Needs Report

Capital Project 966

July 2017

EIRGRID

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2 Introduction

EirGrid follow a six step approach when we develop and implement the best performing solution option to any identified transmission network problem. This six step approach is described in the document 'Have Your Say' published on EirGrid's website[1]. The six steps are shown on a high-level in Figure 1. Each step has a distinct purpose with defined deliverables.

The Needs Report (this document) is a deliverable for Step 1. It will describe an identified transmission network problem. In this case it involves a transmission network problem regarding the transfer of power across the existing 400 kV transmission network from west to east and the transfer of this power within in the transmission network as it reaches the east coast. The issues encountered involve both capacity and voltage.

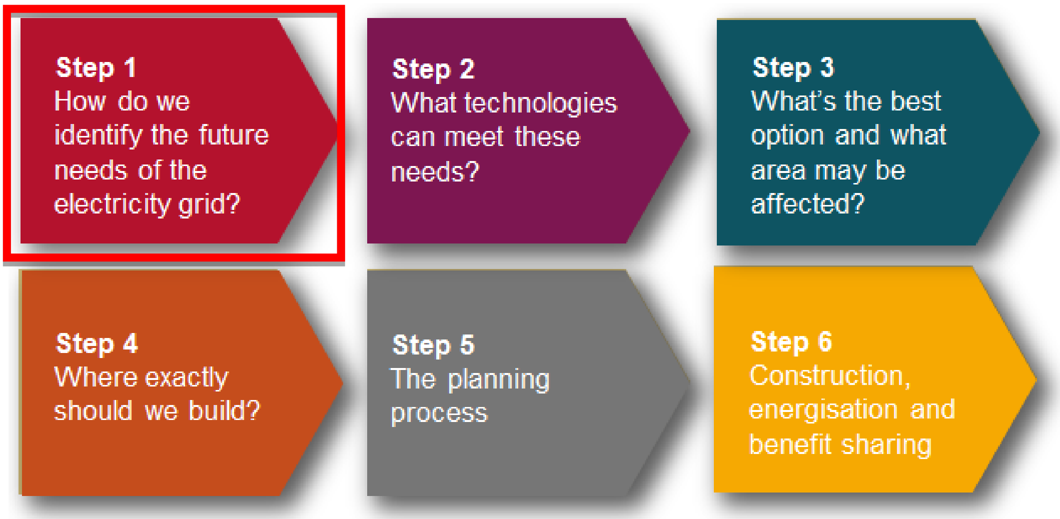

Figure 1 *High Level Project Development Process*

2.1 Our statutory role

EirGrid is the national electricity Transmission System Operator (TSO) for Ireland. Our role and responsibilities are set out in Statutory Instrument No. 445 of 2000 (as amended); in particular, Article 8(1) (a) gives EirGrid, the exclusive statutory function:

"To operate and ensure the maintenance of and, if necessary, develop a safe, secure, reliable, economical, and efficient electricity transmission system, and to explore and develop opportunities for interconnection of its system with other systems, in all cases

[1] http://www.eirgridgroup.com/the-grid/have-your-say/

with a view to ensuring that all reasonable demands for electricity are met and having due regard for the environment."

Furthermore, as TSO, we are statutorily obliged to offer terms and enter into agreements, where appropriate and in accordance with regulatory direction, with those using and seeking to use the transmission system. Upon acceptance of connection offers by prospective network generators and demand users, we must develop the electricity transmission network to ensure it is suitable for those connections.

3 Regulatory Targets and Policy

As mentioned previously, one of our roles is to plan the development of the electricity transmission grid to meet the future needs of society. To do this we consider how electricity may be used and generated years from now and what this means for the electricity grid of today.

The key to this process is considering the range of possible ways that energy usage may change in the future. This means that we will analyse different scenarios that would represent this. Using this approach will allow us to efficiently develop the grid taking account of the uncertainties associated with the future demand for electricity and the future location and technology used to generate electricity.

To help us account of the uncertainties of the future Tomorrow's Energy Scenarios 2017[2] have been developed. We did this using our own experience and significant input received from government departments and agencies, energy research groups and industry representatives. These scenarios have been out for public consultation inviting contributions from energy industry, members of the public and interested groups. The four scenarios are named Steady Evolution, Low Carbon Living, Slow Change and Consumer Action.

The drivers for the need and assumptions used in the analysis for this need are in line with the identified Tomorrow's Energy Scenarios. In particular the scenarios Steady Evolution and Low Carbon Living have specific assumptions that have been included:

- The demand levels in the cases were generally consistent with the demand levels presented in the Forecast Statement 2015-2024 (GCS 15-24). However a number of new and existing customers in the Dublin region have requested new connections or increases in existing connection agreements. This assumption is very similar to the assumptions used in the Steady Evolution scenario.
- Connection of data centres has been accounted for in line with latest known information at the start of the analysis (2016). In total, 900 MW of data centres have been assumed in the cases. This figure is based on executed connection agreements and offered connection agreements. This assumption is in line with the assumed data centre demand figure used in the Steady Evolution scenario, which is 850 MVA.

[2] Tomorrow's Energy Scenarios http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-Tomorrows-Energy-Scenarios-Report-2017.pdf

- The connection of renewable generation to meet the Governance's renewable energy target of meeting 40% electricity demand from renewable generation by 2020 - covered by the Steady Evolution scenario.
- Repowering of coal fired generation – covered by the Low carbon Living scenario.
- Explore and develop opportunities for interconnection of its system with other systems as set out in our licence as Transmission System Operator (TSO) for Ireland. To reflect this, consideration has been given to the construction of additional interconnection on the south coast. In this particular instance an additional 700 MW interconnector at Knockraha in Co Cork - covered by the Steady Evolution scenario.

3.1 Scenarios analysed

The above mentioned assumptions were used to create the cases that were subsequently analysed. In line with our statutory obligation the future scenarios are then analysed to establish that the transmission system is in compliance with the Transmission System Security Planning Standards (TSSPS). If the system is in breach of any of these standards the issue must be addressed

The year 2025 was chosen for analysis as it was deemed an appropriate point in time to assess the long term strategic needs of the system and to design reinforcement options to address those needs. This year has been determined as the earliest stable point in the future. By this time it is expected that a number of network reinforcements will have been implemented. Gate 3 renewable generation will have been integrated into the system and a number of new loads will have been connected into the Dublin network.

Some of the reinforcements that have been assumed to be energised were the series compensation of the existing 400 kV circuits and a 400 kV sub-marine cable across the Shannon Estuary between Moneypoint 400 kV station and Kilpaddoge 220 kV station.

Three seasonal variations were studied to examine the effect of different load profiles, Winter Peak, Summer Valley and Summer Peak. Summer and Winter Peak represent points in time when the system is most heavily loaded and therefore the time when there is most likely to be thermal issues on the system. Summer Valley was also assessed to detect voltage issues which may arise with a lightly loaded system.

The existing Moyle Interconnector and East-West Interconnector (EWIC) were assumed available in 2025. Moyle and EWIC will be assumed to have 500 MW import/export capacity.

We have assumed that an additional interconnector may connect in the south. Under certain operating circumstances, connection of this third interconnector may lead to increased transfers across the transmission system. Likewise, the unavailability of this additional interconnector in the south may also cause increased transfers across the transmission system. Scenarios were created to capture the most extreme operating conditions using the interconnectors. We have model the interconnectors as either importing or exporting simultaneously.

Therefore, during import we have assumed three interconnectors. During export scenarios the most onerous situation would be the transfer of renewable generation in the south and west across the country for export through EWIC and Moyle. Therefore in the Export case it was assumed that the third interconnector in the south was unavailable, to ensure the worst case scenario.

An alternative way to operate the interconnector would have been to create a dispatch where the power is 'wheeling'. This would mean that the power is flowing through the Irish network and on to the National Grid in the UK. It was considered that a 'wheeling' scenario would be a bit too extreme and was not analysed.

A summer peak case and a winter peak case with no interconnection was used was also included.

Seven separate cases were created in order to assess the system and the need identified, namely:

- 2025 Winter peak – Exporting on two interconnectors
- 2025 Winter peak – Importing on three interconnectors
- 2025 Winter peak – No importing or exporting on interconnectors
- 2025 Summer peak – Exporting on two interconnectors
- 2025 Summer peak – Importing on three interconnectors
- 2025 Summer peak – No importing or exporting on interconnectors
- 2025 Summer Valley – Exporting on two interconnectors

4 Statement of Need

With regard to the assumptions identified in Tomorrow's Energy Scenarios there are two key drivers that highlight the need to further development of the transmission system, namely:

1. **Increased demand on East coast**. An increase in electricity demand as part of natural growth is expected. In addition, there is a demand increase in the order of 900 MW due to the connection of data centres. This is based on executed and offered connection agreements in the counties Kildare, Meath and Dublin. Part of this demand is expected to start to connect to the system in 2017 and ramp up to the total demand figure in 2025. The interest is high and it is expected that this trend will continue with further requests for connection.

