Step 3 Confirmation of Need Report

The Kildare-Meath Grid Upgrade

Capital Project 966

July 2020

EIRGRID

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2 Introduction

EirGrid follows 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 at a high-level in Figure 1. Each step has a distinct purpose with defined deliverables. At the time of writing, "The Kildare - Meath Grid Upgrade" is in Step 3 of our six step approach.

In Step 2, this project was publically referred to as Capital Project 966. The name "The Kildare-Meath Grid Upgrade" is now being used in all external engagement material for this project. The aim of the project title update is to provide a greater level of association with where it may be located once built for stakeholders. Capital Project 966 will still be retained as the official technical project name and so this report will still refer to the project as Capital Project 966.

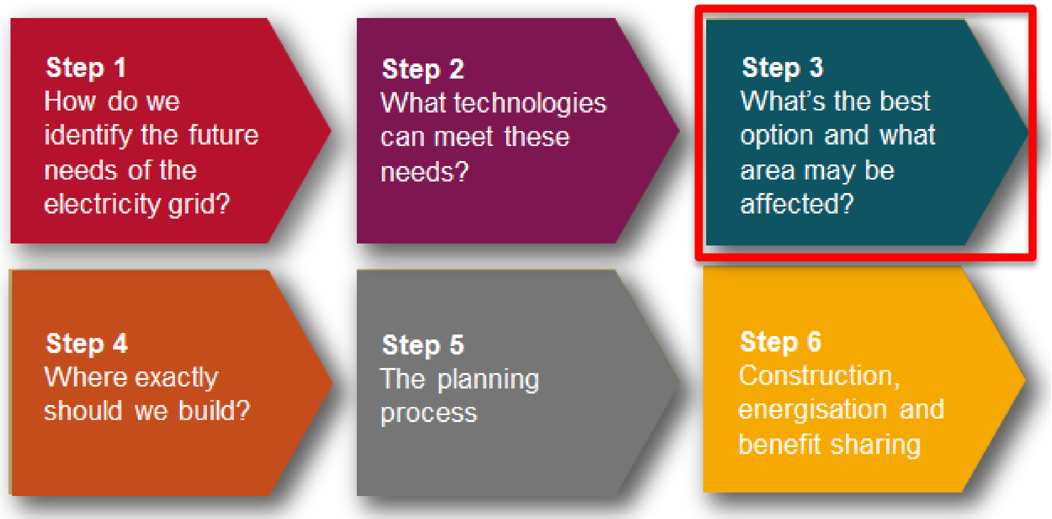

Figure 1 *High Level Project Development Process*

As part of the process for all of our projects, the need is reviewed at each step to ensure that the project is still required and that appropriate investment decisions are made. This report presents the findings of the need assessment in Step 3.

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

There have been significant changes to future generation and demand assumptions and forecasts since the Step 1 need assessment was completed, including accepted connection agreements with new demand and generation customers. Further network reinforcements to accommodate these developments have also been progressed.

The need for Capital Project 966 has become more important and acute with the acceptance of connection offers by new generation and demand customers. To provide unconstrained market access to all connecting parties and achieve Government renewable targets, we must develop the electricity transmission network to ensure a reliable and secure electricity supply for Ireland.

The need for Capital Project 966 relates to problems with the transfer of power across the existing 400 kV transmission network from west to east and the subsequent transmission of this power around the network as it reaches the east coast. In line with the need identified in previous steps, the issues identified in this Step 3 needs assessment relate to voltage, capacity and voltage phase angle. The need identified in Step 1 was based on two drivers. These drivers still remain and have further increased the need to strengthen the transmission network between Dunstown and Woodland stations.

2.1 Our statutory role

EirGrid is the national electricity Transmission System Operator (TSO) for Ireland. Our roles 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 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 connection 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 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 in Section 2.1, 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. To do this, we analyse different future energy scenarios. Using this approach enables us to efficiently develop the grid taking into account all of the uncertainties associated with the future demand for electricity and the future location and technology used to generate electricity.

To help us account for the uncertainties of the future, Tomorrow's Energy Scenarios (TES) 2019[2] have been developed. We developed three scenarios using our own experience and expertise as well as significant input received from government departments and agencies, energy research groups and industry representatives. The three scenarios are called Delayed Transition, Centralised Energy, and Coordinated Action.

The Centralised Energy and Coordinated Action scenarios align with the Government's renewable energy target of meeting 70% of electricity demand from renewable generation by 2030 while the Delayed Transition scenario has a lower renewable generation penetration assumption of 60%. These scenarios have undergone public consultation, with contributions received from the energy industry, members of the public, and various interested groups.

The assumptions used in the analysis underpinning this need assessment are in line with those set out in TES 2019. Where necessary, additional demand and generation has been added due to executed and offered connection agreements.

Since the Step 1 needs assessment was conducted, the assumptions related to future demand and generation, and grid configurations have changed. In the following bullet points, some of the assumptions used for this analysis to reassess the need are highlighted. Where relevant, it is noted where these deviate from the assumptions used in the Step 1 needs assessment and how they relate to TES 2019:

[2] Tomorrow's Energy Scenarios http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-TES-2019-Report.pdf

- The demand levels in the power system model for the need reassessment are generally consistent with the demand levels presented in the Generation Capacity Statement 2019-2028 (GCS 19-28). These demand levels were updated from those used in the Step 1 needs assessment where demand levels were in line with those presented in the GCS 2015-2024. The demand levels in GCS 19-28 closely correspond to demand levels used in the scenarios in TES 2019.
- The connection of large energy users has been accounted for in line with latest known information at the start of the analysis (2019). In total, 1900 MW of large energy users (these are large demand connections, such as data centres) has been assumed in the system models. All of these are located on the East coast. This figure of 1900 MW is based on executed connection agreements and offered connection agreements. The assumption for demand from large energy users has increased relative to the Step 1 needs assessment, for which 900 MW of large energy users was assumed. This represents a significant increase in demand on the East coast which is comparable to a near doubling of the existing Dublin peak demand. In TES 2019, the Coordinated Action scenario assumes circa 1600 MW of large energy users (the Centralised Energy and Delayed Transition TES scenarios assume circa 1250 and 1150 MW of large energy users, respectively).
- The connection of renewable generation with a view to meeting the Government's target of meeting 70% of electricity demand from renewable generation by 2030 is considered in the analysis. At the time of undertaking the Step 1 needs assessment, the Government had a target of meeting 40% of electricity demand from renewable energy by 2020. The system models have been set up in such a way that the renewable generation is utilised as much as possible,
- In line with TES 2019, it is assumed that coal, oil, distillate, and peat stations have been phased out by 2030. Most notably, the coal-powered Moneypoint generators are assumed to have phased out. In the Step 1 needs assessment, several coal, oil, distillate and peat stations formed part of the generation mix.
- Some grid connected batteries have been assumed in the model. Some of these batteries are designed to have short-term energy capacity. This means that they can export at their Maximum Export Capacity (MEC) for a half an hour period before they need to re-charge. These types of facilities should also have reactive

capabilities in line with the Grid Code requirements. Some of these batteries are in locations where they both contribute to, or alleviate, the need depending on whether they are dispatched or not. In the analysis presented, these units have been dispatched on, but where a difference can be seen if they are not available, a comment is made in regards to the effect of their unavailability.

- Assumptions have been made in relation to the construction of additional interconnection on the south coast. In previous needs assessment, an additional 700 MW interconnector, Celtic, was assumed to be connected at Knockraha in Co Cork in addition to the existing Moyle Interconnector and East West Interconnector. For the Step 3 needs assessment, reported in this document, an additional 500 MW interconnector, Greenlink, is assumed to be connected at Great Island, Co. Wexford.

3.1 Scenarios analysed

The assumptions set out above were used to create the power system models in our calculation tool PSSE that were subsequently analysed. From this point on, we will call these power system models 'cases'. In line with our statutory obligations, the future scenarios, described in the PSSE cases, are analysed to establish if the transmission system is in compliance with the Transmission System Security and Planning Standards (TSSPS). If the modelled system is in breach of any of these standards, the issue must be addressed.

The year 2030 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. The year 2030 is considered as the earliest stable point in the future. By this time, it is expected that a number of already planned network reinforcements will have been implemented. It is also expected that the contracted renewable generation will have been integrated into the system at this point, and the currently contracted demand customers on the East coast and future interconnectors will also have been connected.

