The Electromagnetic Transient Analysis in the decision making process at planning stage

Andrea Mansoldo, Mark Norton
Eirgrid, Ireland

Technology & Standards
160 Shelbourne Road
Ballsbridge
Dublin 4, Ireland
Andrea.mansoldo@eirgrid.com
Mark.Norton@eirgrid.com

Abstract - *Following the 2020 targets for CO2 reduction and the subsequent large planned RES deployment in Europe, there is evidence that the present HV Grid is not sufficient to cope with the new future environment. Therefore, TSOs are thoroughly investigating Grid Transmission needs for the future. Nowadays, a large variety of Transmission Technoloies (TT) are available on the market with different capital and operating costs. The location of many of the RES and the increase of environmental sensitivity is obliging TSOs to considering often and often the undergrounding option using HVAC or HVDC cable technology to allow for the Grid upgrading.*
Because of the aggressive 2020 targets, 40% of RES energy by 2020 and the consequence of large amount of RES, about 5000 MW of wind, coupled with their remote location and the weaknesses of the existing network, Eirgrid, the Irish TSO, is trying to conceive a comprehensive methodology for the Grid Expansion planning aiming at identifying the most efficient, reliable and cost effective development strategy of the network in the long term.

The paper describes the implementation of an extensive EMT power system analysis in the Grid Planning department aiming at investigating any low frequency transient issue that can put system at risk. In particular Transmission Technology Alternatives EMT performances is the focus of the analysis.
It is shown how in the planning process the EMT investigation can provide technical insights that are still fundamental for the decision of infrastructure investment.
Some examples are considered, where the EMT technical performances of the best alternatives are compared .

Keywords*: System Planning, TOVs analysis, Cables, ATPDRAW.*

1. Generals

With a 40% RES penetration to be fulfilled by 2020 Republic of Ireland and Northern Ireland (ROI and NI, All Island, AI) are facing a huge challenge in order to make this strategy to happen. Indeed the 5 GW request of connection onshore, especially for wind, and offshore wind, are at a level that allow the target to be covered; however, If NI transmission grid is a strong double circuit 275 kV Grid, this is not the case for ROI, with a meshed 220 kV, and a

radial 400 kV East-West. Moreover, the integrations of the two jurisdictions is also weak, with only one double circuit 220 kV lines and about 400 MW of Net Transfer Capacity (NTC); congestions are expected in the future has the wind beahvior and distribution may dictate frequent North-South transfers.
Because wind resources location, mostly on the West Coast, is far from the main load consumptions in the East and South, a considerable Long Term grid development plan is currently in progress, [1].
On the other end, Offshore wind developer have asked consensus in Irish territorial water and are willing to either increase or request further connection to the Irish Transmission System (ITS). Eirgrid has therefore further investigated potentials and advantages to optimize infrastructure investment to both fulfill onshore/offshore request as well as better integrate the two AI jurisdiction together and with the British and European markets, towards a 2030 horizon year.

Among the focuses are the understanding the future backbone voltage level, the grid structure, the transmission technology and the best long term dynamic expansion strategy to deploy RES connection request as well as integrate the isle of Ireland with neighbouring countries [2]. Eirgrid assumption for onshore grid developments is to consider the OHL based strategy; however, environmental sensitivity in many Irish countryside compels to investigate mitigations measures to make the projects to be delivered. Undergrounding is among the second best alternatives which finds better acceptance.

2. Introduction

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The paper describes the generalities of the Long Term Planning (LTP) approach to fulfill a comprehensive design of a future grid; it focuses on the EMT studies which have been incorporated at the end of the technical/economical investigations.
A Case of study is shown, starting from a potential Grid structure Expansion Solution (GES) towards 2030, based on 5GW + 5GW wind deployment onshore/offshore respectively thoroughly described in [2]. The GES is submitted to an ATP-EMTP analysis to investigate whether they are technically feasible in some switching operational performances. In particular TOVs are of major concerns at this stage as they can generate overvoltages that jeopardize system reliability on a large extension of the transmission system. Mitigation are discussed in terms of options which may include the change to a second best economic planning solution.

