Switching overvoltages and temporary overvoltages in the time domain are above limits. Therefore this configuration was considered as a fail. It should be noted that the first resonant point should be above the 3rd harmonic for long term stability of the solution.

The cable length was then decreased to 70 km which, as with the previous length, was split into sections with a 62 km cable from North Mayo, then a 40 km overhead line and finally an 8km cable connecting to Flagford. Reactive power compensation of 200 Mvar at North Mayo and 125Mvar at Flagford was required. The frequency scan demonstrated that the frequency of the first resonant point increased to 109 Hz as the capacitance decreased with a shorter cable length. The time domain simulations showed that the TOVs were damped, but the magnitude of the TOVs and switching overvoltages were still above limits. As the first resonant point is below the 3rd harmonic and this case shows TOV issues, the cable length was considered to have failed.

The length of the cable was reduced by a further 12 km to 58 km using the same split section arrangement involving 50 km of cable from North Mayo, connected to an overhead line of length 52 km and finally a further 8 km of cable to Flagford. Reactive compensation was provided at North Mayo in the order of 175 Mvar and 50 Mvar at Flagford. The first resonant point increased in frequency to 114 Hz with a magnitude slightly below the 1000 Ω limit. Once again it is seen that as cable is shortened, the frequency is increasing towards the 3rd harmonic. This increase is important as it is evident that changes of the short circuit strength can move the first resonance point either towards the 3rd harmonic or down towards the 2nd harmonic. Hence this cable length would be difficult to manage for an enduring solution. Furthermore, the time domain simulations showed that the switching and TOVs are above the limit, therefore this case is considered to fail and another shorter length was selected for examination.

The cable section on Grid West was reduced by a further 18 km to 40 km, again using a split type arrangement of 32 km cable from North Mayo, 70 km overhead line and an 8 km cable connected into Flagford. Reactive compensation of 75 Mvar at North Mayo and 100 Mvar at Flagford was required. Upon the analysis of the frequency scan results, it was shown that the first resonant point increased to a frequency of 129Hz, but with a magnitude above the required limit. The time domain simulations showed that switching overvoltages and TOVs were above the limit. In this case partial transformer saturation also occurred. After analysis of the results of this case, it was determined that this configuration was a fail due to TOVs above limits and the location and magnitude of the first resonance point above the 1000 Ω limit and below the 3rd harmonic.

The cable section on Grid West was reduced by a further 10 km to 30 km, this arrangement considered a split solution consisting of a 22 km cable from North Mayo, connected to a 80 km overhead line and finally an 8 km cable into the Flagford substation. Reactors were fitted at North Mayo in the order of 60 Mvar and 50 Mvar at Flagford. The frequency scan showed that the first resonant point increased to just below the 3rd harmonic with a magnitude above the limit. The frequency scan shows that the optimum length for the cable should be between 20 km and 30 km in length. The time domain showed that the switching overvoltages are above the limit and the TOVs are only slightly above the limit. This confirms that the length for the cable should be between 20 km and 30 km in total length. As the results are slightly above the limit, the 30 km length was not considered acceptable and a 20 km length was evaluated.

A 20 km 220 kV cable length was evaluated, with a split solution of 12 km of cable from North Mayo, connecting to an overhead line of 90 km and then an 8km cable into the Flagford substation. Reactors of 40Mvar at North Mayo and 50Mvar at Flagford were considered. The frequency scan showed that the frequency of the first resonance point increased above the 3rd harmonic; however it remained significantly high.

The time domain simulations showed that the switching overvoltages were above limits, but these can be reduced with the application of surge arrestors at suitable places in the network. TOVs were slightly outside of the limits. This case slightly fails the evaluation criteria as a possible solution. The high magnitude of the first resonant point above the third harmonic is a concern, as this may produce issues if the system strength of the network changes (but the worst case scenario has been considered). Therefore this is not classed as the optimum solution as it is a marginal fail.

To achieve the optimum solution a 23 km cable was evaluated between North Mayo and Flagford. This was further split into more sections, to consider the landscape which the Grid West circuit traverses. The 23 km cable option consisted of five sections, an 8 km cable section from Flagford connected to a 64 km overhead line, then a 13 km cable and 18 km overhead line and finally a 2 km cable into the North Mayo substation. The frequency scan shows that the first resonant frequency point is slightly above the 3rd harmonic but it remains quite high. The time domain shows that the switching overvoltages are outside the limits and the TOVs are slightly outside the limits. Therefore this is classed as a marginal fail case. There is a concern with the magnitude of the first resonant point and the impact of system strength changes in future potentially moving this, but the worst case scenario has been considered.