Some of the planned and consented reinforcements assumed to be energised are:

- Series compensation of the existing 400 kV circuits;
- A 400 kV sub-marine cable across the Shannon Estuary between Moneypoint 400 kV station and Kilpaddoge 220 kV station;
- Three STATCOMs in Ballyvouskil and Ballynahulla 220 kV stations and Thurles 110 kV station; and

- The uprate of the Maynooth – Woodland 220 kV circuit.

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 times when there are 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.

It was assumed that four interconnectors are available in 2030:

- The existing Moyle Interconnector (Moyle), assumed to have 500 MW import/export capacity;
- The existing East West Interconnector (EWIC), assumed to have 500 MW import capacity and 530 MW export capacity;
- A future interconnector, Celtic, connected in the south of Ireland at Knockraha station, assumed to have 700 MW import/export capacity; and
- A future interconnector, Greenlink, connected in the south of Ireland at Great Island station, assumed to have 500 MW import/export capacity.

Preliminary studies indicated that the Winter Peak case with export provided the most challenging scenario for the network. Export scenarios increase the power transfers from the west and south west of the country to the east relative to import scenarios. This is because three of the four interconnectors, EWIC, Moyle and Greenlink are based on the east of the country.

When importing, these interconnectors provide active power to the east of the country, thus reducing the level of power that needs to be transported from the west of the country. When exporting power on the interconnectors, it is not only necessary to transport active power from west to east, but also extra reactive power is necessarily consumed in the process of this west to east active power transmission. Both these factors result in increased utilisation of both the thermal and reactive power capacities of the existing infrastructure on the Irish grid.

Based on previous analysis of the need and the above preliminary study results, it was determined that the import scenarios will not contribute to further issues above and beyond the ones caused by the export scenarios. As such, in this report, only export scenarios will be examined.

In all cases examined, it was assumed all interconnectors were exporting simultaneously. 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 from France and on to Great Britain. It was considered that a ‘wheeling’ scenario would be too onerous and was therefore not analysed.

For all cases, twelve synchronous generator units were considered available for dispatch in the Dublin area. Of these twelve synchronous generation units, seven were previously available for the generation dispatches in the Step 1 analysis. For clarity, these seven units comprise the two combined cycle gas units at Huntstown (three generator units in total), the three generator units of the combined cycle plant at Shellybanks, and the Dublin Bay unit. A number of new gas units due for installation in Dublin as per GCS 2019-2028 are also considered in the cases; two gas peaker units at North Wall, and three flexgen units to be installed at Corduff, Poolbeg, and Irishtown.

The following seasonal variations were studied:

- Winter Peak 2030
    - High renewable generation; exporting on four interconnectors
- Summer Peak 2030
    - High renewable generation; exporting on four interconnectors
- Summer Valley 2030
    - High renewable generation; exporting on four interconnectors
    - Low renewable generation

4 Statement of Need

We have previously (in Step 1) identified that we need to strengthen the transmission network between Dunstown and Woodland stations. In Step 3, this need has been reviewed and is still robust.

This need was based on two drivers. These drivers still remain and have further increased the urgency to strengthen the transmission network between Dunstown and Woodland stations. These two drivers are identified in Tomorrow's Energy Scenarios (TES) 2019[3] and our studies are in line with the assumptions in this publicly consulted document. Where necessary, additional demand and generation has been added due to executed and offered connection agreements.

The drivers for the need are:

1. **Increased demand on the East coast:** An increase in electricity demand as part of natural growth is expected. In addition, there is a demand increase in the Dublin region resulting in circa 1900 MW of large energy users connecting in this region by 2030. This is based on executed and offered connection agreements in the counties Kildare, Meath and Dublin. Approximately 320 MW of this demand has already connected and it is assumed that demand will ramp up to the total 1900 MW figure by 2030. Interest from large energy users is high and it is expected that there will be further requests for connection.

2. **Integration of generation in the South and West:** Significant levels of new renewable generation have connected or are in the process of connecting to the transmission and distribution systems in the South and South West of Ireland, but also elsewhere in the country. The system models analysed for this report have almost 7000 MW of wind included. This is based on connected and contracted connection agreements. As of July 2020, Ireland has approximately 4000 MW of wind connected. To be able to meet the Government's 70% renewable energy target by 2030, a significant amount of renewable generation will have to be connected in addition to the 7000 MW of wind included in the system models. In addition, the newer and more cost effective existing conventional generation units are also located in the South. There are also high levels of renewable generation

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[3] Tomorrow's Energy Scenarios http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-TES-2019-Report.pdf

on the North West coast. This means that a significant portion of the generation sources are located in the West and South/South West of Ireland away from the main demand centres. The power produced will hence have to be transported 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. The occurrence of the high cross country power flows is dependent on a number of aspects. Firstly, the speed of the uptake and connection of the already contracted large energy users on the East coast will influence the urgency of the requirement for the proposed reinforcement. Similarly, the uptake and connection of the renewable generation around the country will also influence the urgency of the proposed reinforcement. Secondly, some already well advanced grid infrastructure projects will have to be implemented and energised. Some of these will help to utilise the existing 400kV circuits better by encouraging more power to flow on the 400 kV circuits.

When the transmission system is experiencing these generation and demand patterns, the system analysis indicates that the network experiences significant violations of the Transmission System Security and Planning Standards (TSSPS). The TSSPS is the standard the transmission network should adhere to so a reliable and secure electricity system can be provided for all customers in Ireland.

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 unplanned loss of some 220 kV circuits running in parallel with these 400 kV circuits will have the same effect.

The violations relate to two aspects of power transmission:

- Bringing required power to the East coast; and
- Transmission of this power within Counties Dublin, Kildare and Meath once the power reaches 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 Figure 2. The

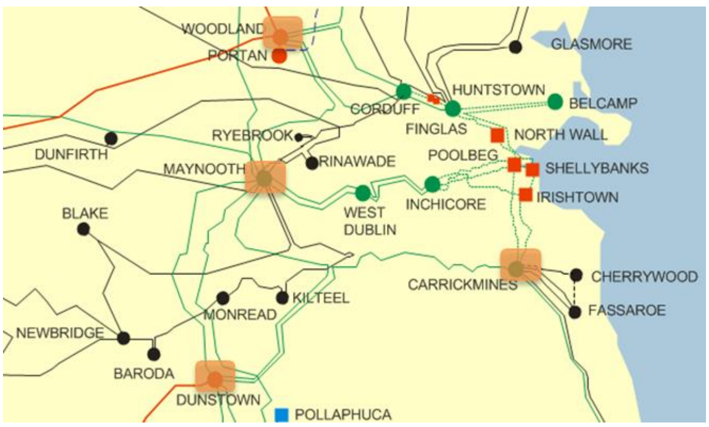


Figure 2 *Main transmission stations for distributing power around the capital.*

network connecting these nodes becomes essential for distributing the power around the capital.

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

- Wide spread Voltage issues and Voltage collapse.
  Voltage collapse means that the voltage cannot be maintained in the transmission system due to widespread insufficient reactive power supply or insufficient network capacity to support the power flows. During certain operating conditions, these severe voltage issues have been identified in Counties Dublin, Kildare and Meath in particular and sometimes extending towards the south east, midlands and north east.
- Capacity problems related to thermal overloads and highly loaded circuits.
  For unplanned losses of any of the 400 kV circuits, or the loss of certain 220kV circuits, or certain 110 kV circuits in the South East the following circuits are overloaded;
  - Maynooth – Shannonbridge 220 kV
  - Oldstreet – Tynagh 220 kV
  - Lanesboro – Mullingar 110 kV
  - Bracklone – Portlaoise 110 kV
  - Killoteran – Waterford 110 kV

  Many 220 kV and 110 kV circuits experience high power loading as a result of these generation and demand patterns. This will become an issue following a subsequent loss of plant and equipment while another is out for planned maintenance. The overloads observed are so severe that significant amounts of generation would have to be re-dispatched to facilitate maintenance under these circumstances. Maintenance of plant and equipment is carried out annually during March to October and as such the indicated overloaded circuits are a concern. To mitigate the risks of the circuits' capacity ratings being exceeded, renewable generation would be heavily constrained and, as a consequence, this constrained renewable power generation would then be displaced with significant amounts of fossil fuel sources of generation with a higher cost.
- 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.

A reinforcement between Dunstown and Woodland stations is essential to:

- Ensure a reliable and secure transmission system for the people of Ireland;
- Achieve the Government's 70% renewable energy target; and,
- Provide unconstrained market access to all connecting parties, including both demand and generation customers.

This need for transmission reinforcement has been indicated in the latest TES 2019 System Needs Assessment[4] (Section 5.1: Area 1 Dublin Mid-East). This need is also present when planned offshore wind generation facilities connect on the East coast. The Government's Climate Action Plan sets a target to connect 3.5 GW of offshore wind by 2030. This is more than three times the peak demand in the East Coast today. Once connected to the transmission system, this offshore power will have to be transported around the network to where it is needed. The need associated with this offshore wind on the East coast is indicated in the TES System Needs Assessment. A reinforcement between Dunstown and Woodland stations will help alleviate this need.

[4] TES 2019 System Needs Assessment http://www.eirgridgroup.com/site-files/library/EirGrid/EirGrid-TES-2019-System-Needs-Assessment-Report_Final.pdf, published December 2019

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, extra reactive compensation was required in some cases.

5.1 Winter Peak Export - Four interconnectors

5.1.1 Description of the case

This case has four interconnectors: Moyle in Northern Ireland (capacity 500 MW), EWIC on the East coast north of Dublin (capacity 500 MW), one additional interconnector located at Knockraha in Co. Cork (capacity 700 MW), and another additional interconnector connected at Great Island, Co. Wexford (capacity 500 MW). In this case, all four interconnectors were set to export 290 MW. It was not possible to achieve full export on all four interconnectors due to network constraints preventing further dispatch.

The winter export dispatch consisted of high renewable generation. Generally higher than 60% of installed wind capacity was dispatched around the country, but in some areas up to 100% renewable generation was dispatched, as can be seen in Appendix 2A.1. The generation was dispatched such that no thermal overloads were observed for an intact system. The system peak demand during winter time is normally around 6 pm and all solar generating facilities across the country were therefore set to 0% output in this case. All remaining non-dispatchable generation such as biomass, wave, biogas, etc. was set to dispatch at 100%.

In order to create the most onerous credible scenario, generation in Dublin was minimised to increase cross country flows over the 400 kV network. However, in order to meet the total demand, it was necessary to keep seven of the total 12 synchronous generators in Dublin and seven in Northern Ireland running. Despite the generation on the East coast, the high demand in the area created a large cross country electricity flow from the South and West towards the East coast of Ireland. The SNSP[5] in the case was 55%.

[5] System Non-Synchronous Penetration

5.1.2 Network problems

With the above generation dispatch, heavy loading (over 50%) on several of the 220 kV circuits and 110 kV on the system was observed e.g. the Maynooth – Shannonbridge 220 kV circuit is at 83% loading under intact network. 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 is in the range of 30-40 %. This is to allow for redistribution of the power flow following a contingency (i.e. unplanned loss) of that circuit.

Under this generation dispatch, a single contingency (unexpected loss of a circuit or piece of equipment), such as the loss of any of the 400 kV circuits, the loss of any of several major 220 kV circuits or the loss of any of several generators or interconnectors leads to major voltage issues and voltage collapse for 47 single contingencies (N-1). A list of these contingencies is included in Appendix 1A.1. This indicates that the security of supply of the transmission system is at risk when a generation dispatch like this is occurring, if no additional transmission reinforcements are added.

To further describe the extent of the voltage issues and voltage collapses observed, two maps are presented in Appendix 3. These maps show the large wide spread issue related to the voltage for one of the worst contingencies. Resolving severe voltage issues as described above is not purely a matter of adding reactive support. Severe issues may be more effectively solved by adding further network capacity and more connectivity in the transmission system in combination with reactive support devices. For the purpose of analysing this issue and to help to understand the issues encountered the voltage in the system models will be supported.

In order to avoid voltage collapse for the 47 indicated single contingencies, an additional circa 350 Mvar of reactive support would be required in the Dublin region. This value was determined by using three ‘representative models of voltage support’ (reactive power output independent of system voltage). The voltage setpoints used for these reactive power support devices were taken as the recorded voltage at the point of connection in an intact case.

The reactive support required is based on the difference between the reactive support provided by these devices before and after a tripping of Woodland – Oldstreet 400 kV circuit, which is the worst contingency. With this reactive support included, voltage collapse could be prevented and single contingencies (N-1) could be analysed.

With the voltage supported in the system model, there were no thermal overloads occurring, above the 110% emergency loading limit, for single contingencies (N-1). It is worth noting that the Maynooth – Shannonbridge 220 kV circuit and the Bracklone – Portlaoise 110 kV circuits are loaded up to 102% and 103% of their capacity for an unplanned loss of any of the 400 kV circuits.

Further voltage issues were observed for single contingencies, which indicate that the system is still not compliant with voltage standards despite the voltage being supported with a relatively large amount of Mvars. The voltage issues appear both north of Dublin in the area around the Meath Hill station for the loss of the Meath Hill – Louth 110 kV circuit and on the South East coast around Arklow for the loss of the Great Island – Lodgewood 220 kV circuit. The voltage issues are shown in Appendix 1A.2.

A single contingency on the Oldstreet – Woodland 400 kV circuit results in a large phase angle difference of 27˚ between the Oldstreet and Woodland stations post the single contingency. The angle observed is below the limit of 40°, set in our Operating Security Standards (OSS). This is still reported as a problem, as in the Irish system this is still a relatively high angle to try to close a circuit breaker on to and it may cause operational difficulties with re-dispatch of generation and/or constraint of renewable generation as the only solutions to reduce the angle before the circuit breaker can be closed. This will lead to higher production costs, higher renewable constraint levels and it may increase the time that the circuit is unavailable with a resulting impact on the reliability of the transmission network.

It should be noted that the above dispatch had some batteries dispatched in the Midlands. These particular battery facilities are designed to have short-term energy capacity. This means that they can export at their MEC for a half an hour period before they need to re-charge. As such, there is a risk that these facilities may not be able to help during the entire period when the indicated problems occur. To check the impact of their unavailability, sensitivity analysis was carried out. This indicated that without the support of these batteries, the voltage issues reported become worse. These batteries were supporting the voltage in in the Midlands and without them the same stations experienced more severe voltage issues while additional stations also began to experience voltage issues.

5.1.3 Re-dispatched case

Another way of preventing voltage collapse and providing reactive support where it is needed is to re-dispatch existing generation. This approach could drive high operational and production cost as generators not normally in merit would be dispatched to provide necessary voltage support. The generation in the case was adjusted until loss of any circuit or generator (single contingency N-1 analysis) could be completed without voltage collapse occurring or thermal overloads above the 110% emergency loading.

The re-dispatch included the reduction of renewable generation levels in the South West and this was replaced with generation in the Dublin region. The re-dispatched wind levels can be seen in Appendix 2A.2. This generation was primarily replaced by three additional conventional generators in Dublin. The extra conventional generators will both reduce the power transfers across the network and provide voltage support in Dublin preventing voltage collapse for any single contingency (N-1) including the loss of a single generator.

The extra generation units in Dublin reduced the loading on the circuits traversing the country, especially the 400 kV network. With this dispatch, the loading of Woodland - Oldstreet 400 kV circuit reduced from 43% to 26%, and the loading of Coolnabacky – Dunstown 400 kV circuit reduced from 29% to 19%. It can be seen that the Woodland – Oldstreet 400 kV circuit (the most northern circuit) carries more power than the parallel Coolnabackey – Dunstown 400 kV circuit. This is due to the system topology at the end of the circuits, especially the fact that the Moyle and EWIC Interconnectors are located on this side of the electricity system and are exporting in the case. On the 220 kV network, the most highly loaded circuit was the Maynooth – Shannonbridge 220 kV circuit and with the re-dispatch, the loading on this circuit reduced from to 81% to 64%.

A single contingency on the Oldstreet – Woodland 400 kV circuit results in a large phase angle difference of 24˚ between the Oldstreet and Woodland stations after the single contingency. As can be seen, the re-dispatch did not significantly reduce the phase angle and as such will still remain as an issue. As described in Section 5.1.2, this may cause operational difficulties with re-dispatch of generation and/or constraint of renewable generation as the only solutions to reduce the angle before the circuit breaker can be closed. This will lead to higher production costs, higher renewable constraint levels and it may increase the time that the circuit is unavailable and, as such, have an impact on the reliability of the transmission network.

5.2 Summer Peak Export - Four interconnectors

5.2.1 Description of the case

This case has four interconnectors: Moyle in Northern Ireland, EWIC connected north of Dublin, Celtic connected in the South in Co. Cork, and Greenlink connected in Great Island in the East at Co. Wexford, all on full export capacity.

The summer export dispatch consisted of high renewable generation. Generally, higher than 95% of installed wind capacity was dispatched around the country, but generation was dispatched at circa 50% in the North West due to local export restrictions, as can be seen in Appendix 2B.1. Because this was a summer peak case, all solar generating facilities across the country were set to 100% output. All remaining non-dispatchable generation such as biomass, wave, biogas, etc. was set to dispatch at 100%.

In order to create the most onerous credible scenario, generation in Dublin was minimised to increase cross country flows over the 400 kV network. However, in order to meet the total demand, it was necessary to keep five of the total 12 synchronous generators in Dublin and six in Northern Ireland running. Despite the generation on the East coast, this case created a large cross country electricity flow from the South and West towards the East coast of Ireland. The SNSP in the case is 67%.

5.2.2 Network problems

Under these generation assumptions the Maynooth – Shannonbridge 220 kV circuit is overloaded to 103% under intact network conditions. In regards to the rest of the circuits, heavy loading (over 50%) on several of the 220 kV and 110 kV circuits on the system was observed. It should 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 is 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 and to allow for maintenance of circuits.

Under this generation dispatch, a single contingency (unexpected loss of a circuit or piece of equipment), leads to major voltage issues and voltage collapse for two single contingencies (N-1). A list of these contingencies is included in Appendix 1B.1.

This indicates that the security of supply of the transmission system is at risk when a generation dispatch like this is occurring, if no additional transmission reinforcements are added. Resolving severe voltage issues as described above is not purely a matter of adding reactive support. Severe issues may be more effectively solved by adding further network capacity and more connectivity in the transmission system in combination with reactive support devices. For the purpose of analysing this issue and to help to understand the issues encountered the voltage in the system models will be supported.

In order to avoid voltage collapse, an additional circa 390 Mvar of reactive support would be required in the Dublin region. This value was determined by using three ‘representative models of voltage support’ (reactive power output independent of system voltage). The voltage setpoints used for these reactive power support devices were taken as the recorded voltage at the point of connection in an intact case. The reactive support required is based on the difference between the reactive support provided by these devices before and after a tripping of Woodland – Oldstreet 400 kV circuit, which is the worst contingency.

With the reactive support included, a number of thermal overloads were identified. These are outlined in Appendix 1B.2. The thermal overloads were mainly caused by single contingencies (N-1) of the 400 kV network and overloaded Bracklone – Portlaoise 110 kV, Oldstreet – Tynagh 220 kV, and Lanesboro – Mullingar 110 kV circuits. As stated previously Maynooth – Shannonbridge 220 kV circuit was already overloaded, at 103% loading, for an intact network.

An unplanned loss of the Oldstreet – Woodland 400 kV circuit (N-1 contingency), results in a large phase angle difference of 29˚ between the Oldstreet and Woodland stations post the single contingency. The angle observed is below the limit of 40°, set in our Operating Security Standards (OSS). This is still reported as a problem, as in the Irish system this is still a relatively high angle to try to close a circuit breaker on to, and it may cause operational difficulties with re-dispatch of generation and/or constraint of renewable generation as the only solutions to reduce the angle before the circuit breaker can be closed. This will lead to higher production costs, higher renewable constraint levels and may increase the time that the circuit is unavailable and as such will impact the reliability and security of the transmission network.

It should be noted that the above dispatch had some batteries dispatched in the Midlands. These particular battery facilities are designed to have short-term energy capacity. This means that they can export at their MEC for a half an hour period before they need to re-charge. As such, there is a risk that these facilities may not be able to help during the entire period when the indicated problems occur.

To check the impact of their unavailability, sensitivity analysis was carried out. This indicated that the intact overload on Maynooth – Shannonbridge 220 kV circuit is no longer present. These batteries were supporting the voltage in in the Midlands and without them the same stations experienced more severe voltage issues while additional stations also began to experience voltage issues.

5.2.3 Re-dispatched case

Another way of preventing the voltage collapse and providing reactive support where it is needed is to re-dispatch existing generation. This approach could drive high operational production costs as generators not normally in merit would be dispatched to provide necessary voltage support. The generation in the case was adjusted until loss of any circuit or generator (single contingency N-1 analysis) could be completed without voltage collapse occurring or thermal overloads above the 110% emergency loading.

The re-dispatch included the reduction of renewable generation levels in the North West, South West, and East and replaced with generation elsewhere, primarily in the Dublin region and Belfast. The dispatch of wind generation can be seen in Appendix 2B.2.

The extra generation on the East coast reduced the loading on the circuits traversing the country, especially the 400 kV network. With this generation dispatch, the loading of Woodland - Oldstreet 400 kV circuit reduced from 48% to 43%, and the loading of Coolnabacky – Dunstown 400 kV circuit reduced from 29% to 27%.

It can be seen that the Woodland – Oldstreet 400 kV circuit (the most northern circuit) carries more power than the parallel Coolnabackey – Dunstown 400 kV circuit. This is due to the system topology at the end of the circuits, especially the fact that the Moyle and EWIC Interconnectors are located on this side of the electricity system and are exporting in the case. On the 220 kV network, the most highly loaded circuit was previously the Maynooth – Shannonbridge 220 kV circuit and with the re-dispatch, the loading on this circuit reduced from to 105% to 90% under intact network conditions.

A single contingency on the Oldstreet – Woodland 400 kV circuit results in a large phase angle difference of 28˚ between the Oldstreet and Woodland stations post the single contingency. As can be seen, the re-dispatch of generation did not significantly reduce the phase angle and as such will still remain as an issue. As described in Section 5.2.2, this may cause operational difficulties with further re-dispatch of generation and/or constraint of renewable generation as the only solutions to reduce the angle before the circuit breaker can be closed. This will lead to higher production costs, higher renewable constraint levels and may increase the time that the circuit is unavailable and as such will impact the reliability and security of the transmission network.

5.2.4 Maintenance trip concerns (N-1-1)

An assessment was undertaken into keeping the transmission network within standards following a loss of plant and equipment while another is out for planned maintenance. Maintenance is carried out annually during March to October. For planned outages, some re-dispatch of generation is allowed, but this should be kept to a maximum of 400 MW to ensure the most cost effective generation is dispatched.

Before maintenance trip combinations were assessed, the circuits that were identified to be overloaded under intact network conditions and following single contingency events (N-1) described in Section 5.2.2 were assumed to have been uprated to a higher capacity. Under the assumed circumstances described in Sections 5.2.1 and 5.2.2, the network experiences major voltage issues and voltage collapse. The voltage in the system models has been supported in order to assess the impact of a subsequent loss of plant and equipment whilst another is out for planned maintenance.

This assessment shows that the transmission system is heavily stressed in terms of network capacity and is experiencing severe voltage issues with further support of the voltage required to allow maintenance of circuits.

In addition, there are several circuits which exceed their capacity rating significantly under maintenance conditions. The thermal overloads observed are so severe that significant amounts of generation would have to be re-dispatched to facilitate maintenance under these circumstances.

To mitigate the risks of the capacity ratings of these circuits being exceeded, renewable generation would be heavily constrained and as a consequence this constrained renewable power generation would then be displaced with significant amounts of fossil fuel sources of generation with a higher cost. The capacity ratings of 44 circuits were exceeded for multiple maintenance trip combinations (N-1-1). The highest circuit capacity loading observed was 177.5%. All maintenance trip combinations analysed and the resulting thermal overloads can be seen in Appendix 1B.3.

5.3 Summer Valley Export - Four interconnectors

5.3.1 Description of the case

This case has four interconnectors: Moyle in Northern Ireland, EWIC on the East coast north of Dublin, Celtic in the South in Co. Cork, and Greenlink at Great Island in the East at Co. Wexford, all on full export capacity. The summer export dispatch consisted of a high renewable generation dispatch of circa 97% in the South West, and a low renewable generation dispatch of circa 30% in the rest of the country, as can be seen in Appendix 2C.1.

The generation was dispatched such that no thermal overloads were observed for an intact system. Because this was a summer valley case, all solar and hydro units were set to 0% output, and the Turlough Hill pumped storage units were set to overnight pumping in order to increase its storage capacity to be used for the peak situations (this unit effectively operates as a demand during night time). All remaining non-dispatchable generation such as biomass, wave, biogas, etc. was set to dispatch at 100%.

In order to create the most onerous credible scenario, generation in Dublin was minimised to increase cross country flows over the 400 kV network. However, in order to meet the total demand, it was necessary to keep two of the total 12 synchronous generators in Dublin and four in Northern Ireland running. Despite the generation on the East coast, this created a large cross country electricity flow from the South towards the east coast of Ireland. The SNSP in the case is 72%.

5.3.2 Network problems

With the above generation dispatch heavy loading (over 50%) on several of the 220 kV and 110 kV circuits on the system was observed. 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 is 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 and to allow for maintenance of circuits. There were no contingencies that resulted in voltage collapse.

In Appendix 1C.1, it can be seen that several circuits become overloaded for N-1 contingencies. The thermal overloads were mainly caused by single contingencies (N-1) of 400 kV network and overloaded Maynooth – Shannonbridge 220 kV circuit and Oldstreet – Tynagh 220 kV circuit. The Killoteran-Waterford 110 kV circuit became overloaded due to the loss of Cullenagh-Waterford 110 kV circuit in the South East.

An unplanned loss of Oldstreet – Woodland 400 kV circuit caused a phase angle difference of 31° between Oldstreet and Woodland stations post the single contingency. The angle observed is below the limit of 40°, set in our Operating Security Standards (OSS).

This is still reported as a problem as in the Irish system this is still a relatively high angle to try to close a circuit breaker on to, and it may cause operational difficulties with re-dispatch of generation and/or constraints of renewable generation as the only solution to reduce the angle before the circuit breaker can be closed. This will lead to higher production costs, higher renewable constraint levels and may increase the time that the circuit is unavailable and as such will impact the reliability and security of the transmission network.

5.4 Summer Valley Low Renewable Generation

5.4.1 Description of the case

In this case, the system is evaluated for a low renewables scenario. No wind is dispatched in the country. With no wind dispatched, it was necessary to import 290 MW using EWIC. Because this was a summer valley case, all solar, hydro and hybrid units were set to 0% output, and the Turlough Hill pumped storage units were set to overnight pumping in order to increase its storage capacity to be used for the peak situations ((this unit effectively operates as a demand during night time). All remaining non-dispatchable generation such as biomass, wave, biogas, etc. was set to dispatch at 100%.

In order to create the most onerous credible scenario, generation in Dublin was minimised to increase cross country flows over the 400 kV network. However, in order to meet the total demand, it was necessary to keep two of the total 12 synchronous generators in Dublin and six in Northern Ireland running. The SNSP in the case is 7%.

5.4.2 Network problems

This dispatch did not result in any N-1 voltage collapses, overloading, or voltage violations.

5.5 Summary of network problems

The analysis of the transmission network indicates that there are a number of breaches of our Transmission System Security and Planning Standards (TSSPS) that are required to be addressed. The following subsections summarise the findings for all cases analysed. The technical solution must either resolve these issues on its own or be considered in conjunction with other future works.

5.5.1 Widespread Voltage issues and Voltage collapse

Voltage collapse means that the voltage cannot be maintained in the transmission system due to widespread insufficient reactive power supply or insufficient network capacity to support the power flows.

With the assumed generation and demand patterns, a single contingency (unexpected loss of a circuit or piece of equipment), such as the loss of any of the 400 kV circuits, the loss of any of several major 220 kV circuits or the loss of any of several generators or interconnectors leads to major voltage issues and voltage collapse in counties Dublin, Kildare and Meath in particular and sometimes extending towards the South East, Midlands and North East.

One way to avoid voltage collapse can be to re-dispatch generation. However, this would result in renewable generation having to be heavily constrained and, as a consequence, this constrained renewable power generation would be displaced with significant amounts of fossil fuel generation with a higher cost.

Another way to avoid voltage collapse can be to add reactive support. The analysis indicates that a significant amount of reactive support, above 400 Mvar, is required to maintain the voltage support. Furthermore, the analysis indicates that the low voltage and voltage collapse issue is widespread across a large part of the country. Resolving severe voltage issues as described above is not purely a matter of adding reactive support. Severe issues may be more effectively solved by adding further network capacity and more connectivity in the transmission system in combination with reactive support devices.

5.5.2 Capacity problems related to thermal overloads highly loaded circuits

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.

With the assumed generation and demand patterns, for unplanned losses of any of the 400 kV circuits, or the loss of certain 220kV circuits, or certain 110 kV circuits in the South East the following circuits are overloaded;

- Maynooth – Shannonbridge 220 kV (113-117% of its rated capacity)
- Oldstreet – Tynagh 220 kV (115-124% of its rated capacity)
- Lanesboro – Mullingar 110 kV (111-118% of its rated capacity)
- Bracklone – Portlaoise 110 kV (115-122% of its rated capacity)
- Killoteran – Waterford 110 kV (123% of its rated capacity)

In the Summer Peak case, it was noted that the Maynooth - Shannonbridge 220 kV circuit is overloaded to 103% loading of the circuit capacity in an intact network condition.

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 overloads are observed. This is particularly evident during high regional power transfers from the South, and West, to the East coast.

Many 220 kV and 110 kV circuits experience high power transfers with the assumed generation and demand patterns. This will become an issue following the loss of plant and equipment while another is out for planned maintenance. The analysis indicates that the capacity rating of 44 circuits would be exceeded for multiple maintenance trip combinations (N-1-1).

The highest circuit capacity loading observed was 177.5%. The overloads observed are so severe that significant amounts of generation would have to be re-dispatched to facilitate maintenance under these circumstances. Maintenance of plant and equipment is carried out annually during March to October and as such the indicated number of overloaded circuits is a concern.

To mitigate the risks of the circuits' capacity ratings being exceeded, renewable generation would be heavily constrained and, as a consequence, this constrained renewable power generation would then be displaced with significant amounts of fossil fuel sources of generation with a higher cost, unless a reinforcement is added.

5.5.3 Phase angle issues

Phase angles can be described as the effect or measurement of two things: connectivity and the amount of power being transported through a circuit. The connectivity in the transmission network refers to how many circuits are connected to a substation. The more circuits, the less the angle difference will be before and after circuits are taken out of service for a fault or maintenance. The angles will also be larger before and after circuits are taken out of service if more power was being transported on the circuit before it was unexpectedly lost. The demand and generation patterns analysed have relatively high loadings on the existing circuits.

Large phase angle issues have persisted since the Step 1 needs assessment. Angles between 24 - 31 degrees have been observed.

The angle observed is below the limit of 40° set in our Operating Security Standards (OSS). This standard is currently under review. This is still reported as a problem, as in the Irish system this is still a relatively high angle to try to close a circuit breaker on to, and it may cause operational difficulties with re-dispatch of generation and/or constraints of renewable generation as the only solution to reduce the angle before the circuit breaker can be closed. This will lead to higher production costs, higher renewable constraint levels and may increase the time that the circuit is unavailable and as such will impact the reliability and security of the transmission network.

6 Differences from previous analysis in Step 1

The two drivers highlighted in Step 1 still remain and the need has increased, due to additional demand increases and generation changes. As described in Section 3, the demand from large energy users on the East coast has increased from 900 MW assumed in the Step 1 needs assessment to 1900 MW by 2030 assumed in this analysis. The two drivers are:

1. **Increased demand on the East coast.**
2. **Integration of generation in the South and South West.**

The increases and changes have further increased the need to strengthen the transmission network between Dunstown and Woodland stations.

A direct comparison between the results from the previous Step 1 analysis and the results from this Step 3 analysis cannot be made. The assumptions have changed significantly with regard to both demand and generation, and the assumed locations for these. As a result, the transmission of power across the network is stressing different parts of the network when compared to the Step 1 analysis.

In certain instances, completely different circuits have been indicated as overloaded. Some of these overloads are independent of the issues that Capital Project 966 is trying to solve. As the changes are significant, further grid infrastructure reinforcements in addition to Capital Project 966 may be required to ensure security of supply.

There have been some changes to the circuits that have been observed as overloaded for a single contingency (unexpected loss of a circuit or piece of equipment). In Step 1, multiple circuits in the network corridor between Dunstown and Woodland, and the Bracklone – Portlaoise 110 kV circuit, were overloaded following a single contingency (N-1).

The Bracklone – Portlaoise 110 kV circuit still remains as an issue with the new assumptions included, but as can be seen in Section 5.5, several other circuits are also overloaded. The 220 kV circuits spanning the network corridor between Dunstown and Woodland do not become overloaded with the new assumptions included as they did in Step 1. For example, the corridor between Dunstown and Woodland is no longer overloaded for the single contingency of the Oldstreet – Woodland 400 kV circuit.

There are a number of contributing factors to these changes. As mentioned previously, the change in assumptions is a factor. Another factor is that the Maynooth – Woodland

220 kV circuit will be uprated in the coming years due to a large demand customer connecting at a new 220 kV station, to be looped into that circuit, called Kellystown. The uprate will contribute to a higher capacity being available in this corridor and hence the analysis did not find the previously indicated thermal overloads.

Another contributing factor is the planned reinforcement of Maynooth 220 kV substation. In previous analysis, this substation was assumed to be operated split (effectively two stations) due to high short circuit levels, whereas in the new analysis, it is operated as one station as a reinforcement to resolve the issues is planned.

The voltage issues observed have become more severe in this recent analysis. They are more widespread and relate to more single contingencies compared to the analysis conducted in Step 1.

7 Conclusions

We have previously (in Step 1) identified that we need to strengthen the transmission network between Dunstown and Woodland 400 kV stations. In Step 3, this need has been reviewed and is still robust. The need is more urgent with the identified issues being slightly worse compared with the results of previous analysis conducted in Step 1. In addition, some changes in the observed overloaded circuits have occurred.

The need identified in Step 1 was based on two drivers. These drivers still remain and have further increased the urgency to strengthen the transmission network between Dunstown and Woodland stations.

These two drivers were also identified in Tomorrow's Energy Scenarios (TES) 2019 and our studies are in line with the assumptions in this publicly consulted document. Where necessary, additional demand and generation has been added due to executed and offered connection agreements.

The two drivers are:

1. **Increased demand on the East coast.**
2. **Integration of generation in the South and South West.**

These two drivers introduce cross country power flows on the existing transmission system from the West to the East coast. Network need has been identified 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, and some 220kV circuits.

The need is in relation to two aspects of power transmission:

- Bringing required power to the East coast; and
- Transferring this power within counties Dublin, Kildare and Meath once the power reaches the East coast.

The analysis of the transmission network indicates that there are a number of breaches of our Transmission System Security and Planning Standards (TSSPS) that are required to be addressed. The violations observed can be further divided into three technical categories:

- Wide spread Voltage issues and Voltage collapse;
- Capacity problems related to thermal overloads on highly loaded circuits; and

- Phase angle issues.

A network reinforcement between Dunstown and Woodland stations is essential to:

- Ensure a reliable and secure transmission system for the people of Ireland;
- Achieve the Government's 70% renewable energy target; and
- Provide unconstrained market access to all connecting parties, including both demand and generation customers.

This need for transmission reinforcement has been indicated in the latest TES 2019 System Needs Assessment (Section 5.1 Area 1 Dublin Mid-East). The need is also present when planned offshore wind generation facilities connect on the East coast. Once connected to the transmission system, this offshore power will have to be transported around the network to where it is consumed. The need associated with this offshore wind on the East coast is indicated in the TES 2019 System Needs Assessment. A reinforcement between Dunstown and Woodland stations will help alleviate this need.

Appendix 1 – Analysis Results

Appendix 1A - Winter Export, 4 interconnectors

Appendix 1A.1 - Non Converged N-1 Contingencies

	Non-Converged Contingency Description
1	74520 CAST2 - 74521 BELFAST_CCGT - 275 kV - No.1
2	COOLKEERAGH RUN-BACK CONTINGENCY
3	66122 ORIEL LANDIN - 66123 ORIEL OFFSHO - 220 kV - No.1
4	2742 GREAT ISLAND - 3342 KELLIS - 220 kV - No.1
5	5464 WOODLAND - 380 kV Transformer - No.1
6	GREENLINK
7	LOSS TANDRAGEE-KILROOT-CAST2
8	3082 INCHICORE - 3122 IRISHTOWN - 220 kV - No.1
9	1742 CARRICKMINES - 2202 DUNSTOWN - 220 kV - No.1
10	5464 WOODLAND - 90440 TURLEENA - 380 kV - No.1
11	3842 MAYNOOTH B - 5202 TURLOUGH HIL - 220 kV - No.1
12	3852 MAYNOOTH A - 4943 SHANNONBRIDG - 220 kV - No.1
13	5464 WOODLAND - 380 kV Transformer - No.4
14	MONEYPOINT-LAOIS 400KV CKT
15	CKM-ARK_&_ARK-BEG
16	LAOIS-DUNSTOWN 400KV CKT
17	CKM-ARK_&_CKM-BEG
18	2562 FINGLAS - 220 kV Transformer - No.3
19	LOSS OF MOYLE
20	2742 GREAT ISLAND - 3642 LODGEWOOD - 220 kV - No.1
21	2842 GORMAN - 3522 LOUTH - 220 kV - No.1
22	4384 OLDSTREE - 380 kV Transformer - No.1
23	2042 CORDUFF - 2972 HUNTSTOWN 2 - 220 kV - No.1
24	1472 BELCAMP - 5022 SHELLYBANKS - 220 kV - No.1
25	LOSS OF COOLKEERAGH DOUBLE CIRCUIT
26	LOSS OF CORDUFF-FINGLAS DOUBLE CIRCUIT
27	3464 KILP - 3934 MNYPG1 - 380 kV - No.1
28	2002 CULLENAGH - 3203 KNOCKRAHA - 220 kV - No.1
29	1122 ARKLOW - 3642 LODGEWOOD - 220 kV - No.1
30	MAGF-TAMN
31	MONEYPOINT-OLDSTREET 400KV CKT
32	OLDSTREET-WOODLAND 400KV CKT
33	1522 CLONEE - 5462 WOODLAND - 220 kV - No.1
34	30820 INCHICORE - 220 kV Transformer - No.3
35	LOSS GEN_COOL ST & GT
36	3082 INCHICORE - 220 kV Transformer - No.4
37	LOSS OF TYNAGH
38	4472 POOLBEG SOUT - 30820 INCHICORE - 220 kV - No.2
39	66121 ORIEL - 66122 ORIEL LANDIN - 220 kV - No.1
40	2571 FIN_RURAL - 2701 GLASMORE - 110 kV - No.1
41	4942 SHANNONBRIDG - 4943 SHANNONBRIDG - 220 kV - No.1
42	2563 FINGLAS220B - 4242 NORTH WALL - 220 kV - No.1
43	2562 FINGLAS - 220 kV Transformer - No.2
44	4461 POOLBEG - 4651 RINGSEND - 110 kV - No.3
45	4382 OLDSTREET - 5172 TYNAGH - 220 kV - No.1
46	3472 CASTLEBAGOT - 3852 MAYNOOTH A - 220 kV - No.2
47	3192 KNOCKANURE - 3462 KILPADDOGE - 220 kV - No.2

Appendix 1A.2 - With reactive compensation – Low Voltage Violations

	Low Voltage Range Node	Lowest Voltage [p.u.]	Contingency Description
1	1371 POLLAHONEY - 110 kV	0.895	2742 GREAT ISLAND - 3642 LODGEWOOD - 220 kV - No.1
2	3821 MEATH HILL - 110 kV	0.872	3821 MEATH HILL - 35211 LOUTHB - 110 kV - No.1
3	4901 SHELTON ABBE - 110 kV	0.898	2742 GREAT ISLAND - 3642 LODGEWOOD - 220 kV - No.1
4	6700 ARKLOW_BATTE - 110 kV	0.898	2742 GREAT ISLAND - 3642 LODGEWOOD - 220 kV - No.1
5	1121 ARKLOW - 110 kV	0.898	2742 GREAT ISLAND - 3642 LODGEWOOD - 220 kV - No.1

Appendix 1B- Summer Peak Export, 4 interconnectors

Appendix 1B.1 -– Non Converged N-1 Contingencies

	Non-Converged Contingency Description
1	2042 CORDUFF - 2972 HUNTSTOWN 2 - 220 kV - No.1
2	OLDSTREET-WOODLAND 400KV CKT

Appendix 1B.2 - With reactive compensation – N-1 overloads

	Thermal Overload Description	Rating [MVA]	Highest Loading [%]	Contingency Description
1	3852 MAYNOOTH A - 4943 SHANNONBRIDG - 220 kV - No.	269	103.3	BASE CASE
2	1791 BRACKLONE - 4481 PORTLAOISE - 110 kV - No.1	99	121.7	LAOIS-DUNSTOWN 400KV CKT
3	1791 BRACKLONE - 4481 PORTLAOISE - 110 kV - No.1	99	114.9	OLDSTREET-WOODLAND 400KV CKT
4	3501 LANESBORO - 4001 MULLINGAR - 110 kV - No.1	99	117.6	OLDSTREET-WOODLAND 400KV CKT
5	3501 LANESBORO - 4001 MULLINGAR - 110 kV - No.1	99	115.9	OLDSTREET 380 KV TRANSFORMER
6	3501 LANESBORO - 4001 MULLINGAR - 110 kV - No.1	99	115.9	4382 OLDSTREET - 5172 TYNAGH - 220 kV - No.1
7	3501 LANESBORO - 4001 MULLINGAR - 110 kV - No.1	99	113.9	MONEYPOINT-LAOIS 400KV CKT
8	3501 LANESBORO - 4001 MULLINGAR - 110 kV - No.1	99	112.9	3852 MAYNOOTH A - 4943 SHANNONBRIDG - 220 kV - No.1
9	3501 LANESBORO - 4001 MULLINGAR - 110 kV - No.1	99	111.3	CELTIC
10	4382 OLDSTREET - 5172 TYNAGH - 220 kV - No.1	434	124.1	MONEYPOINT-OLDSTREET 400KV CKT

Appendix 1B.3 – Maintenance trip / N-1-1 overloads

	Thermal Overload Description	Maintenance Description	Contingency Description	Rating (MVA)	Highest Loading (%)
1	NORTH_WA – POOLBE_N 220 kV No.1	OLDSTREET_WOODLAND 400 kV	BELCAM - SHELLY - 220 kV - No.1	332	177.5
2	FINGLA – NORTH_WA 220 kV No.1	OLDSTREET_WOODLAND 400 kV	BELCAM - SHELLY - 220 kV - No.1	332	176.6
3	KILLOT – WATERF 110 kV No.1	CULLENAGH_WATERFO 110 kV	CULLEN - GREAT_IS - 220 kV - No.1	99	159.6
4	ARVA – CARRIC_O 110 kV No.1	OLDSTREET_WOODLAND 400 kV	FLAGFO - LOUTH - 220 kV - No.1	104	148.3
5	CLOON – LANESB 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	63	144.1
6	BRACKL – NEWBRI 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	136	142.8
7	IRISHT – SHELLY 220 kV No.1	OLDSTREET_WOODLAND 400 kV	MAYNOO_A_KELLYS	593	139.5
8	LANESB – SLIABH_B 110 kV No.1	LAOIS_MNYPG 400 kV	FLAGFO - LOUTH - 220 kV - No.1	99	132.8
9	BARODA – MONREA 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	99	131.3
10	POOLBE_S – INCHIC 220 kV No.1	INCHICORE_POOLBEG_S220	IRISHT - SHELLY - 220 kV - No.1	267	130.5
11	CLONEE – WOODLA 220 kV No.1	CORDUFF_WOODLAND 220 kV	EWIC	434	130
12	CULLEN – WATERF 110 kV No.1	CULLENAGH_GT_ISLAND 220 kV	CELTIC	178	128.8
13	FINGLA – NORTH_WA 220 kV No.1	INCHICORE_IRISHTOWN	BELCAM - SHELLY - 220 kV - No.1	332	128.5
14	CLONEE – WOODLA 220 kV No.1	LAOIS_MNYPG 400 kV	CORDUFF_WOODLAND220	434	128.5
15	CORDUF – WOODLA 220 kV No.2	CLONEE_WOODLAND 220 kV	EWIC	434	128
16	INCHIC – IRISHT 220 kV No.1	OLDSTREET_WOODLAND 400 kV	IRISHT - SHELLY - 220 kV - No.1	562	127.3
17	CORDUF – WOODLA 220 kV No.2	LAOIS_MNYPG 400 kV	CLONEE - WOODLA - 220 kV - No.1	434	127.2
18	CASTLE – MAYNOO_A 220 kV No.2	INCHICORE_IRISHTOWN	CASTLE - MAYNOO_B - 220 kV - No.1	761	123.7

19	DRYBRI – LOUTHA 110 kV No.1	GORMAN_LOUTH	WOODLA - ORIEL - 220 kV - No.1	99	123.1
20	CASTLE – MAYNOO_B 220 kV No.1	INCHICORE_IRISHTOWN	CASTLE - MAYNOO_A - 220 kV - No.2	761	120.5
21	BRACKL – PORTLA 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	178	119.6
22	NORTH_WA – POOLBE_N 220 kV No.1	OLDSTREET_WOODLAND 400 kV	BELCAM - FINGLA - 220 kV - No.1	332	119.2
23	ATHY – CARLOW 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	99	119.1
24	ARKLOW – BALLYB 110 kV No.1	OLDSTREET_WOODLAND 400 kV	ARKLOW - CARRIC - 220 kV - No.1	99	117.4
25	MAYNOO_B – BLAKE_T 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	99	117.4
26	COOLNA – PORTLA 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	178	116.4
27	LOUTHA – RATRUS 110 kV No.1	OLDSTREET_WOODLAND 400 kV	FLAGFO - LOUTH - 220 kV - No.1	95	115.2
28	BARODA – NEWBRI 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	122	114.5
29	CORDUF – FINGLA 220 kV No.2	LAOIS_MNYPG 400 kV	CORDUF - FINGLA - 220 kV - No.1	434	114.3
30	CORDUF – FINGLA 220 kV No.1	LAOIS_MNYPG 400 kV	CORDUF - FINGLA - 220 kV - No.2	434	114.3
31	CRANE – WEXFOR 110 kV No.1	GT_ISLAND_LODGEWOOD 220 kV	GREENLINK	99	114
32	MAYNOO_A – TIMAHO 110 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	112	111.2
33	KILLON – SHANNO 220 kV No.1	LAOIS_MNYPG 400 kV	MNYPG_OLDSTREET 400 kV	269	109.7
34	BUTLER – CULLEN 110 kV No.1	CULLENAGH_WATERFO 110 kV	CULLEN - GREAT_IS - 220 kV - No.1	178	109.6
35	BALLYN – GLENLA 110 kV No.1	MNYPG_OLDSTREET 400 kV	UNIT_TYC	124	109.2
36	CAHIR – DOON 110 kV No.1	KNOCKRA_CULLEN 220 kV	CELTIC	178	109.1
37	FLAGFO – LOUTH 220 kV No.1	DUNSTOWN_LAOIS 400 kV	OLDSTREET_WOODLAND 400 kV	384	107.8
38	POOLBE_S – INCHIC 220 kV No.2	INCHICORE_POOLBEG_S220	IRISHT - SHELLY - 220 kV - No.1	351	104.7
39	WOODLA – ORIEL 220 kV No.1	WOOD_TURL 400 kV	MOYLE	434	103.8
40	DUNGAR – WOODHO 110 kV No.1	KNOCKRA_CULLEN 220 kV	CELTIC	178	102.8
41	CARRIC – IRISHT 220 kV No.1	OLDSTREET_WOODLAND 400 kV	GREENLINK	593	101.5
42	CASHLA – PROSPE 220 kV No.1	MNYPG_OLDSTREET 400 kV	LAOIS_MNYPG 400 kV	392	101.2
43	KNOCKR_A – GALWAY 110 kV No.1	CORDUFF_HUNSTOWN 220 kV	UNIT_TYC	99	101.2
44	AGANNY – SHANNO 110 kV No.1	LAOIS_MNYPG 400 kV	MNYPG_OLDSTREET 400 kV	104	101
45	GORMAN – MAYNOO_B 220 kV No.1	WOOD_TURL 400 kV	MOYLE	350	100.8
46	BALLYDINE – DOON 110 kV No.1	KNOCKRA_CULLEN 220 kV	CELTIC	178	100.4

Appendix 1C- Summer Valley Export, 4 interconnectors

Appendix 1C.1 - Summer Valley Export, 4 interconnectors – N-1 overloads

	Thermal Overload Description	Rating [MVA]	Highest Loading [%]	Contingency Description
1	3401 KILLOTERAN - 5441 WATERFORD - 110 kV - No.1	99	122.5	2001 CULLENAGH - 5441 WATERFORD - 110 kV - No.1
2	3852 MAYNOOTH A - 4943 SHANNONBRIDG - 220 kV - No.1	269	116.7	OLDSTREET-WOODLAND 400KV CKT
3	3852 MAYNOOTH A - 4943 SHANNONBRIDG - 220 kV - No.1	269	114.2	LAOIS-DUNSTOWN 400KV CKT
4	3852 MAYNOOTH A - 4943 SHANNONBRIDG - 220 kV - No.1	269	113.3	MONEYPOINT-LAOIS 400KV CKT
5	4382 OLDSTREET - 5172 TYNAGH - 220 kV - No.1	434	115	MONEYPOINT-OLDSTREET 400KV CKT

Appendix 2 Wind dispatch levels

Map showing the indicative four general areas that represent the wind dispatch in the tables below

Appendix 2A - Winter Export, 4 interconnectors

Appendix 2A.1 – Wind dispatched for base case with N-1 voltage collapse

AREA	Wind Dispatched in Area [MW]	Total Wind Capacity in Area [MW]	% Wind Scheduled in Area
South West	2434	2733	89%
North West	1132	1896	60%
NI	1298	1298	100%
East	791	1009	78%

Appendix 2A.2 – Wind redispatched to avoid N-1 voltage collapse

AREA	Wind Dispatched in Area [MW]	Total Wind Capacity in Area [MW]	% Wind Scheduled in Area
South West	2250	2733	82%
North West	1132	1896	60%
NI	1298	1298	100%
East	791	1009	78%

Appendix 2B- Summer Peak Export, 4 interconnectors

Appendix 2B.1 – Wind dispatched for base case with N-1 voltage collapse

AREA	Wind Dispatched in Area [MW]	Total Wind Capacity in Area [MW]	% Wind Scheduled in Area
South West	2698	2733	100%
North West	982	1896	52%
NI	1298	1298	100%
East	974	1009	96%

Appendix 2B.2 – Wind redispatched to avoid N-1 voltage collapse

AREA	Wind Dispatched in Area [MW]	Total Wind Capacity in Area [MW]	% Wind Scheduled in Area
South West	2389	2733	87%
North West	612	1896	32%
NI	1298	1298	100%
East	687	1009	68%

Appendix 2C- Summer Valley Export, 4 interconnectors

Appendix 2C.1 – Wind dispatched for case (base case had no associated N-1 voltage collapse. Thus no redispatching was conducted)

AREA	Wind Dispatched in Area [MW]	Total Wind Capacity in Area [MW]	% Wind Scheduled in Area
South West	2641	2733	97%
North West	439	1896	23%
NI	389	1298	30%
East	335	1009	33%

Appendix 3 – Extent of voltage issue

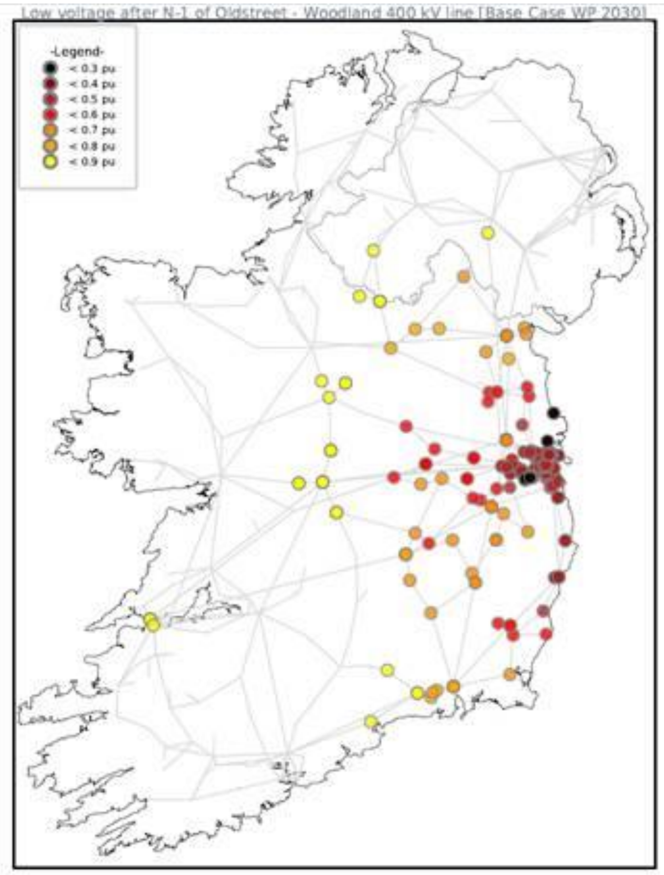
The maps shown below illustrate the extent of the widespread voltage issues for an unplanned loss of the Oldstreet – Woodland 400kV circuit for a winter peak scenario. This is one of 47 voltage collapses indicated in the winter peak scenario, shown as an example.

The results shown in Map 1 are with the Midlands batteries included while Map 2 does not have the Midlands batteries included. As stated earlier in the report, these battery facilities are designed to have short-term energy capacity. This means that they typically can export at their MEC for a half an hour period before they need to re-charge. As such, there is a risk that these facilities may not be able to help during the entire period when the indicated problems occur.

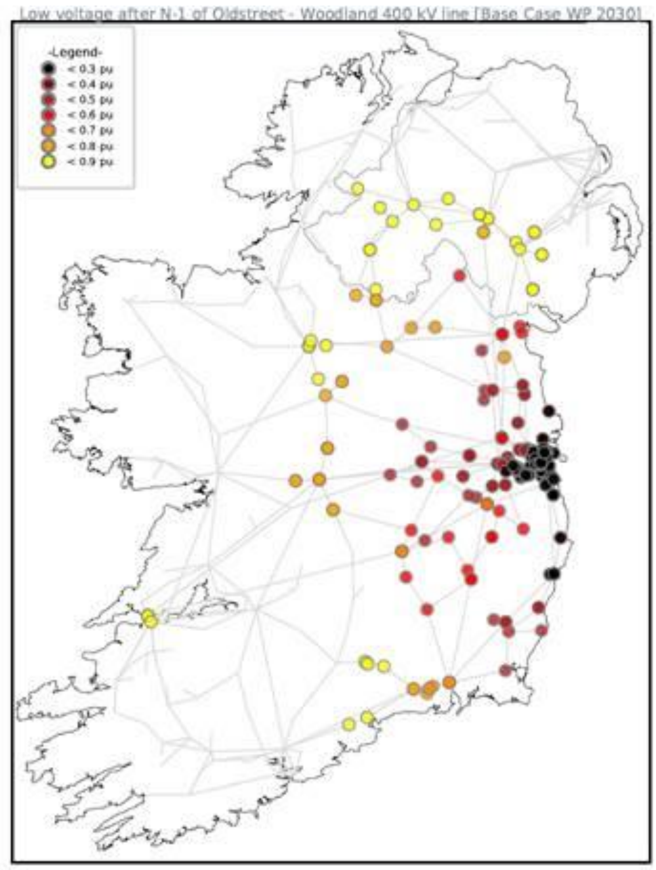
The two maps show that the voltage situation will become worse when the battery facilities are not available.

The maps also show the effect of what is happening on the system during voltage collapse. Effectively, the entire system collapses as the voltage cannot be supported. It further shows that the effect is widespread across most of the country.

The extent of the problem indicates that the issue cannot solely be solved by adding reactive support.



Map 1



Map 2