2. **Integration of generation in South and South West.** Significant levels of new renewable generation have connected or are in the process of connecting to the transmission and distribution system in the south and south west of Ireland. This is also where the newer and more cost effective existing conventional generation units are located. This results in that a significant portion of the generation sources are located in the south and south west of Ireland away from the main demand centres. The power produced will hence have to be transported to get to where it is needed.

These two drivers introduce cross country power flows on the existing transmission system from the West to the East coast. These cross country power flows will start to appear when the renewable generation and the demand increases connect to the system. The current indications as of July 2017 are that nearly 1000 MW of wind is already connected in the south west[3] and that an additional 1600 MW of wind in this area is due to connect between now and 2025. Similarly, for the demand increase, 90 MW is due to connect in 2017 and this will ramp up to 900 MW between now and 2025.

Under these circumstances the system analysis indicates that the network is experiencing significant violations of the compliance with the Transmission System Security Planning Standards (TSSPS). The violations occur for the unplanned loss of any of the existing 400 kV circuits between Moneypoint 400 kV station in the West and

[3] South West refer to counties Clare, Cork, Kerry, Limerick, Tipperary

Dunstown 400 kV in County Kildare and Woodland 400 kV station in County Meath in the East.

The violations relates to two aspects:

- Bringing required power to the East coast; and
- Transferring this power within Counties Dublin, Kildare and Meath once the power reach the east coast.

The main nodes for distributing the power around the capital and its surrounding areas are Carrickmines, Dunstown, Maynooth and Woodland transmission stations. The stations are highlighted in the Figure 2.The network connecting these nodes becomes essential for distributing the power around the capital.

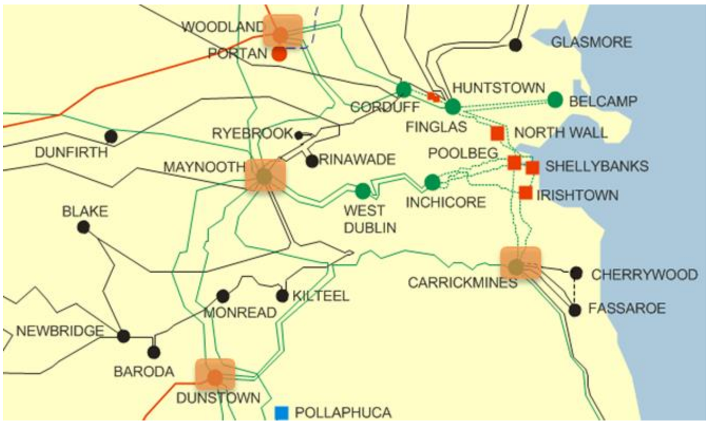

Figure 2 *Main transmission stations for distributing power around the capital.*

The violations observed can be further divided into three technical issues:

– Thermal overloads

For unplanned losses of any of the 400 kV circuits between the west coast and the east coast the following circuits are overloaded, Maynooth – Woodland 220 kV, Dunstown – Maynooth 220 kV, Maynooth – Ryebrook 110 kV, Killonan – Shannonbridge 220 kV, Maynooth – Shannonbridge 220 kV, Cashla – Prospect 220 kV and Bracklone – Portlaoise 110 kV. These circuits are also overloaded for maintenance trip combinations despite remedial action using generation dispatch of 400 MW.

– Voltage collapse

Voltage collapse means that the voltage cannot be maintained in the transmission system. The voltage in the transmission system is supported by reactive power. During certain operating conditions, a lack of sufficient reactive power in Counties Dublin, Kildare and Meath area have been identified.

– Large phase angles

Large phase angles are observed due to high power transfers on existing lines and the low connectivity between transmission stations during certain operating conditions

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5 Detailed analysis

This section will describe in detail the network problems which were identified for each case analysed. To be able to fully investigate and describe the need identified, generation re-dispatch was required in some cases.

5.1 Winter Export

5.1.1 Description of the case

In this case the two existing interconnectors, Moyle in Northern Ireland and EWIC on the east coast north of Dublin, are exporting, 500 MW each. The winter export dispatch consisted of a high wind dispatch of 95% in the south west and 40% elsewhere on the system. In order to demonstrate the most onerous credible scenarios there were relatively low levels of conventional generation close to load centres with two generators dispatched in Dublin and three generators in Northern Ireland. The remaining power requirements to supply the peak system demand along with 1000 MW of exported generation was provided by conventional generators in the south and west at Great Island, Whitegate, Aghada and Moneypoint. This creates a large cross county electricity flow from the south towards the east coast of Ireland. The SNSP[4] in the case is 72%.

5.1.2 Network problems

Power system analysis indicate heavy loading on the existing 400 kV circuits traversing the country with an intact system and the generation dispatch described in section 5.1.1. The existing 220 kV circuits traversing from the south west to the east coast are also experiencing heavy loading. It should, however, be noted that the circuits are not overloaded. This means that they are still operating within their power carrying capacity. Typical loading for transmission circuits are in the range of 30-40 %. This is to allow for redistribution of the power flow on a circuit following a contingency of that circuit. The loading of the 400 kV circuits in this case, intact system, is up to 56% with 220 kV circuits in the south east loaded up to 58%. These heavy loaded circuits are highlighted in Figure 3. A loss of any of the highlighted circuits or any generator in the

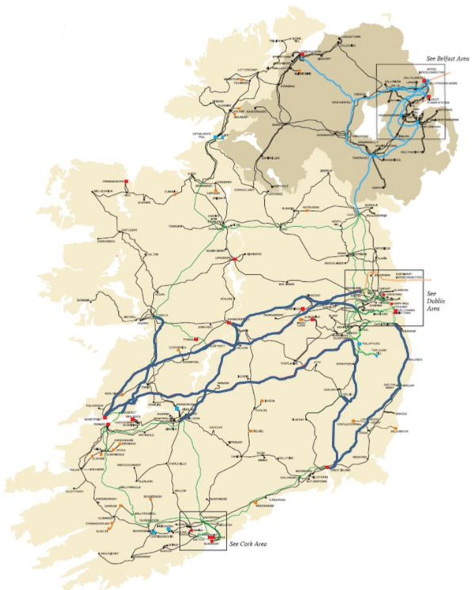

Figure 3 *Heavy loaded circuits (>50%) in an intact system Winter Export*

[4] Simultaneous Non Synchronous Penetration

Dublin region leads to major voltage issues and voltage collapse for 18 single contingencies (N-1). A list of these contingencies is included in Appendix 1A.

In order to avoid voltage collapse, an additional circa 850 MVars of reactive support would be required in the Dublin region. This value was determined by using four ‘dummy generators (at 0 MW)’ with a voltage setpoint of 1.02 pu in the Dublin network. Out of this, circa 90 Mvars would be required in the intact system for the generators in the Dublin area to move away from providing maximum reactive support and maintain voltages of 1.02 pu. With this reactive support included voltage collapse could be prevented and single contingencies (N-1) could be analysed.

With the reactive support included, a number of thermal overloads were identified. They are outlined in Appendix 1B. The thermal overloads were all caused by the single contingency (N-1) of Woodland – Oldstreet 400 kV circuit. The worst thermal overloads were observed on Maynooth – Woodland 220 kV circuit and Dunstown - Maynooth cct 2 220 kV circuit, with a loading of 168% and 127% respectively over their rated capacity. It is worth mentioning that Maynooth 220 kV station is planned to be operated in a ring arrangement by 2025 after extensive refurbishment and reconfiguration. When this project is completed the overload observed on the Dunstown - Maynooth cct 2 220 kV circuit will be reduced to 104%, and overloads on the Maynooth – Woodland 220 kV circuit will be 153%.

The same contingency caused a large phase angle difference of 40° between Oldstreet and Woodland 400 kV stations post the single contingency (N-1). The large phase angle would prevent auto-reclosing which would have impacts on system security.

5.1.3 Re-dispatched Case

Another way of preventing the voltage collapse and provide reactive support where it is needed, is to re-dispatch existing generation. This principal could drive high operational cost as generators not normally in merit would be scheduled to provide necessary voltage support. The generation in the case was adjusted until all N-1 analysis could be completed without voltage collapse occurring. The re-dispatch included the reduction of renewable and conventional generation levels in the south west and replaced with generation in the Dublin and Belfast regions. This required a reduction in generation at Moneypoint from 730 MW to 315 MW. This generation was replaced by two additional conventional generators in Dublin and one additional in Northern Ireland bringing the total of conventional generators in each region to four. The extra conventional generators provide voltage support in Dublin preventing voltage collapse for any single contingency (N-1) including the loss of a single generator. The extra generation in Dublin would reduce the loading on the circuits traversing the country, especially the 400 kV network. With this dispatch the loading of Woodland - Oldstreet and Laois - Dunstown 400 kV circuits in this case reduced to 47% and 26% respectively while the 220 kV circuits in the south east maintained a loading of up to 56%. It can be seen that the Woodland – Oldstreet 400 kV circuit (the most northern circuit) carries more power than the parallel Laois - Dunstown 400 kV circuit. This is due to the system topology at the end of the circuits, especially the fact that the exporting Interconnectors Moyle in Northern Ireland and EWIC connecting at Woodland are located north of Dublin.

The re-dispatch prevented any voltage issues, but thermal overloads and large phase angles remained. They are outlined in Appendix 1C. The thermal overloads were all caused by the single contingency (N-1) of Woodland – Oldstreet 400 kV circuit. The worst thermal overload was observed on Maynooth – Woodland 220 kV circuit with a loading of 127% over its rated capacity. The same contingency caused a large phase angle difference of 34° between Oldstreet and Woodland 400 kV stations post the single contingency (N-1). An angle of 34° is below the limit set in our Operating Security Standards (OSS) of 40°. In the Irish system this is still a relatively high angle to try to close a circuit breaker onto. The large phase angle would prevent auto-reclosing which would have impacts on system security.

5.2 Winter Import

5.2.1 Description of the case

This case have three interconnectors, Moyle in Northern Ireland (500 MW), EWIC on the east coast north of Dublin (500 MW), and an additional 700 MW interconnector located at Knockraha in Co. Cork. They are all importing at maximum capacity, which corresponds to 1700 MW in total. The wind was dispatched at 95% in the south west and 10% elsewhere. Two conventional generators were dispatched in Dublin and three in Northern Ireland. The remaining power requirements were made up by conventional generators in Great Island, Whitegate and Moneypoint in the South and West. When this import case is compared with the export case, this case has 2700 MW less power that is required to be generated and transported on the transmission network.

5.2.2 Network problems

Voltage collapse occurred for seven single contingencies (N-1). This included the loss of any Dublin generator and the loss of Moneypoint – Laois 400 kV circuit. A list of these contingencies is included in Appendix 1D. In order to avoid voltage collapse an additional circa 175 Mvars of reactive support would need to be required in the Dublin region. This value is based on a voltage setpoint of 1.02 pu at Belcamp 110 kV bus. With this reactive support included voltage collapse could be prevented and single contingencies (N-1) could be analysed. The only contingency that caused a thermal overload is listed in Appendix 1E. The overload observed is a local problem around Waterford and will not be addressed as part of this identified need.

5.2.3 Re-dispatched Case

Another way of preventing the voltage collapse and provide more reactive power where it is needed, is to re-dispatch generation. The redistribution of generation in the form of dispatching a third generator in Dublin and reducing thermal generation in the south supports the network and prevents voltage collapse for all contingencies. No other changes were made to this dispatch and the same local overload remains in Waterford as listed in Appendix 1E

A phase angle difference of 21° can be seen between Laois and Moneypoint 400 kV stations post the single contingency (N-1) of Laois- Moneypoint 400 kV circuit. A phase angle difference of 18° can be seen between Oldstreet and Woodland 400 kV stations post the single contingency (N-1) of Woodland – Oldstreet 400 kV circuit.

5.3 Winter No Import or Export on Interconnectors

5.3.1 Description of the Case

In this case the two existing interconnectors, Moyle in Northern Ireland and EWIC on the east coast north of Dublin, are not used for import or export. Nor are they offering reactive support. The winter dispatch consisted of a high wind dispatch of 95% in the south west and 40% elsewhere on the system. There were relatively low levels of conventional generation close to load centres with two generators dispatched in Dublin and two generators in Northern Ireland. The remaining power requirements were made up by conventional generators in Great Island, Whitegate and Moneypoint in the South and West.

5.3.2 Network problems

No network violations were identified for this dispatch.

5.4 Summer Export

5.4.1 Description of the case

In this case the two existing interconnectors, Moyle in Northern Ireland and EWIC on the east coast north of Dublin, are exporting, 500 MW each. The summer export dispatch consisted of a high wind dispatch of 85% in the south west and 21% elsewhere on the system. There were relatively low levels of conventional generation close to load centres with two generators dispatched in Dublin and three generators in Northern Ireland. The remaining power requirements to supply the peak system demand along with 1000 MW of exported generation was provided by conventional generators in the south and west at Great Island, Whitegate, Aghada and Moneypoint. This creates a large regional electricity flows from the south towards the east coast of Ireland.

5.4.2 Network problems

With this dispatch voltage collapse was observed for the single contingency (N-1) of Oldstreet – Woodland 400 kV circuit. In order to avoid voltage collapse an additional circa 240 Mvars of reactive support would be required in the Dublin region. This value is based on a voltage setpoint of 1.02 pu at two locations in the Dublin Network. With this reactive support included voltage collapse for this contingency could be prevented and results reported.

With the reactive support included, thermal overloads were identified throughout the network for a number of single contingencies (N-1). The thermal overloads were mostly caused by the single contingencies (N-1) of the 400 kV circuits. They are outlined in Appendix 1F. The worst thermal overloads were observed on Maynooth – Woodland 220 kV circuit and Dunstown – Maynooth 220 kV circuit, with a loading of 201% and 149% respectively over their rated capacity. It is also worth mentioning that the Maynooth – Ryebrook 110 kV circuit, is overloaded to 113% of its rated capacity for the loss of Oldstreet – Woodland 400 kV circuit. This circuit is already uprated to the largest conductor allowed on the 110 kV system. Other overloaded circuits are Killonan – Shannonbridge 220 kV, Maynooth – Shannonbridge 220 kV, Cashla – Prospect 220 kV and Bracklone – Portlaoise 110 kV.

The same contingency caused a large phase angle difference of 40° between Oldstreet and Woodland 400 kV stations post the single contingency (N-1). The large phase angle would prevent auto-reclosing which would have impacts on system security.

5.4.3 Re-dispatched Case

Again, to prevent voltage collapse and provide more reactive support where it is needed, a generation re-dispatch was carried out. The generation in the case was adjusted until all single contingency analysis could be completed without voltage collapse occurring. The re-dispatch included the reduction of renewable and conventional generation levels in the south west and replaced with generation in the Dublin and Belfast regions. The renewable generation in the south west was dispatched at 81%, 4% elsewhere in the Republic of Ireland (ROI) and 18% in Northern Ireland (NI). This dispatch was selected to maintain high west-east flows while adding support close to load centres. The reduced wind generation was replaced by one additional conventional generator in Dublin and two additional generators in Northern Ireland. The extra conventional generators provide voltage support in Dublin preventing voltage collapse for any single contingency (N-1). The remainder of the power came from Great Island, Whitegate, Aghada and Moneypoint in the south and west.

Following re-dispatch a single contingency (N-1) analysis was carried out. The results indicated that there was a number of thermal overloads were observed for contingencies of the 400 kV network, but no voltage issues observed for this case. The results are outlined in Appendix 1G. The worst contingency is the loss of Oldstreet – Woodland 400 kV circuit which caused overloads on the 220 kV network between Dunstown and Woodland with Woodland – Maynooth and Dunstown – Maynooth loaded to 150% and 121% respectively of their rated capacity. Other overloaded circuits are Cashla – Prospect 220 kV and Bracklone – Portlaoise 110 kV.

A phase angle difference of 30° can be seen between Oldstreet and Woodland 400 kV stations post the single contingency (N-1) of Oldstreet – Woodland 400 kV circuit. The large phase angle would prevent auto-reclosing which would have impacts on system security.

5.4.4 Maintenance Trip combinations (N-1-1)

Maintenance - trip (N-1-1) analysis was conducted on the case which was adjusted so no intact system violations occurred. A list of circuits considered for the maintenance trip (N-1-1) analysis can be found in Appendix 2A. The results of the analysis indicated a number of maintenance - trip (N-1-1) combinations with non – convergence or voltage collapse. Appendix 2B list all the non – convergences observed for the maintenance – trip combinations. To prepare for maintenance of circuits in the system, a generation re-dispatch of a maximum of 400 MW is allowed. Wind generation of 387 MW in the south west was replaced with generation from Poolbeg in Dublin. When this was done almost all cases converged. The exceptions were some maintenance trip combinations of the 400 kV circuits, which still cause voltage collapse. The results from the maintenance trip analysis (following re-dispatch) are listed in Appendix 2C. The circuits which were overloaded are highlighted in Figure 4. It should be noted that the violations which occurred for N-1 contingencies were exacerbated by the maintenance trip combinations.

These overloads occurred for a large number of maintenance trip combinations (N-1-1) and therefore only the worst overloads have been reported in the results.

Overloads occur during maintenance trip combinations of Oldstreet – Woodland 400 kV and Inchicore – Irishtown 220 kV / Maynooth Gorman 220 kV. This combination will limit the paths for the power to flow and as such limit the power transfer capability in Dublin. For these combinations the Woodland – Maynooth 220 kV and Dunstown – Maynooth 220 kV will see loadings of 170% and 140% of their ratings respectively.

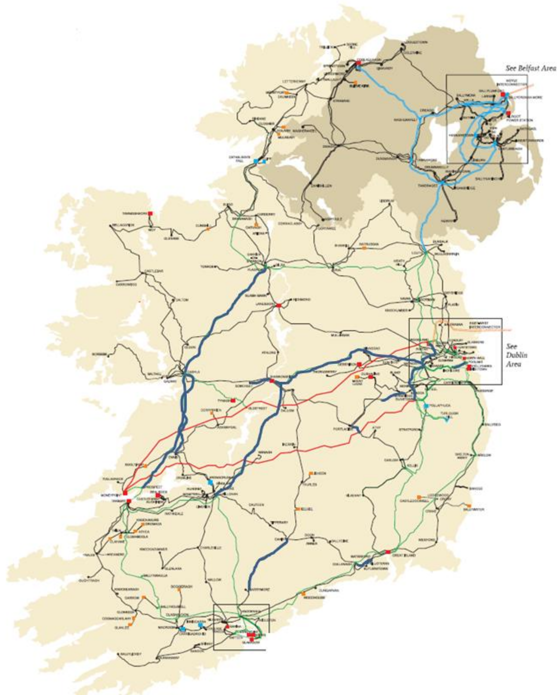

Figure 4 *N-1-1 overloads which could not be mitigated through the re-dispatch of 400 MW of generation*

In addition, some of the maintenance trip combinations of the 400 kV circuits cause thermal overloads on the 220 kV circuits traversing the country between Killonan and Maynooth 220 kV stations, especially Killonan - Shannonbridge between 117 – 139% of its rated capacity and Maynooth – Shannonbridge between 118 – 139% of its rated capacity. Cashla – Prospect 220 kV circuit also see overloads up to 169%. Maintenance trip combinations of Cullenagh – Great Island 220 kV and other circuits in the south region cause an overload on Killoteran – Waterford 110 kV circuit. Barrymore – Cahir 110 kV circuit is loaded up to 131% for the loss of Ballynahulla – Knockanure 220 kV or Knockanure – Kilpaddoge 220 kV circuits. These overloads are observed despite allowing 400 MW of generation re-dispatch.

5.5 Summer Import

5.5.1 Description of the case

This case have three interconnectors, Moyle in Northern Ireland (500 MW), EWIC on the east coast north of Dublin (500 MW), and an additional 700 MW interconnector located at Knockraha in Co. Cork. They are all importing at maximum capacity which corresponds to 1700 MW. The wind was dispatched at 85% in the south west and elsewhere in Republic of Ireland at 4% and 3% in Northern Ireland. This dispatch was selected to maintain high west-east flows. Two conventional generators were dispatched in Dublin and two in Northern Ireland. The remaining power requirements were made up by conventional generators in Great Island, Aghada in the South. When this import case is compared with the export case, this case has 2700 MW less power that is required to be generated and transported on the transmission network.

5.5.2 Network problems

There was no voltage issues observed for this case. The contingency analysis indicated thermal overloads were observed in the south east, namely Waterford – Killoteran and Waterford – Cullenagh 110 kV circuits. These overloads are being addressed by an independent needs assessment. Thermal overloads were also observed on the 220 kV circuits between Corduff – Finglas – Woodland - Clonee for the loss of a parallel circuit. These overloads were due to the level of generation being fed through Woodland 400 kV station from EWIC and the renewable and conventional generation coming from the south and west. A sensitivity assessment was carried out to examine the effect of the additional generation from the third interconnector. By removing this interconnector, and dispatching generation in Dublin in its place, the overloads between Corduff and Woodland could be removed. A list of all overloads can be found in Appendix 1H.

5.5.3 Maintenance trip combinations (N-1-1)

Maintenance trip analysis was conducted on the less onerous Summer Import Case without an interconnector at Knockraha included. The less onerous case was chosen due to the high level for non-convergence for N-1 on the more onerous case. The interconnector was excluded as N-1 overloads associated purely with this new infeed had been identified in the previous analysis. A list of circuits considered for the maintenance trip (N-1-1) analysis can be found in Appendix 2A. The results of the analysis indicated a large number of maintenance - trip (N-1-1) combinations with overloads, non – convergence or voltage collapse. Appendix 2D lists all the non – convergences observed for the maintenance – trip combinations. To prepare for maintenance of circuits in the system, a generation re-dispatch of a maximum of 400 MW is allowed. Wind generation of 387 MW in the south west was replaced with generation from Poolbeg in Dublin. When this was done all cases converged. All thermal overloads which remained following the re-dispatch of generation are listed in Appendix 2E. The overloading of Killoteran – Waterford featured once more. In addition the Cashla – Prospect 220 kV circuit was loaded to 114% for the maintenance trip combination of Moneypoint – Oldstreet and Laois – Moneypoint 400 kV circuits.

5.6 Summer No Import or Export on Interconnectors

5.6.1 Description of the case

In this case the two existing interconnectors, Moyle in Northern Ireland and EWIC on the east coast north of Dublin, are not used for import or export. Nor are they offering reactive support. The summer dispatch consisted of a high wind dispatch of 95% in the south west and 21% elsewhere on the system. There were relatively low levels of conventional generation close to load centres with two generators dispatched in Dublin and two generators in Northern Ireland. The remaining power requirement to supply the peak system demand was provided by conventional generators in the south and west at Great Island and Moneypoint. This creates a large cross country electricity flows from the south towards the east coast of Ireland.

5.6.2 Network problems

There was no voltage issues observed for this case. The single contingency analysis indicated thermal overloads on three circuits. An N-1 on Oldstreet - Woodland 400 kV circuit caused the Woodland – Maynooth 220 kV circuit to be loaded to 119%.Bracklone – Portlaoise 110 kV circuit was loaded to 116.5% for an N-1 of Dunstown – Laois 400 kV circuit. Finally Bandon-Dunmanway 110 kV circuit was loaded to 114% for the loss of Clashavoon – Knockraha 220 kV circuit. The details of these overloads are included in Appendix 1I.

5.6.3 Maintenance Trip Combinations (N-1-1)

Maintenance trip analysis was conducted on the Summer Night Valley Case, the list of circuits included in the maintenance can be found in Appendix 2A.

A large number of maintenance trip combinations were observed. To prepare for maintenance of circuits in the system, a generation re-dispatch of a maximum of 400 MW is allowed. The case was re-dispatched with a reduction of 391 MW of wind generation from the south west and replaced with generation from Poolbeg in Dublin. All thermal overloads which remained following the re-dispatch of generation are listed in Appendix 2F.

5.7 Summer Valley

5.7.1 Description of the case

In this case the two existing interconnectors, Moyle in Northern Ireland and EWIC on the east coast, are each exporting 500 MW. In this case wind in the south west was dispatched at 58% with wind elsewhere on the system at 21%. Generation in Dublin was supplied by Dublin Bay and two generators in Northern Ireland. Great Island, Whitegate and Aghada provided power in the south and east.

5.7.2 Network problems

There were no voltage issues observed for this case. An N-1 on Oldstreet - Woodland 400 kV circuit caused the Woodland – Maynooth 220 kV circuit to be loaded to 118%. No other overloads were observed. The results are outlined in Appendix 1I

5.7.3 Maintenance trip combinations (N-1-1)

Maintenance trip analysis was conducted on the Summer Night Valley Case, the list of circuits included in the maintenance can be found in Appendix 2A.

A large number of maintenance trip combinations were observed. To prepare for maintenance of circuits in the system, a generation re-dispatch of a maximum of 400 MW is allowed. The case was re-dispatched with 392 MW of wind generation from the south west and replaced with generation from Poolbeg in Dublin.

All thermal overloads which remained following the re-dispatch of generation are listed in Appendix 2G. A large number of maintenance trip combinations caused overloads on the Maynooth – Woodland 220 kV circuit. Only the worst case combination has been included in Appendix 2G. The worst overload seen on this circuit was 135% for the maintenance of Gorman – Maynooth 220 kV and a subsequent tripping of Oldstreet – Woodland 400 kV circuit. Thermal overloads on Killonan - Shannonbridge (111% of its rated capacity) and Maynooth – Shannonbridge (between 118 – 126% of its rated capacity) and Maynooth – Ryebrook 110 kV (between 113 – 128% of its rated capacity) has been observed for maintenance trip combinations of various 400 kV circuits and 220 kV circuits.

5.8 High Impact Low Probability Analysis

High Impact Low Probability (HILP) analysis was carried out on a selected number of HILP combinations. A list of all HILP combinations can be found in Appendix 3. This analysis was carried out on the less onerous, re-dispatched summer and winter export cases. No issues were identified.

5.9 Summary of network problems

The analysis of the transmission network indicates that there are a number of issues in breach of our Transmission System Security Planning Standards (TSSPS) and therefore require to be addressed. The below paragraphs summarise the findings for all cases analysed. The technical solution must either resolve these issues inherently or be considered in conjunction with other future works.

5.9.1 Thermal overloads

A thermal overload can occur when the power flow on a circuit exceeds its power carrying capacity causing overheating of the circuit. Overheating will cause increased conductor sag and possibly breach safe clearance distances, and eventually lead to mechanical damage to the conductor. Under a number of scenarios thermal overloads on some of the existing circuits have been identified, namely:

Single contingency (N-1)

Three cases indicate thermal overloads for single contingencies (N-1). These cases all involve export on the interconnectors. For summer the worst overloads observed involve:

- Maynooth – Woodland 220 kV circuit (between 119 - 201% of its rated capacity)
- Dunstown – Maynooth 220 kV circuit (between 116 - 149% of its rated capacity)
- Bracklone – Portlaoise 110 kV circuit (132% of its rated capacity)
- Killonan – Shannonbridge 220 kV circuit (120% of its rated capacity)
- Maynooth – Shannonbridge 220 kV circuit (121% of its rated capacity)
- Maynooth – Ryebrook 110 kV circuit (113% of its rated capacity)

The worst contingency for the Summer export case is the loss of Oldstreet Woodland 400 kV circuit.

For winter scenarios the worst overload observed involve:

- Maynooth – Woodland 220 kV circuit (between 127 - 168% of its rated capacity)
- Dunstown – Maynooth 220 kV circuit (128% of its rated capacity).
- Bracklone – Portlaoise 110 kV circuit (120% of its rated capacity).

The overloads occur for the loss of the Oldstreet – Woodland 400 kV circuit.

This indicates that the network is short of capacity when certain high voltage circuits are lost. The loss of these circuits forces the power to take alternative paths through the transmission network and as a result thermal overload are observed. This is particularly evident during high regional power transfers from the south to the east coast.

Maintenance trip combinations (N-1-1)

During maintenance trip combinations (N-1-1) thermal overload have also been observed on circuits despite utilising generation re-dispatch to prepare for the maintenance. Overload of the Maynooth –Woodland 220 kV (up to 169% of its rated capacity) and Dunstown – Maynooth 220 kV (up to 140% of its rated capacity) have been seen for various maintenance trip combinations of 400 kV circuits and 220 kV in Dublin. In addition, maintenance trip combinations of the 400 kV circuits cause thermal overloads on the 220 kV circuits traversing the country between Killonan and Maynooth 220 kV stations, especially Killonan - Shannonbridge between 111 – 139% of its rated capacity and Maynooth – Shannonbridge between 118 – 139% of its rated capacity. Cashla – Prospect 220 kV circuit also see overloads up to 169%. In the summer peak export scenario the Maynooth – Ryebrook 110 kV circuit is also overloaded to 128% for the maintenance trip combination of Oldstreet – Woodland 400 kV and Woodland – Maynooth 220 kV.

5.9.2 Voltage collapse

If an adequate level of reactive power is not available to the network, a voltage collapse and loss of supply may occur. The analyses indicate that there is a lack of reactive power in the greater Dublin area during certain operating conditions. These operating conditions usually occur when the east coast relies on generation to be produced elsewhere and then transported to supply the demand in the greater Dublin area. Facilitation of new generation together with existing generation along with increased demand in Dublin introduces large regional electricity flows from the south towards the east coast of Ireland. During periods of high wind, there may arise scenarios where conventional generation in Dublin is displaced by cheaper wind generation and/or conventional generation located in the south of the country. In these instances large power transfers are seen between the south towards the east coast of Ireland. In these situations the existing 400 kV and 220 kV circuits are heavily loaded. An unplanned loss of any of these circuits (N-1[5]) increases the loading on remaining circuits. In three cases voltage collapse is seen when certain high voltage circuits are lost. Indicative figures of reactive support levels from 150 Mvar to 640 Mvar in the greater Dublin area are required to mitigate voltage collapse.

Another way voltage collapse can be avoided is by dispatch of generation to the greater Dublin area. It should be noted that this would be seen as potentially uneconomic during this operating condition and a disturbance to the market. Also it would not be compliant

[5] (N-1) – a loss of one item of plant on the transmission network (e.g. a circuit or transformer).

with EirGrid's legal and license requirement to plan the transmission network reliant on the particular location of generators.

5.9.3 Large phase angles

Alternating electrical current or voltage is mathematically represented in waves (sinusoidal in shape). The difference in time between the peaks of the voltage and current waves is known as the phase angle and is expressed in degrees. The phase angle will vary at every point across the network due to the physical characteristics of the network that links these points together and the power transferred between those points.

Large phase angles can lead to instability; this will potentially lead to the loss of parts of the network as with a large phase angle it may not be possible to restore circuits to operation. Generator stability could also be impacted, a large phase angle change following a line tripping could lead to instability if insufficient damping and synchronizing torque is available.

This means that additional circuit(s) added into the network will affect the phase angles in a positive way (reduction) due to better connectivity. Also, with high power transfers across the network, an increased difference occurs between the phase angles at either end of circuits. When the network has circuits out of service, power will be redistributed across remaining circuits and will thereby increase the power flowing through these. The result is increased difference between the phase angle at either end of the circuits.

In this analysis phase angles of up to 40° have been indicated in two scenarios. This is just at the limit set in the Operating Security Standards (OSS), which are set at no more than 40°. Currently the Irish transmission system experiences phase angles which are less than 20° when re-closing/energising occurs.

6 Plausible scale of solutions

Section 5 describes large regional electricity flows from the south towards the east coast of Ireland cause three issues which affect security of supply of the transmission system. The identified need also indicates that the transmission system is short of capacity in the greater Dublin area. Plausible candidate solutions to these identified network problems must solve each individual issue or provide an overall system solution or involve a combination of these. A brief description of what type of solutions the three identified issues could require is given below to provide an estimate of the scale of the plausible options for reinforcement.

The identified voltage issues are caused by a lack of reactive power within the network or a lack of connectivity between generators/ reactive power source and demands/loads of reactive power. It should also be highlighted that heavily loaded circuits use more reactive power than lightly loaded circuits and this may also contribute to voltage issues. The solution to the voltage related issues may be the addition of a reactive power source or the addition or upscaling of new or existing circuits or a combination of both.

The large phase angles are caused by a lack of connectivity between various nodes in the network. Heavily loaded circuits absorbing reactive power also contribute to large phase angles. The large phase angles can be addressed in different ways by re-distributing power to other existing circuits or by the introduction of additional circuits.

The thermal overloads are due to excess powerflow through particular circuits for the loss of another circuit. The solution could involve diverting power by use of phase shifting transformers or other power flow control devices to encourage the use of other existing circuits. It could also involve the introduction of additional circuits or upscaling of existing circuits thus providing additional capacity and relieving the overloaded circuit.

The three identified issues can introduce a range of solution options involving both locally based reinforcements and/or provision of additional capacity in the form of new circuits. All solutions should maximise the utilisation or enhancement of existing infrastructure where spare capacity may exist prior to introducing new infrastructure. It is almost certain that even with the existing infrastructure maximised it may not be enough to resolve the issues identified and new infrastructure will have to be built. Considerations should be given to the level of additional power transfer capacity required. Dublin region is an area of rapid growth and any new infrastructure should provide sufficient capacity to cater for the future to minimise additional investment. The existing AC voltage level is 220 kV and 400 kV in the Dublin transmission network and any new AC infrastructure should be based on these levels. Based on existing technology the scale of a potential project with an assumed distance of 60 km provides an initial estimate in the range of €70m – €100m. The estimate can easily vary, depending on technology used (such as HVDC). The solution options will be further investigated in Step 2. The nature of a solution Counties Dublin, Kildare and Meath will very likely require extensive communication, stakeholder engagement and consultation.

7 Conclusions

There are two drivers that highlight the need to further development of the transmission system, namely:

1. **Increased demand on East coast**. An increase in electricity demand as part of natural growth is expected. In addition, there is a demand increase in the order of 900 MW due to the connection of data centres. This is based on executed and offered connection agreements mostly in the counties Kildare, Meath and Dublin. Part of this demand is expected to start to connect to the system in 2017 and ramp up to the total demand figure in 2025. The interest is high and it is expected that this trend will continue with further requests for connection.

2. **Integration of generation in South and South West.** Significant levels of new renewable generation have connected or are in the process of connecting to the transmission and distribution system in the south and south west of Ireland. This is also where the newer and more cost effective existing conventional generation units are located. This results in that a significant portion of the generation sources are located in the south and south west of Ireland away from the main demand centres. The power produced will hence have to be transported to get to where it is needed.

These two drivers introduce cross country power flows on the existing transmission system from the West to the East coast. Under these circumstances the system analysis indicates that the network is experiencing significant violations of the compliance with the Transmission System Security Planning Standards (TSSPS). The violations occur for the unplanned loss of any of the existing 400 kV circuits between Moneypoint 400 kV station in the West and Dunstown 400 kV in County Kildare and Woodland 400 kV station in County Meath in the East.

The violations relates to two aspects:

- Bringing required power to the East coast; and
- Transferring this power within Counties Dublin, Kildare and Meath once the power reach the east coast.

The violations observed can be further divided into three technical issues:

– Thermal overloads

  Under certain system conditions, for unplanned losses of any of the 400 kV circuits between the west coast and the east coast the following circuits are overloaded,

  - Maynooth – Woodland 220 kV,
  - Dunstown – Maynooth 220 kV,
  - Maynooth – Ryebrook 110 kV
  - Killonan – Shannonbridge 220 kV
  - Maynooth – Shannonbridge 220 kV
  - Cashla – Prospect 220 kV and
  - Bracklone – Portlaoise 110 kV.

  These circuits are also overloaded for maintenance trip combinations despite remedial action using generation dispatch of 400 MW.

– Voltage Profile

  Lack of reactive power in Counties Dublin, Kildare and Meath during certain operating conditions

– Large phase angles

  Due to high power transfers on existing lines and the low connectivity between transmission stations during certain operating conditions

Appendix 1 – Analysis Results

Appendix 1A - Winter Export – Non Converged Contingencies

Contingency
ARKLOW - LODGEWOOD 220 kV CCT 1
CORDUFF - HUNTSTOW 220 kV CCT 1
DUNSTOWN - LAOIS 400 kV CCT 1
GREAT ISLAND - KELLIS 220 kV CCT 1
GREAT ISLAND - LODGEWOOD 220 kV CCT 1
INCHICORE - IRISHTOWN 220 kV CCT 1
KNOCKANURE - BALLYNAHULLA 220 kV CCT 1
KNOCKANURE - KILPADDOGE 220 kV CCT 2
LAOIS - MNYPG3 400 kV CCT 1
MAYNOOTH - SHANNONBRIDGE 220 kV CCT 1
MNYPG1 - OLDSTREET 400 kV CCT 1
OLDSTREET - WOODLAND 400 kV CCT 1
WOODLAND - PORTAN 400 kV CCT 1 Loss of Generation/Power in-feed
ORIEL - ORIEL 220 kV CCT 1 Loss of Generation/Power in-feed
GREAT ISLAND - ENDESA 220/20 kV TRAFO Loss of Generation/Power in-feed
HUNTSTOWN - HUNTSTOWN 220/20 kV TRAFO Loss of Generation/Power in-feed
IRISHTOWN – DUBLIN BAY 220/ 20 kV TRAFO Loss of Generation/Power in-feed
COOLKEERAGH 275/15.800 TRAFO Loss of Generation/Power in-feed

Appendix 1B - Winter Export – Reactive Support N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
OLDSTREET - WOODLAND 400 kV CCT 1	DUNSTOWN - MAYNOOTH 220 kV CCT 2	534.0	682.5	127.8
OLDSTREET - WOODLAND 400 kV CCT 1	MAYNOOTH - WOODLAND 220 kV CCT 1	534.0	899.3	168.4
OLDSTREET - WOODLAND 400 kV CCT 1	BRACKLONE – PORTLAOISE 110 kV CCT 1	128.0	153.8	120.2

Appendix 1C - Winter Export – Re-dispatched N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
OLDSTREET - WOODLAND 400 kV CCT 1	DUNSTOWN - MAYNOOTH 220 kV CCT 2	534.0	549.8	103.1
OLDSTREET - WOODLAND 400 kV CCT 1	MAYNOOTH - WOODLAND 220 kV CCT 1	534.0	674.5	127.1

Appendix 1D - Winter Import Original N-1 Non –Converged Cases

Contingency
CORDUFF - HUNTSTOW 220 kV CCT 1
KNOCKANU BALLYNAH 220 kV CCT 1
LAOIS - MNYPG3 400 kV CCT 1
WOODLAND - PORTAN 400 kV CKT 1 Loss of Generation/Power in-feed
EASTWEST - PORTAN 400 kV CKT 1 Loss of Generation/Power in-feed
HUNTSTOWN - HUNTSTOWN 220/20 kV TRAFO Loss of Generation/Power in-feed
IRISHTOWN – DUBLIN BAY 220/ 20 kV TRAFO Loss of Generation/Power in-feed

Appendix 1E – Winter Import Reactive Support N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
CULLENAGH - GREAT IS 220 kV CCT 1	CULLENAGH - WATERFORD 110 kV CCT1*	219.0	249.0	112.0

* This overload is a local problem for the Waterford Area and will not be addressed as part of the need identified

Appendix 1F - Summer Export Reactive Support N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
CUSHALING - PORTLAOISE 110 kV CCT 1	BRACKLONE - PORTLAOISE 110 kV CCT 1	105.0	124.2	113.9
POOLBEG - INCHICORE 220 kV CCT 2	POOLBEG - INCHICOR 220 kV CCT 1	267.0	371.2	135.5
DUNSTOWN - LAOIS 400 kV CCT 1	BRACKLONE - PORTLAOISE 110 kV CCT 1	105.0	133.9	122.4
LAOIS - MNYPG3 400 kV CCT 1	KILLONAN - SHANNONBRIDGE 220 kV CCT 1	269.0	317.9	113.6
MNYPG1 - OLDSTREE 400 kV CCT 1	CASHLA - PROSPECT 220 kV CCT 1	392.0	530.0	131.4
	BRACKLONE - PORTLAOISE 110 kV CCT 1	105.0	125.9	123.0
	DUNSTOWN - MAYNOOTH 220 kV CCT 2	434.0	584.4	138.2
	KILLONAN - SHANNONBRIDGE 220 kV CCT1	269.0	324.5	118.1
	MAYNOOTH - WOODLAND 220 kV CCT 1	434.0	714.7	170.1
OLDSTREET - WOODLAND 400 kV CCT 1	BRACKLONE - PORTLAOISE 110 kV CCT 1	105	138.5	131.9
	DUNSTOWN - MAYNOOTH 220 kV CCT 2	434	646.4	148.9
	KILLONAN - SHANNONBRIDGE 220 kV CCT1	269	323.7	120.3
	MAYNOOTH - WOODLAND 220 kV CCT 1	434	874	201
	MAYNOOTH - RYEBROOK 110 kV CCT 1	187	212.3	113.5
	MAYNOOTH - SHANNONBRIDGE 220 kV CCT 1	269	324.8	120.7

Appendix 1G - Summer Export –Re-dispatched N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
MNYPG1 - OLDSTREE 400 kV CCT 1	CASHLA - PROSPECT 220 kV CCT 1	392.0	525.5	126.7
	DUNSTOWN - MAYNOOTH 220 kV CCT 2	434.0	522.2	116.0
	MAYNOOTH - WOODLAND 220 kV CCT 1	434.0	594.2	132.3
OLDSTREET - WOODLAND 400 kV CCT 1	BRACKLON - PORTLAOISE 110 kV CCT1	105.0	122.0	113.5
	DUNSTOWN - MAYNOOTH 220 kV CCT 2	434.0	542.0	121.4
	MAYNOOTH - WOODLAND 220 kV CCT 1	434.0	667.4	150.2

Appendix 1H - Summer Import – N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
CULLENAGH - WATERFOR 110 kV CCT 1	KILLOTERAN - WATERFOR 110 kV 1 CCT	99.0	117.7	113.9
CULLENAGH - GREAT IS 220 kV CCT 1	CULLENAGH - WATERFORD 110 kV CCT1	178.0	215.5	117.6
CORDUFF - FINGLAS 220 kV CCT 1	CORDUFFB - FINGLAS2 220 kV CCT2	434.0	514.2	112.0
CLONEE - WOODLAND 220 kV CCT 1	CORDUFFB - WOODLAND 220 kV CCT 2	434.0	509.0	110.2
CORDUFFB - FINGLAS2 220 kV CCT 2	CORDUFF - FINGLAS 220 kV CCT 1	434.0	514.2	112.0
CORDUFFB - WOODLAND 220 kV CCT 2	CLONEE - WOODLAND 220 kV CCT 1	434.0	511.7	110.7
GREAT ISLAND - LODGEWOO 220 kV CCT 1	GREAT ISLAND - WEXFORD 110 kV CCT1	99.0	156.4	150.1

Appendix 1I - Summer No Import/Export – N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
CLASHAVOON-KNOCKRAHA 220 kV CCT1	BANDON – DUNMANWAY 110 kV CCT1	99	116.7	114.1
DUNSTOWN - LAOIS 400 kV CCT 1	BRACKLON - PORTLAOISE 110 kV CCT1	105.0	128.1	116.5
MAYNOOTH – WOODLAND 220 kV CCT1	OLDSTREET – WOODLAND	434.0	525.0	118.9

Appendix 1J - Summer Night Valley – N-1 Overloads

Contingency	Overloaded Circuit	Rating	Loading	%Loading
OLDSTREET - WOODLAND 400 kV CCT 1	MAYNOOTH - WOODLAND 220 kV CCT 1	434.0	519.7	118.0

Appendix 2 –Maintenance Trip

Appendix 2A – Circuits Included for Maintenance

Moneypoint - Oldstreet 400 kV
Laois – Moneypoint 400 kV
Dunstown - Laois 400 kV
Woodland - Turleenan 400 kV
Killonan - Knockraha 220 kV
Killonan - Shannonbridge 220 kV
Killonan - Kilpaddoge 220 kV
Knockanure - Ballynahulla 220 kV
Knockraha - Cullenagh 220 kV
Great Island - Kellis 220 kV
Great Island - Lodgewood 220 kV
Cullenagh - Great Island 220 kV
Corduff - Huntstown 220 kV
Dunstown - Maynooth 220 kV circuit 1
Dunstown - Maynooth 220kV circuit 2
Maynooth - Woodland 220 kV
Corduff - Woodland 220 kV
Corduff - Finglas 220 kV
Corduff - Finglas 220 kV
Clonee - Woodland 220 kV
Inchicore - Poolbeg 220 kV
Inchicore - Irishtown 220 kV Circuit 1
Inchicore - Irishtown 220 kV Circuit 2
Maynooth – Gorman 220 kV
Gorman - Louth 220 kV
Killoteran - Waterford 110 kV
Cullenagh - Waterford 110 kV
Great Island - Wexford 110 kV
Corduff - Ryebrook 110 kV

Appendix 2B – Summer Export Maintenance Combinations Which Cause Non-Convergence Prior to Re-Dispatch

Maintenance	Contingency
Moneypoint - Oldstreet 400 kV	CASHLA 220.00 (1642) - PROSPECT 220.00 (4522) CKT 1
	CORDUFF 220.00 (2042) - HUNTSTOW 220.00 (2972) CKT 1 Loss of Generation/Power in-feed
	DUNSTOWN 400.00 (2204) - LAOIS 400.00 (3554) CKT 1
	FINGLAS 220.00 (2562) - HUNTSTOW 220.00 (2962) CKT 1
	LAOIS 400.00 (3554) - MNYPG3 400.00 (3944) CKT 1
	BELCAMP 110.00 (1471) - AMAZON 20.000 (14701) CKT 1
	BELCAMP 110.00 (1471) - AMAZON 20.000 (14701) CKT 2
	2962 HUNTSTOW TRAFO CKT 1 Loss of Generation/Power in-feed
	HUNTSTOW 220.00 (2972) - HUNTSTOW 20.000 (29673) CKT 2 Loss of Generation/Power in-feed
	IRISHTOW 220.00 (3122) - DUBLIN_B 21.000 (31271) CKT 1 Loss of Generation/Power in-feed
	HUNT_CC Loss of Generation/Power in-feed
Laois – Moneypoint 400 kV	MNYPG1 400.00 (3934) - OLDSTREE 400.00 (4384) CKT 1
	OLDSTREE 400.00 (4384) - WOODLAND 400.00 (5464) CKT 1
	CAUTEEN 110.00 (5271) - KILLONAN 110.00 (32810) CKT 1
Dunstown - Laois 400 kV	MNYPG1 400.00 (3934) - OLDSTREE 400.00 (4384) CKT 1
	OLDSTREE 400.00 (4384) - WOODLAND 400.00 (5464) CKT 1
Killonan - Knockraha 220 kV	BALLYNAH 220.00 (3332) - DUMMY 220.00 (8882) CKT 1
	KILPADDO 220.00 (3462) - DUMMY 220.00 (8882) CKT 2
Cullenagh - Great Island 220 kV	CAUTEEN 110.00 (5271) - KILLONAN 110.00 (32810) CKT 1
Corduff - Huntstown 220 kV	FINGLAS 220.00 (2562) - HUNTSTOW 220.00 (2962) CKT 1 Loss of Generation/Power in-feed
	MNYPG1 400.00 (3934) - OLDSTREE 400.00 (4384) CKT 1
	OLDSTREE 400.00 (4384) - WOODLAND 400.00 (5464) CKT 1
	BELCAMP 110.00 (1471) - AMAZON 20.000 (14701) CKT 1
	BELCAMP 110.00 (1471) - AMAZON 20.000 (14701) CKT 2
	2962 HUNTSTOW TRAFO CKT 1 Loss of Generation/Power in-feed
	HUNT_CC Loss of Generation/Power in-feed
Inchicore - Irishtown 220 kV Circuit 1	BELCAMP 110.00 (1471) - AMAZON 20.000 (14701) CKT 1
	BELCAMP 110.00 (1471) - AMAZON 20.000 (14701) CKT 2
	GRANGE C 110.00 (2861) - GRANGE C 10.000 (28601) CKT 2

Appendix 2C Summer Export Maintenance Trip Overloads Following Re-Dispatch

Maintenance	Contingency	Monitored Bus	Pre-Cnt	Post – Cnt	Rating (MVA)	% Loading
Moneypoint - Oldstreet 400 kV	Laois - Moneypoint 400 kV	Not converged	-	-	-	-
Laois - Moneypoint 400 kV	Moneypoint - Oldstreet 400 kV	Not converged	-	-	-	-
Laois - Moneypoint 400 kV	Oldstreet - Woodland 400 kV	Not converged	-	-	-	-
Cullenagh - Great 220kV Ckt 1	CULLENAG - WATERFOR 110 CKT 1	KILLOTER - WATERFOR 110 ckt 1	79.5	223.7	99	220.1
	KILPADDO - KNOCKANURE 220 CKT 2	KILLOTER - WATERFOR 110 ckt 1	79.5	118.2	99	119.7
	BALLYNAH - KNOCKANURE 220 CKT 1	KILLOTER - WATERFOR 110 ckt 1	79.5	117.4	99	118.7
Moneypoint - Oldstreet 400 kV	CASHLA - PROSPECT 220 ckt 1	CASHLA - ENNIS 110 ckt 1	167.7	255.8	178	142.3
		SHANNONB - SOMRST T 110 ckt 1	65	122.8	105	113.9
		LAOIS - PORTLAOI 110 ckt 1	164.8	203.7	178	111.1
		KILLONAN - SHANNONB 220 ckt 1	269.4	330.2	269	117.7
	DUNSTOWN - LAOIS 400CKT 1	KILLONAN - SHANNONB 220 ckt 1	269.4	383.6	269	137.9
		BRACKLON - NEWBRIDG 110 ckt 1	94.3	171.5	136	127.1
		MAYNOOTH - SHANNONB 220 ckt 1	194	323.5	269	118.7
		CASHLA - ENNIS 110 ckt 1	167.7	207.2	178	114.8
	POOLBEG - INCHICOR 220 CKT 2	POOLBEG - INCHICOR 220 CKT 1	198.9	411	267	147.7
Dunstown - Laois 400 kV	MONEYPOINT- OLDSTREET 400 CKT 1	LAOIS - PORTLAOI 110 ckt 1	164.5	316.4	178	173.3
		KILLONAN - SHANNONB 220 ckt 1	244.4	383.8	269	138
		CASHLA - PROSPECT 220 ckt 1	328	696.7	392	169.1
		BRACKLON - PORTLAOI 110 ckt 1	107.2	193.7	105	183.1
	OLDSTREET - WOODLAND 400 CKT 1	LAOIS - PORTLAOI 110 ckt 1	164.5	303	178	167.3
		MAYNOOTH - SHANNONB 220 ckt 1	194.2	376.4	269	139.5
		KILLONAN - SHANNONB 220 ckt 1	244.4	387.6	269	139
		CASHLA - FLAGFORD 220 ckt 1	198.4	471	405	114.3
Killonan - Knockraha 220kV Ckt 1	KILPADDO - KNOCKANURE 220 CKT 2	BARRYMOR - CAHIR 110 ckt 1	71.1	140.4	105	130.6
	BALLYNAH - KNOCKANURE 220 CKT 1	BARRYMOR - CAHIR 110 ckt 1	71.1	140.4	105	130.6
Inchicore - Irishtown 220kV Ckt 1	OLDSTREET - WOODLAND 400 CKT 1	DUNSTOWN - MAYNOOTH 220 ckt 2	396.5	629.5	434	140
Maynooth - Gorman 220kV Ckt 1	OLDSTREET - WOODLAND 400 CKT 1	MAYNOOTH - WOODLAND 220 ckt 1	343.7	762.6	434	169.1

Appendix 2D Summer Import Maintenance Trip Combinations Which Cause Non-Convergence Prior to Re-Dispatch

Maintenance	Contingency	Monitored line
Killonan - Knockraha 220kV Ckt 1	KILPADDO - KNOCKANURE 220 CKT 2	NOT CONVERGED

Appendix 2E Summer Import Maintenance Trip Overloads Following Re-Dispatch

Maintenance	Contingency	Monitored Bus	Pre-Cnt	Post – Cnt	Rating (MVA)	% Loading
Cullenagh - Great 220kV Ckt 1	CULLENAG - WATERFOR 110 CKT 1	KILLOTER - WATERFOR 110 ckt 1	49.4	151.8	99	147.4
	BUTLERST - CULLENAG 110 CKT 1	CULLENAG - WATERFOR 110 CKT 1	134.3	209	178	112.4
MNYPG - OLDSTREE 400kV Ckt 1	LAOIS - MONEYPOINT 400 CKT 1	CASHLA - PROSPECT 220 ckt 1	275.1	471.6	392	114.2

Appendix 2F - Summer No Import/Export – Maintenance Trip Combination overloads following Re-Dispatch