As the 20 km, 23 km and 30 km cable solutions only failed marginally it was suggested that measures could be employed to mitigate the issues observed. It was also believed that these mitigation measures may enable the longer cable length of 30 km to be implemented. Hence the cable length chosen to be studied along with mitigation measures was 30 km.

The mitigation measures involved the use of a high pass filter connected at the Flagford 220 kV busbar. The length of the total Grid West cable sections was reduced to 22 km (20 km + 2 km), and due to constraints entering the Flagford substation it was decided that the existing 220 kV overhead line from Flagford to Srananagh would be cabled for the first 8 km. This would allow the approximately 2 km double circuit towers to be used for the existing Cashla – Flagford line and 2 km of the new Grid West circuit, along with the remaining 6 km of single circuit towers of the Flagford – Srananagh 220 kV line to be used for Grid West.

This split partial cable solution therefore consists of:

- The Flagford to Srananagh circuit with 8km 220 kV underground cable together with a 45 km overhead line. The existing Cashla – Flagford 220 kV line and 2 km of the new Grid West circuit will use the existing double circuit overhead line tower route;

- The Grid West circuit from North Mayo with 2 km cable, 11 km overhead line, 20 km cable, 72 km overhead line and finally the double circuit overhead line section to Flagford; and
- A simple high pass filter.

This high pass filter was designed with a corner frequency of 143 Hz to filter harmonics above the third harmonic. The frequency scan shows the first resonant point at 123 Hz with a magnitude well below the threshold. Time domain simulations show that the TOVs are well below the threshold. High voltage events produced by switching can be mitigated by the use of surge arrestors.

All the results discussed in this chapter are summarised in Tables 15, 16 and 17 below.

Cable length	Line length	Case	Voltage	Wind Farm Cables	Result	Comments
90km	10km	SVB	400kV	No	Fail	TOV Issues

Table 15: 400 kV cable evaluation

Cable length	Line length	Case	Voltage	Wind Farm Cables	Result	Comments
120km	0km	SVB	220kV	No	Fail	Transformer saturation Switching/TOV issues Below the 2nd harmonic
99.7km	10.8km	SVB	220kV	Yes	Fail	Switching/TOV issues Below the 2nd harmonic
80km (72+8)	30km	SVB	220kV	Yes	Fail	Switching/TOV issues Below the 3rd harmonic
70km (62+8)	40km	SVB	220kV	Yes	Fail	Switching/TOV issues Below the 3rd harmonic
58km (50+8)	52km	SVB	220kV	Yes	Fail	Switching/TOV issues Below the 3rd harmonic
40km (32+8)	70km	SVB	220kV	Yes	Fail	Switching/TOV issues Below the 3rd harmonic
30km (22+8)	80km	SVB	220kV	Yes	Fail	Switching/TOV issues Below the 3rd harmonic
20km (12+8)	90km	SVB	220kV	Yes	Fail	Above 3rd harmonic Short duration TOV issues

Table 16: 220 kV cable evaluation

Cable length	Line length	Case	Voltage	Wind Farm Cables	Result	Comments
23km (8+13+2)	82km (64+18)	SVB	220kV	Yes	Fail	Switching issues[3] Above 3rd harmonic Short duration TOV issues
30km[1] (2+20)[2]	85km (11+72+2)	SVB WPA	220kV	Yes	Pass	Switching issues[3]

Table 17: 220 kV Split Cable Evaluation

[1]High pass filter used.

[2]Flagford-Srananagh circuit – 8 km 220 kV + 45 km Overhead line.

[3]Surge arrestors must be installed to control switching transients.

6 CONCLUSIONS

The Grid West project is the reinforcement of the network from Flagford to North Mayo to facilitate the renewable generation expected to connect in the North Mayo region. A number of options are under consideration including an AC option that utilises a cable or a partial cable solution. The studies first considered a possible 400 kV solution, but this produced issues with temporary overvoltages.

The voltage was therefore decreased to lower the cable capacitance per unit length and reduce the reactive power generated. A full 220 kV cable option of 120 km produced a significant increase in the system voltage initiating transformer saturation at North Mayo and Flagford, coupled with temporary overvoltages also being witnessed in this case.