3. The Proposed Long Term Planning (LTP) methodology

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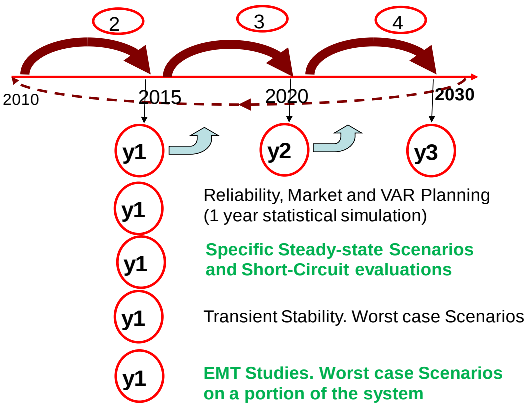
With reference to fig.1, the proposed LTP methodology is shown. A first screening among all possible Alternatives is performed providing incremental GES y1, y2 .. y3. This analysis is based on a linear Load Flow (DCLF) approach.
They are first all submitted to two steady refinement; reliability analysis where possible extra reinforcements are introduced and AC load-flow calculations. At this stage possible extra Compensation is located and a short-circuit analysis is performed to verify the compliance of the future grid with present Transmission Planning Criteria (TPC).

Following a Transient Stability calculation, an EMT study is performed with the main purpose of evaluating whether the GES withstands some operational switching procedures. In particular the analysis concentrates on low frequency resonances phenomena which may be triggered by transients following some switching procedure.



This is of particular concerns **because** the phenomena:

a) has an high energy contents
b) may not be mitigated or mitigation may not be cost effective by traditional devices, i.e. surge arresters, pre-insertion resistors, harmonic filters
c) may be disruptive on long distances, i.e. 300-400 km
d) may be due to the proposed specific transmission technology

Fig.1. Proposed LTP for future Grid design

4. The EMT analysis using ATP-EMTP

To perform such investigation Eirgrid Technology & Standards proposed the ATP-EMTP code [], which is already in use in the Operation Department. Because of the focus of the analysis it has been proposed to represent the ITS 400/220 kV system thoroughly into detail. This may be necessary to investigate TOVs propagation area, should any resonance occurs.

4.1. Resonance phenomena

The resonance phenomenum has always attracted attention to the Power system planner because of its unpredictable occurrances and the corresponding system outage it can produce. Moreover, cascading events may also be triggered in, causing the outage to extend to a large part of the system. Two possibility can be singled out, a parallel resonance and a series resonance.

4.1.1 Parallel

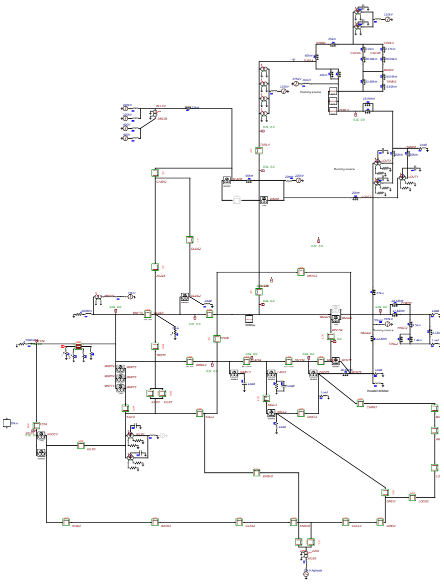
Parallel resonance may occur when energy stored into the system inductance encounters favourable conditions to exchange with the grid capacitances, see fig. 6.

4.1.2 Series

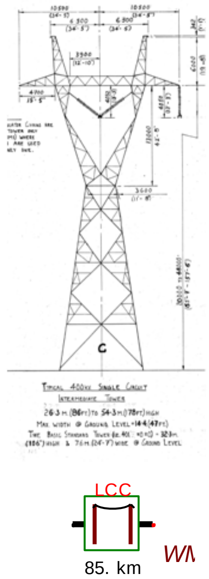
4.2.Modelling set-up

The focus of the analysis is the low frequency resonance and therefore it may be expected a propagation over long distances in particular in case of parallel resonance. This is a consequence of the lower dumping losses, which are voltage dependant, i.e. skin effect, iron core transformer losses, and the energy exchanges between capacitance and inductances.

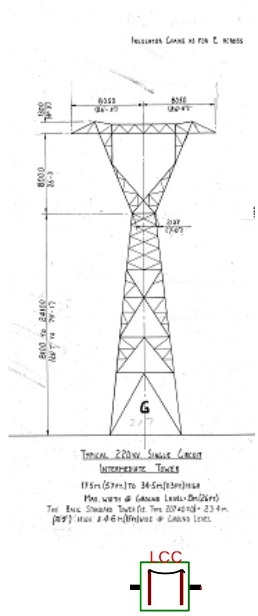
That said, an ATP-EMTP circuit of the 400/220 kV grid of the All Island Transmission System (AITS) has been implemented, see fig.2a.



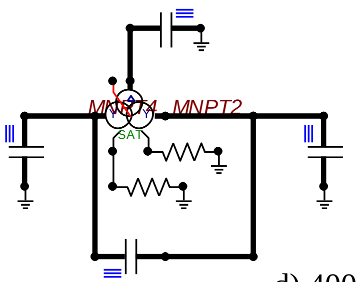
a) ATP-EMTP AITS

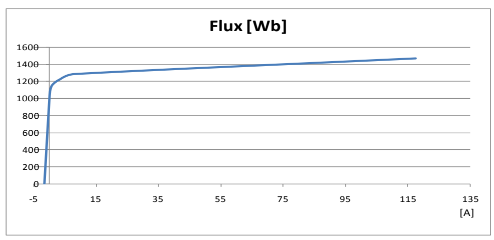


b) 400 kV OHL

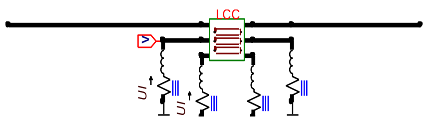


c) 220 kV OHL

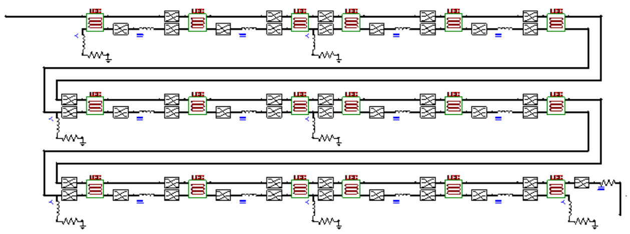




d) 400/220 kV Transformer Model



e) submarine cable model



f) underground cable model

Fig.2. ATP modelling set up

In figg. b, c and d model components are also shown according to ATPDRAW representation; in particular:

1. 400 and 220 kV Overhead lines have been modelled using the J-marti frequency dependent option in the frequency range 0-500 kHz.
2. Transformers have been modelled using BCTRAN option. In the area of investigation, the model has also been considered with the relevant magnetising characteristics.
3. Cables have been modelled using the Cable Parmeters (CP) constant frequency option, using 250 Hz has tuning frequency. Has shown in fig. 2e,f, submarine cable has been considered as one sections with sheath solid bonded connected, whereas for underground cable a cross-bonded shetah connection have been considered with relevant minor/major cross-bonded sections.

4.3. Frequency Scan (FS) and Time Domain (TD) simulations

An extensive N and N-1 contingency, frequency scan is performed in order to identify critical areas/grid assets. In particular the following criteria have been used to single out for each busbar the worst case scenario:

1) lowest resonance frequency
2) corresponding impedance module at that frequency

At present, FS calculations have been perfomed using an alternative tool, IPSA-Power []; suitable additionals scripts allows the automatisation of topology and current injections changes, as well as the store of the results. Investigation are currently in progress to implement the same methodology using ATP-EMTP.

Frequency Scan analysis allows to singled out, grid assets that may be prone to trigger low frequency resonances. These scenarios have to be submitted to a Time Domain (TD) simulation, where evidence of TOVs existence is given. In particular, TOVs is quantified and compared with IEC standards with the purpose of:

1. verify the withstand of existing grid components
2. identify suitable requirements for new components
3. indetify field test parameter for new components

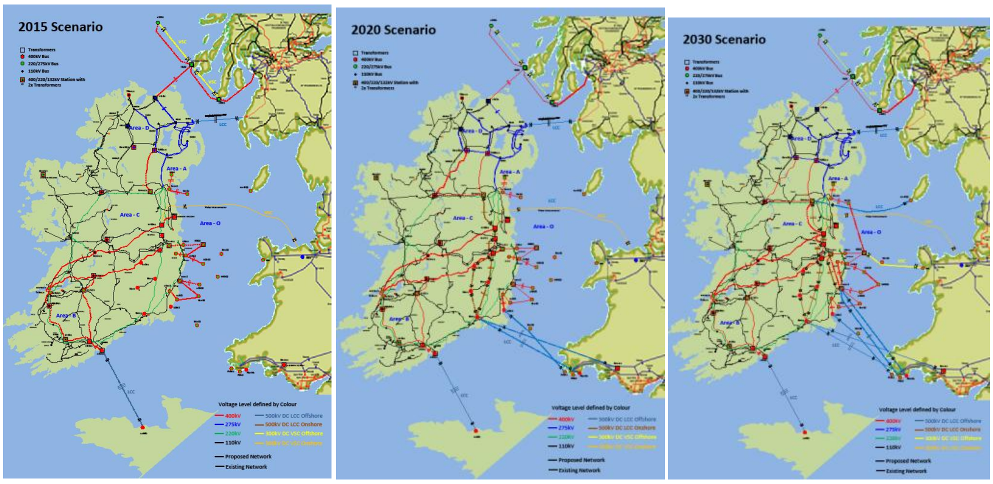
Should IEC standrads limits be exceeded, the TDS can also be used to identify mitigation measures like:

1. additional protection device, i.e. surge arresters, pre-insertion resistors, synchronised switching
2. additional filtering device to detune the grid asset
3. change in the transmission technology to detune the grid asset

5. A Case of Study: an AI GES to 2030.

The described methodology have been applied to a potential development of the AITS to 2030. Using and 'ad hoc' Expansion Planning tool developed by Eirgrid in Cooperation with Ricerca sul Sistema Energetico (RSE) Italy, an offshore grid study have been performed and is thoroughly described in []. An onshore/offshore wind deployment of 5+5 GW has been assumed according to the GATE 3 process results, and information from National Offshore Wind (NOW) association for future offshore installation.

A number of GES has been obtained, also in intermediate steps, as a result of a analysis which optimise Operation and Investment costs, by using a DCLF approach.
Following, an AC analysis have been considered in order to investigate the need and location of var supports. With reference to fig.3, GES for 2015, 2020 and 2030 are shown.
The onshore grid is assumed to be reinforced using OHL technology; for offshore connection both AC and DC technology have been allowed for connection. Selection have been performed by the Optimisation process.



a) 2015 b) 2020 c) 2030

Fig.3. Grid Expansion Solution(GES) to 2030

.With reference to Figg.3, in early stages, only radial connection are considered for offshore wind, whereas some 400 kV reinforcements have been selected onshore, South east and North. More interconnections is then selected towards England following increase in Wind deployment onshore (up to 2020) and offshore.

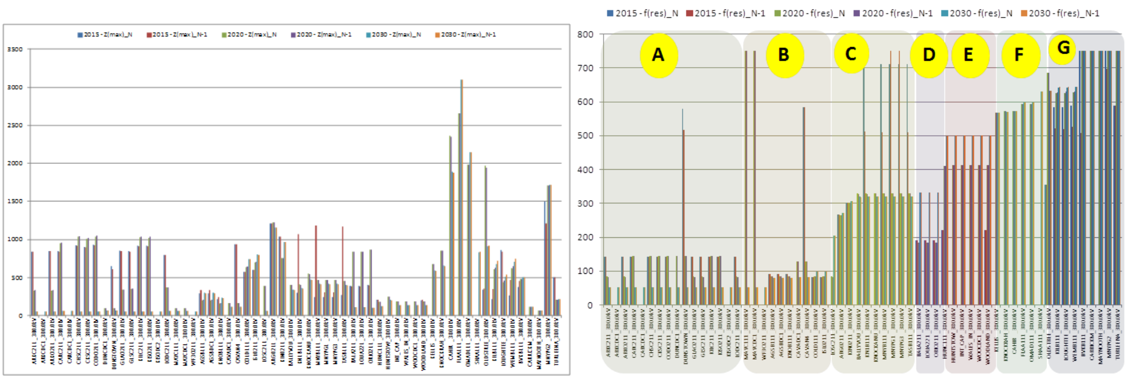
By 2030, a meshed Offshore Grid id obtained, meshing the AITS on the East Cost, using AC technology. Moreover, an Offshore DC is also selected from the Offshore space to further interconnect the country using VSC technology. This latter solution is an example of how synergies can be exploited between Interconnections and Wind farm connections.

5.1.Results

An extensive FS analysis have been performed in N and N-1 conditions on the previously describe GES. Following, some scenarios have been selected to investigate whether any potential TOVs, in some switching operation occurr.

5.2.Frequency Scan

With reference to fig.4, the FS results are shown both for N and N-1 (worst case) conditions.



a) Impedance Module b) Natural System Frequency (NSF)

Fig.4. FS results for Grid Expansion Solution(GES) to 2030

From fig. 4b, it is possible to identify areas with the same beahavior in terms of NSF; in particular, in Area A, NSF tend to decrease as a consequence of increase amount of Capacitances installed in the area, submarine cables and SVC for LCC technology.

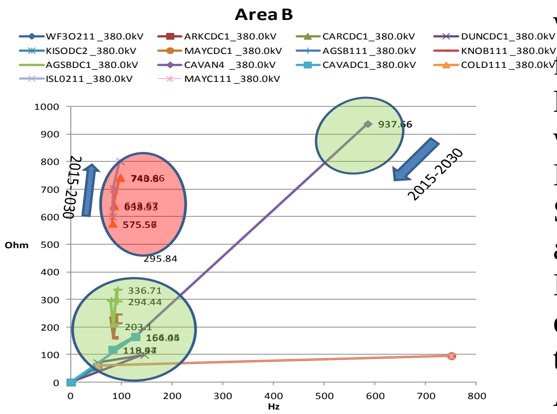
5.2.1 Criterium for Worst Cases (WC) screening

Area A

With reference to fig.5, all the nodes show a low NSF, except Dunstown in 2015, (out of scale). Initially, 2015 they also show high impedance module which make all scenarios at risk.
In 2030 all nodes are in low NSF but alsoin low IM, so no scenarios are at risk. This is due to the prevailing effect of network reinforcements to the increase capacitance (East Offshore Grid AC).

Fig.5. Area A NSF vs. Ohm

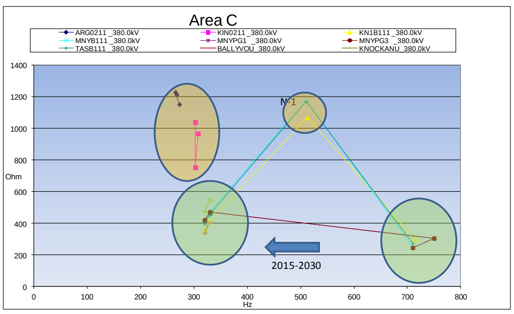
Area B



With reference to fig.10, the NSF behaviour is the following for the nodes; Cavan shows a lowering of NSF but with a contemporary lowering of the IM, which keeps a safe combination parameters.
ISLE offshore and Coleraine in NI and Offshore Scotland are at risk over trhe entire period of analysis, with a low NSF, below 100 Hz and an high IM, above 500 Ohm. This is due to the use of AC offshore cables combined with a radial structure of the grid.
All the other nodes are confined in a low NSF/low IM area which make them not at risk during the system development.

Fig.6. Area **B** NSF vs. Ohm

Area C



With reference to fig.7, different dynamic behaviour can be singled out in 2015-2030 GES:
The Offshore development in Scotland, Argyll and Isle, connected to NI, shows potential risk all over the period with NSF as low as 300 Hz and IM between 800 and 1200 Ohms.
The North Kerry, Moneypoint Area moving towards lower NSF it is not at risk because of the low IM; however temporary high IM in N-1 conditions are shown in some scenarios that require TD simulations.

Fig.7. Area **C** NSF vs. Ohm

Area D

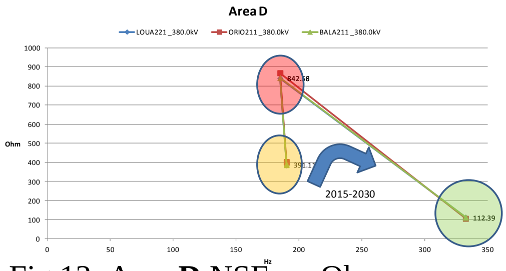


Fig.12. Area **D** NSF vs. Ohm

With reference to fig.12, the D grouping shows a starting point of potential risk, orange area, moving to a risk asset with low NSF and high IM, 900 Ohm and than evolving to a safer grid arrangement.
The final stage is due to the large offshore meshed GES, cfr fig.16, a and b.

Area E

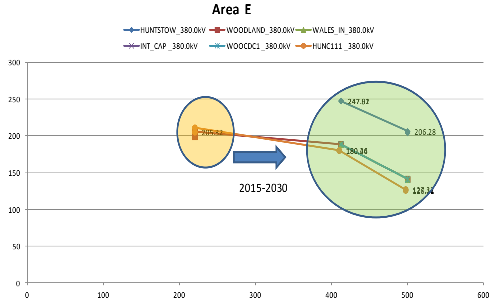


Fig.13. Area **E** NSF vs. Ohm

With reference to fig.13, none of the nodes shows particular critical conditions, in particular because IM is kept low over the GEX 2015-2030.
Because of the relatively low NSF, 200 Hz, an early stage TD is suggested

Area F

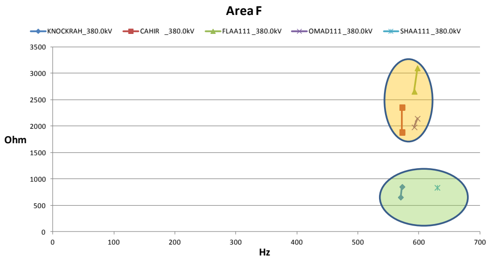


Fig.14. Area **E** NSF vs. Ohm

With reference to fig.14, none of the nodes shows particular critical conditions, in particular because NSF is kept above 500 Hz over the GEX 2015-2030.
Because of the high IM, some 2000-3000 Ohm, some TDs are suggested for Flagford and Cahir 380 kV.

Area G

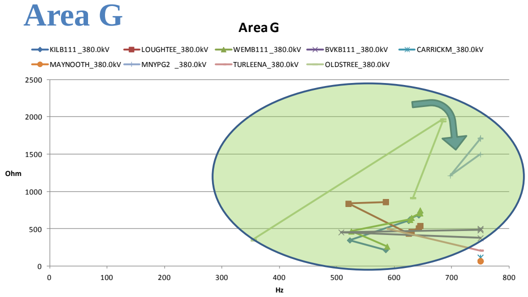
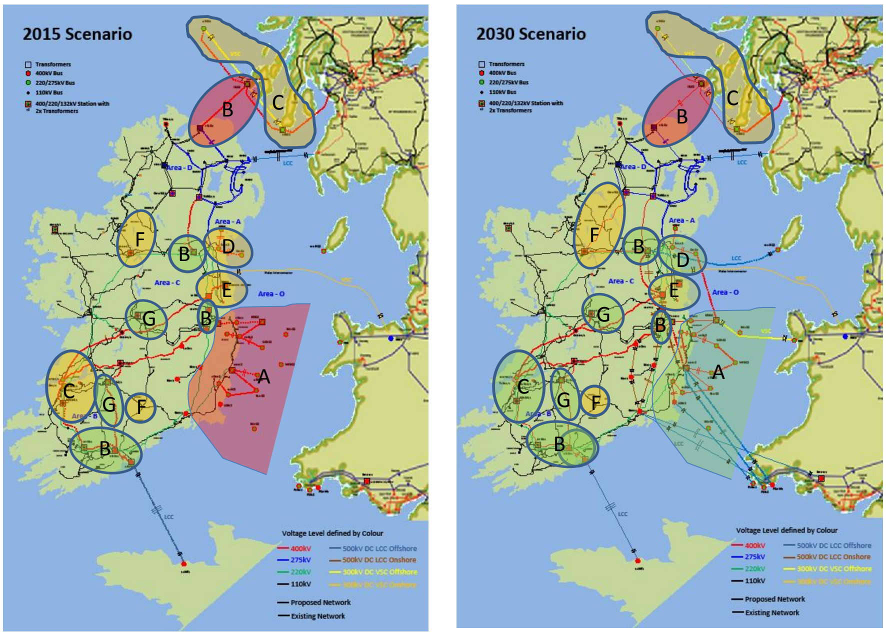


Fig.15. Area **E** NSF vs. Ohm

With reference to fig.15, none of the nodes shows particular critical conditions; both NSF and IM put grid assets out of potential risks for resonances and TOVs over the GEX 2015-2030.

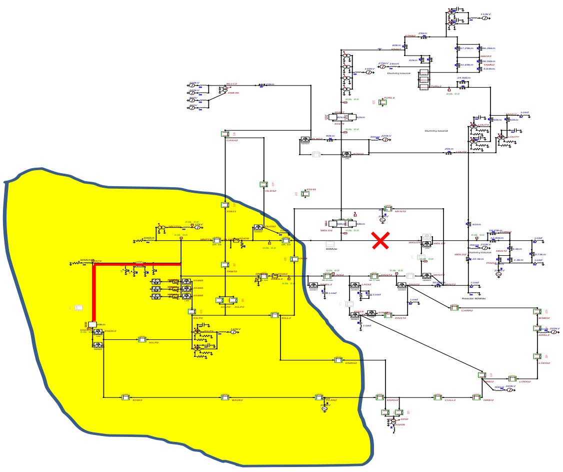


a) 2015 b) 2030

Fig.16. Evolution of critical areas for Resonance phenomena

5.3 Example:North-Kerry reinforcement

One of the areas that can be critical, according to fig.16a is area C, in North-Kerry. The area is submitted to some development projects, aiming at solving congestions, using an extra interconnection between Moneypoint power station and Knocanurha This is also higlighted below in the ATP model, fig.17.



The link foresees a submarine cable to cross the Shannon bay of about 7 km, from Moneypoint to Tarbert shore; following an OHL based solution has been proposed by Eirgrid to connect Tarbert shore with Knockanurha substation at 400 kV. However, feasibility of 400 kV cable options is also evaluated, should any opposition raise for the OHL solution. Tab.1 describes the combination of examined options

Fig.17. North Kerry reinforcement plan

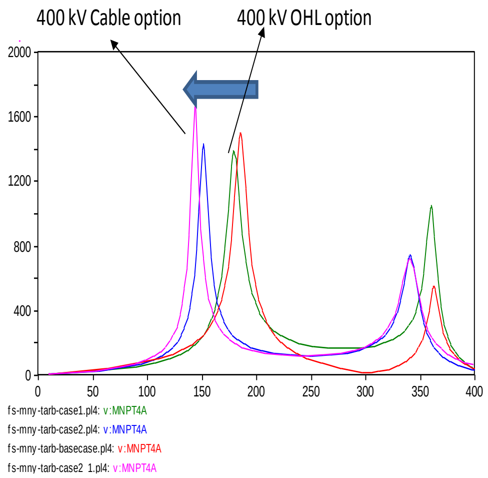
tab.1. Description of cases

	Existing Grid	MNP-TARB SUBC	TARB-KNOCKANURHA OHL	OLDST-WOODLAND OUTAGE
Basecase	YES	NO	NO	NO
Case1	YES	YES	YES	NO
Case1_1	YES	YES	YES	YES
Case2	YES	YES	NO	NO
Case2_1	YES	YES	NO	YES

5.3.1 Frequency Scan

Area evidenced already conditions suitable for resonances; the additional reinforcements might have counteracting effects:

1) reinforce the system thus increasing NSF
2) introducing extra large capacitance, submarine cable and UGC in Case 2, thus decreasing NSF



It is worth notice that:

A. Basecase has already a low NSF, about 180 Hz

B. the additional reinforcement

a. keeps resonance the same if OHL+SUBC

b. reduces NSF to 150 Hz if it is UGC+SUBC

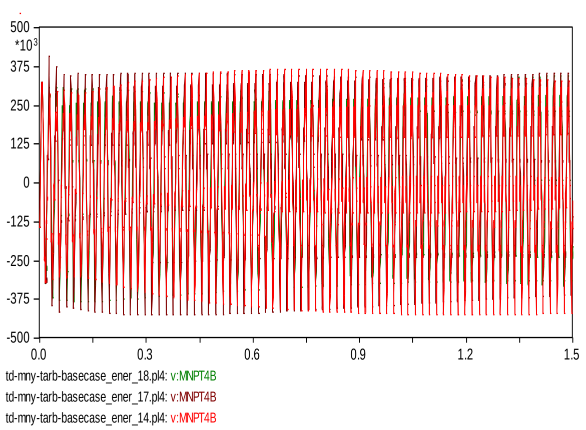
c. reduces NSF further, increasing IM in contingency of a 400 kV circuit.

Fig.18. FS with different options reinforcements Vs. without

5.3.2 Time Domain Simulation

Time domain simulation is performed in order to verify if Resonance occurs and whether determines TOVs that put system at risk.

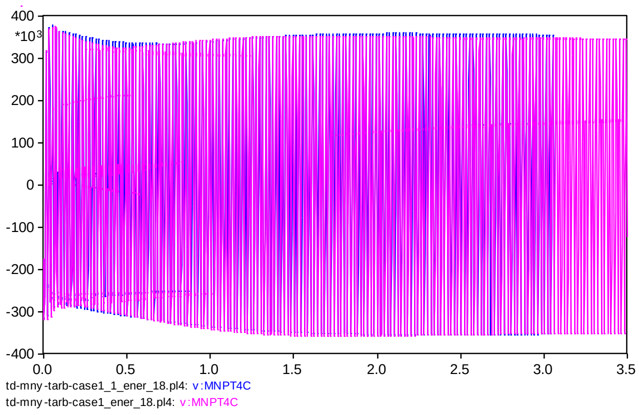
Transformer energisation is considered critical in particular weak grid assets due to low harmonic order injected into the system through the inrush current. This is the most severe case and it is likely to triggered large TOVs in system with natural frequency around the 2nd harmonics. Different switching time will be considered.



From fig.19 it can be seen that no TOVs are triggered from the switching however a voltage higher the nominal, about 1.1Uo. It is worth notice that they are sustained for more than 1 second, which means that a slight resonance effect is hidden underneath.

Fig.19. TD in the base case.Phase to Ground Voltage in Moneypoint

When introducing the Project as mixed Submarine Xlpe cable and OHL, case1, results are shown in fig.3.5, with also the contingency on the OLD-WOOD.

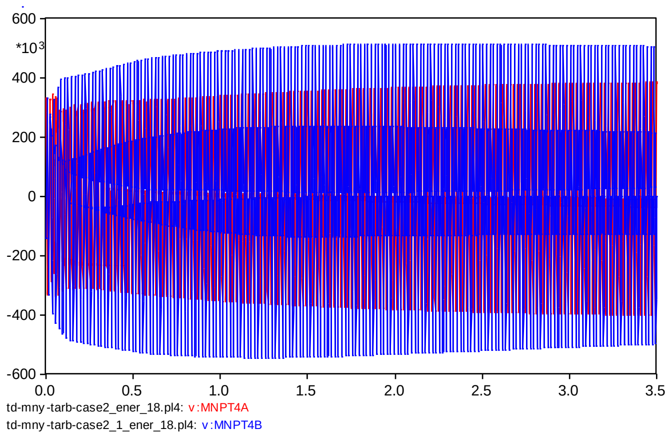


Values are still around the 1.1Uo, sustained for more than 1 sec. In fig.20, same results are shown for a longer lasting simulation interval.

The trend to resonate is evident from the picture. The voltage amplifies after 1 second remaining however in a 1.1Uo range.

Fig.20. TD in Case1.Phase to Ground Voltage in Moneypoint

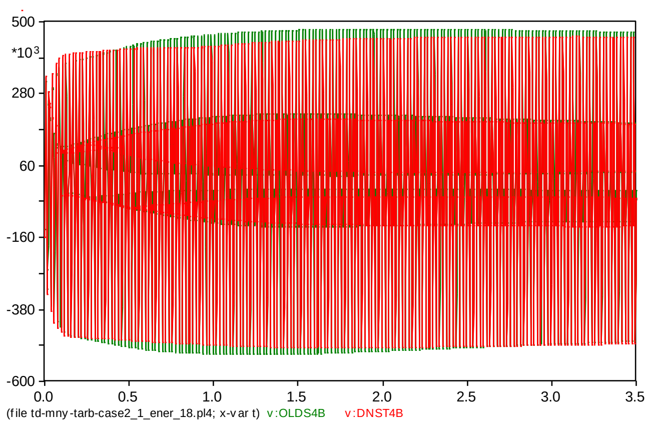
If TARB-KNOCKANURHA is connected using an UGC system results are shown in fig.21.



It is note worthy the effect of the Oldstreet-Woodland contingency. In N conditions, the overvoltages after energisation is kept within 420 kV peak phase to ground which is 1.3p.u. This is acceptable with stand voltage for the cable provided that a suitable after laying testing voltage is chosen. Note that length of cable may determine some difficulties for the AC testing voltage to be performed in one length,i.e. 20 km.

Fig.21. TD in Case2.Phase to Ground Voltage in Moneypoint

A contingency on OLDStreet-Woodland make the system weaker and the amplitude to rise at 1600 Ohm, see Frequency scan fig.18. As a consequence resonances are triggered with a sustaine TOVs of about 543 kV peak, about 1.7Uo. This would put the cable at risk unless using a 500 kV AC cable.



Furthermore, insulation coordination review of nearby equipments has to be undertaken as the overvoltage spreads still dangerous as far as Dunstown and Oldstreet, see fig.22.

Fig.22. Case2. Phase to Ground Voltage in Dunstown and Oldstreet

6. Conclusions

A methodology has been described aiming at identifying areas that are potentially critical for low frequency Electromagentic transient Overvoltages, TOVs. The methodology has been applied within the process a Long Term Planning Analysis to techno/economic solutions of Grid Expansion within years 2015 to 2030.
An extensive Harmonic analysis have been carried on to single out potential system assets at risk for low frequency resonances.

Results have shown that, the broad initial frequency scan indications may be suitable to focus on specific planned reinforcement technologies to identify feasibility of different Transmission technology options.
The additional information using Time domain simultations to identify critical grid assets can further evaluate whether the system can be put at risk using different Transmission Technology options and therfore to integrate the decision making process of the planned reinforcement.
It has also been verified the counteracting influence on NSF of grid reinforcements which depends not only on the Transmission Technology but also on the Grid topology. Infact, whether it is meshed or radial plays and important role in the changing of NSF for each area as well as whether ist is OHL or UGC based.
As general trends for the specific GES, it looks that early stages assets are more likely to provide critical scenarios to be investigated.

7. References

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