Maintenance	Contingency	Monitored Bus	Pre	Post	Rating (MVA)	% Loading
Dunstown - Laois 400 kV	MONEYPOINT- OLDSTREET 400 CKT 1	LAOIS 110.00 (3551) - PORTLAOI 110.00 (4481) ckt 1	151	282.2	178	154.5
		CASHLA 220.00 (1642) - PROSPECT 220.00 (4522) ckt 1	257.7	579.2	392	139.5
		BRACKLON 110.00 (1791) - NEWBRIDG 110.00 (4201) ckt 1	99.6	164.6	136	122.4
		KILLONAN 220.00 (3282) - SHANNONB 220.00 (4942) ckt 1	206.6	326.6	269	117.1
		MAYNOOTH 220.00 (3852) - SHANNONB 220.00 (4943) ckt 1	205.6	317.6	269	116
	OLDSTREET - WOODLAND 400 CKT 1	LAOIS 110.00 (3551) - PORTLAOI 110.00 (4481) ckt 1	151	275.2	178	151.7
		MAYNOOTH 220.00 (3852) - SHANNONB 220.00 (4943) ckt 1	205.6	368.7	269	135.9
		BRACKLON 110.00 (1791) - NEWBRIDG 110.00 (4201) ckt 1	99.6	173.2	136	130.4
		KILLONAN 220.00 (3282) - SHANNONB 220.00 (4942) ckt 1	206.6	333	269	119.3
Moneypoint – Oldstreet 400kV Ckt 1	CASHLA 220.00 (1642) - PROSPECT 220.00 (4522) CKT 1	MAYNOOTH 220.00 (3852) - WOODLAND 220.00 (5462) ckt 1	404.2	505.1	434	113
	CUSHALIN 110.00 (1941) - PORTLAOI 110.00 (4481) CKT 1	BRACKLON 110.00 (1791) - PORTLAOI 110.00 (4481) ckt 1	97.3	126.4	105	115.9
	Dunstown - Laois 400 kV	BRACKLON 110.00 (1791) - PORTLAOI 110.00 (4481) ckt 1	97.3	179	105	167.6
		LAOIS 110.00 (3551) - PORTLAOI 110.00 (4481) ckt 1	129.4	281.8	178	154.3
		CASHLA 220.00 (1642) - PROSPECT 220.00 (4522) ckt 1	361.9	578.9	392	139.4
		BRACKLON 110.00 (1791) - NEWBRIDG 110.00 (4201) ckt 1	86.9	164.6	136	122.4
		KILLONAN 220.00 (3282) - SHANNONB 220.00 (4942) ckt 1	213.2	326.4	269	116.9
		MAYNOOTH 220.00 (3852) - SHANNONB 220.00 (4943) ckt 1	187.9	318.3	269	116.1
	GORMAN 220.00 (2842) - MAYNOOTH 220.00 (3842) CKT 1	MAYNOOTH 220.00 (3852) - WOODLAND 220.00 (5462) ckt 1	404.2	505.5	434	112.3
	INCHICOR 220.00 (3082) - IRISHTOW 220.00 (3122) CKT 1	DUNSTOWN 220.00 (2202) - MAYNOOTH 220.00 (3852) ckt 2	390.2	508.2	434	113.2
	Laois – Moneypoint 400 kV	CASHLA 220.00 (1642) - PROSPECT 220.00 (4522) ckt 1	361.9	684.5	392	181.3
		KILLONAN 220.00 (3282) - SHANNONB 220.00 (4942) ckt 1	213.2	402.8	269	152
		MAYNOOTH 220.00 (3852) - SHANNONB 220.00 (4943) ckt 1	187.9	345.8	269	135.2
		AGANNYGA 110.00 (1071) - SHANNONB 110.00 (4941) ckt 1	83.2	124.7	105	120.8
	MAYNOOTH 220.00 (3852) - WOODLAND 220.00 (5462) CKT 1	MAYNOOTH 110.00 (3851) - RYEBROOK 110.00 (4621) ckt 1	153.1	215.9	187	112.8
	POOLBEG 220.00 (4462) - POOLBEG 220.00 (4472) CKT 1	MAYNOOTH 220.00 (3852) - WOODLAND 220.00 (5462) ckt 1	404.2	535.7	434	119

Laois – Moneypoint 400 kV	CLASHAVO 220.00 (1602) - KNOCKRAH 220.00 (3202) CKT 1	BANDON 110.00 (1441) - DUNMANWA 110.00 (2221) ckt 1	80.3	116.2	99	113.3
	MONEYPOINT- OLDSTREET 400 CKT 1	CASHLA 220.00 (1642) - PROSPECT 220.00 (4522) ckt 1	283.3	679.5	392	180.6
		KILLONAN 220.00 (3282) - SHANNONB 220.00 (4942) ckt 1	231.8	405.3	269	152.4
		MAYNOOTH 220.00 (3852) - SHANNONB 220.00 (4943) ckt 1	208.7	344.8	269	133.9
		AGANNYGA 110.00 (1071) - SHANNONB 110.00 (4941) ckt 1	93.1	126	105	121.4
	OLDSTREET - WOODLAND 400 CKT 1	MAYNOOTH 220.00 (3852) - SHANNONB 220.00 (4943) ckt 1	208.7	397.7	269	158.1
		KILLONAN 220.00 (3282) - SHANNONB 220.00 (4942) ckt 1	231.8	406.4	269	153.5
		AGANNYGA 110.00 (1071) - SHANNONB 110.00 (4941) ckt 1	93.1	133.5	105	128.9
		CASHLA 220.00 (1642) - FLAGFORD 220.00 (2522) ckt 1	163.6	493.1	405	122.1
		ARVA 110.00 (1181) - CARICKON 110.00 (1861) ckt 1	54.2	117.9	99	120.5
		LANESBOR 110.00 (3501) - MULLINGA 110.00 (4001) ckt 1	57.8	114.5	105	114
Corduff – Huntstown 220 kV	OLDSTREE 400.00 (4384) - WOODLAND 400.00 (5464) CKT 1	MAYNOOTH 220.00 (3852) - WOODLAND 220.00 (5462) ckt 1	231.6	537.6	434	121.7

Appendix 2G- Summer Night Valley Maintenance Trip Combination overloads following Re-Dispatch

Maintenance	**Contingency**	**Monitored Bus**	**Pre**	**Post**	**Rating (MVA)**	**% Loading**
Dunstown - Laois 400 kV	OLDSTREET - WOODLAND 400 CKT 1	BRACKLON - PORTLAOI 110 ckt 1	77.4	146.8	105	134.4
	OLDSTREET - WOODLAND 400 CKT 1	MAYNOOTH - SHANNONB 220 ckt 1	187.4	326.3	269	118
	MONEYPOINT- OLDSTREET 400 CKT 1	BRACKLON - PORTLAOI 110 ckt 1	77.4	127.9	105	117.4
Maynooth - Woodland 220kV Ckt 1	OLDSTREET - WOODLAND 400 CKT 1	MAYNOOTH - RYEBROOK 110 ckt 1	152.3	240.8	187	128
	OLDSTREET - WOODLAND 400 CKT 1	POOLBEG - POOLBEG 220 ckt 1	279.3	537.2	450	116
	POOLBEG - POOLBEG 220 CKT 1	MAYNOOTH - RYEBROOK 110 ckt 1	152.3	214.8	187	113
Laois – Moneypoint 400 kV	OLDSTREET - WOODLAND 400 CKT 1	MAYNOOTH - SHANNONB 220 ckt 1	185.4	343.3	269	125.8
	OLDSTREET - WOODLAND 400 CKT 1	KILLONAN - SHANNONB 220 ckt 1	170.7	309.7	269	111.5
Moneypoint - Oldstreet 400 kV	DUNSTOWN - LAOIS 400 CKT 1	BRACKLON - PORTLAOI 110 ckt 1	76.8	128.1	105	117.7
Great - Kellis 220kV Ckt 1	ARKLOW - CARRICKM 220 CKT 1	ARKLOW - BALLYBEG 110 ckt 1	66	158.1	136	117.5
Great - Kellis 220kV Ckt 1	ARKLOW - CARRICKM 220 CKT 1	BALLYBEG – CARRICKM 110 ckt 1	62.8	153.6	136	115.2
Cullenagh - GI 220kV Ckt 1	CULLENAG - WATERFOR 110 CKT 1	KILLOTER - WATERFOR 110 ckt 1	41.8	112	99	110.8
Maynooth - Gorman 220kV Ckt 1	OLDSTREET - WOODLAND 400 CKT 1	MAYNOOTH - WOODLAND 220 ckt 1*	288.2	594.7	434	134.6

*This circuit was overloaded for many maintenance trip combinations. Only the worst case is reported here.

Appendix 3 - High Impact Low Probability Analysis

Circuit 1	Circuit 2
Woodland – Corduff 220 kV cct 1	Woodland – Corduff 220 kV cct 2
Woodland – Corduff 220 kV cct 1	Maynooth – Woodland 220 kV cct 1
Woodland – Corduff 220 kV cct 2	Louth – Woodland 220 kV cct 1
Maynooth – Woodland 220 kV cct 1	Maynooth –Shannonbridge 220 kV cct 1
Dunstown – Moneypoint 400 kV cct 1	Moneypoint – Prospect 220 kV cct 1
Dunstown – Carrickmines 220 kV cct 1	Dunstown – Maynooth 220 kV cct 1
Dunstown – Kellis 220 kV cct 1	Great Island – Kellis 220 kV cct 1
Inchicore – Maynooth 220 kV cct 1	Inchicore – Maynooth 220 kV cct 2
Corduff – Finglas 220 kV cct 1	Corduff – Finglas 220 kV cct 2