Evaluations focused on reducing the cable length and increasing the proportion of overhead line until a solution that did not violate the acceptance criteria was found. The criteria considered, for a pass condition that the first resonant point was above the 3rd harmonic, and all resonance points below this frequency to be within system impedance limits. Additionally, in the time domain the temporary overvoltages should be within acceptable limits and any overvoltages decay significantly within 1s.

The following additional partial cable lengths were considered: 99.7 km, 80 km, 70 km, 58 km, and 40 km; with many having several configurations. Every time the cable length decreased, the first resonant point increased in frequency, as the capacitance of the cable decreased. Switching overvoltages were an issue for most of the cable lengths but, in many cases, these can be controlled with the application of surge arrestors in the correct locations.

Partial cable lengths of 30 km and 20 km were studied and these showed that the 30 km was a borderline fail case. The frequency scan shows that the optimum length for the cable should be between 20 km and 30 km in length. The time domain shows that the switching overvoltages are above the limit and the TOVs are only slightly above the limit. The 20 km case frequency scan showed that the first resonance point was above the 3rd harmonic and time domain simulations demonstrated that temporary overvoltages were slightly above the limits and switching overvoltages generated can be controlled with the installation of surge arrestors.

As the 20 km, 23 km and 30 km cable solutions only failed marginally, mitigation measures were investigated on the 30 km case, which removed the unwanted temporary overvoltages observed. The installation of a high pass filter connected at the Flagford 220 kV busbar was required.

Operational and installation limitations were considered in this final evaluation. As it is possible to utilise consequential undergrounding on the nearby Flagford-Srananagh 220 kV line, the final option utilises 8 km of the total 30 km cable allowance in the area on this nearby circuit. This enables the Grid West circuit to avail of the corridor made available by this consequential undergrounding. The balance of 22 km of the 30 km cable allowance is utilised on Grid West itself, with the remainder of the Grid West circuit being overhead line.

Based on these studies and other parallel environmental considerations by EirGrid, the recommended configuration for a partial AC underground cable/overhead line solution of Grid West is a hybrid 220 kV circuit with the sections as listed in Table 18 below. A simple high pass filter was designed, with a corner frequency of 143 Hz to filter harmonics above 150 Hz. The frequency scan showed the first resonant point at 123 Hz at a magnitude well below the threshold. Time domain simulations confirmed that the resulting TOVs are well below the threshold. High voltage events produced by switching can be mitigated by the use of surge arrestors.

Case	**Route**	**Section 1**	**Section 2**	**Section 3**	**Section 4**	**Section 5**
30 km	Flagford to North Mayo (22km Cable)	2km Double circuit/OHL	72km OHL	20km Cable	11km OHL	2km Cable
	Flagford to Srananagh (8km)	8km Cable	45km OHL			

Table 18: Recommended 220 kV Hybrid solution sections

The objective of the study was to find the maximum possible cable length. The optimal solution incorporates:

- Overall cable length of 30 km (22 km on Grid West itself and consequential cabling of 8 km on the existing Flagford-Srananagh 220 kV line)
- A filter at Flagford 220 kV busbar
- 100 Mvar reactive support at North Mayo
- 50 Mvar reactive support at Flagford.

Switching overvoltages must be controlled with the application of surge arrestors.

7 RECOMMENDATIONS

It was concluded that the preferred technical solution of a partial AC underground cable/overhead line solution of Grid West is a hybrid 220 kV circuit with 22 km of cable on Grid West and 8 km cable on the existing Flagford Srananagh 220 kV line, with the additional mitigation of a high pass filter. This configuration achieves the maximum possible length for cabling in the area with the introduction of Grid West. This solution also requires 100 Mvar of reactive support at North Mayo and 50 Mvar of reactive support at Flagford. This solution option has been evaluated for various outages and system conditions for both the Winter Peak A and Summer Valley B cases.

It is recommended that surge arrestors are placed on the 220 kV circuit at North Mayo, on the 220 kV busbar at Flagford and on the 220 kV side of the Flagford-Srananagh transformer. Energy ratings and exact locations of surge arrestors should be confirmed in additional insulation co-ordination studies.

It is recommended, that when more detailed design information is available for the cable and the wind farm connection configuration at North Mayo, a suite of studies are completed to confirm this partial 220 kV AC cable solution with additional scenarios and network possibilities.

During the study only a simple filter design was considered, therefore it is recommended that a full design of a filter is completed to ensure lower losses and a more practical and cost effective design to be achieved.

NOTES:
