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Exhibit H - Impact of ElecLink, a new 1000 MW DC link between France and Great Britain, on the continental European transmission system

Study prepared for

ElecLink Limited

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Draft final report

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Contents

Executive Summary

STAR Capital Partners (STAR Capital) and Groupe Eurotunnel plan to build a direct current (DC) interconnector between France and Great Britain (ElecLink). As such, Eleclink is in the process of requesting an exemption from the relevant articles of Europe regulation so that it might construct a 1,000 MW interconnector between the electricity systems of France and Great Britain on a merchant basis. As part of this process, the Commission de Régulation de l'Énergie (CRE) has requested that Eleclink provide more information of the impact on the French transmission network of the connection of the new interconnector.

The CRE have requested the technical analysis from three perspectives. These are:

- **Issue 1: Stability constraints.** The CRE wishes to understand the impact on the dynamic stability of the transmission system close to the point of the connection in the event of faults on the new interconnection.
- **Issue 2: Thermal constraints.** The CRE wishes to understand the extent to which the new interconnector will cause congestion on the French electricity network. This might cause additional costs to be incurred by the French Transmission System Operator (TSO) because it would either need:
    - to invest in additional transmission investment to relieve the bottleneck; or
    - to incur redispatch costs in which it adjusts the intended output of generation plants in France to mitigate the congestion and, in so doing, incurs a cost.
- **Issue 3: Voltage constraints**. Finally, the CRE wishes to understand the extent to which the new interconnector will impact on voltage constraints on the network. Typically, voltage issues are mitigated by reactive power services that are purchased by the TSO.

ElecLink has commissioned Consentec to consider the issues raised by CRE. We briefly set out the main findings on each issue.

Issue 1: Stability constraints

The impact on stability constraints of the new interconnector is likely to be minimal. The main rationale for this conclusion is that the 1,000 MW of inflow or outflow that the new interconnector represents is much in lower volume than other generation or loads connected to the French network. Given that the TSO already needs to take account of the potential loss of much larger generation plants or DC flows then, in practice, it is not likely to need to take additional actions to manage the potential loss of the 1,000 MWs of capacity that the new interconnector represents.

A related issue is whether, in the vicinity of the new connection point, there might be potential repercussions from a technical failure of the interconnector that the TSO might need to take into account. We consider that the current technology of converter stations and its associated protection settings means that this, in practice, will not be an issue that will cause additional costs to be incurred by the TSO.

Issue 2: Thermal constraints

We have modelled the technical operation of the French network under a range of potential scenarios to assess the extent to which the new interconnector will trigger thermal constraints on the French grid.

In this context it is worth noting that the connection point of the new interconnector will be near two very large existing sources of generation / load. Specifically, these are the Gravelines nuclear power station that has an installed generation capacity of 5,700MW and the existing interconnector between France and England (IFA) that has an installed capacity of 2,000MW. As a result of this concentration of infeed sources, totalling 7,700MW, the transmission network in the area is already very dense and there is significant transmission capacity in the region. For example, the Gravelines power station is connected to the Warande substation where transmission lines with a capacity of about 12,000MW are merging.

We have modelled the impact of the new interconnector so that, instead of considering a maximum total infeed of 7,700MW that is the case at the moment, the total infeed would be 8,700MW, under a range of possible scenarios. The main findings are that:

- In situations of relatively low demand in France, and full export on all interconnectors (and full output of the Gravelines power station as well as full output of a smaller 800 MW gas fired power station in Dunkirk as far as it is in operation depending on the considered demand situation) there will be occasions in which two of the 380-kV-lines in the area are overloaded. The two lines are the Warande - Les attaques line and the Les attaques - Mandarins line.

- However, in our view, for these cases of overloading, remedies, such as switching measures, are available to the TSO that can be activated in a sufficiently short period of time so that further critical loadings can be avoided. This means that the need for the TSO to redispatch plants (and so incur costs) in these instances is rare.
- This potential for overloading on these two lines (relative to the n-1 security standard) is a feature of the current operation of the network. The presence of the ElecLink line only marginally exacerbates this overloading so that, even then, it is not sufficient to trigger re-dispatch costs or the need for further investment in the network.
- The only situation in which the TSO is likely to incur additional costs is in the event of an outage of critical transmission lines in the area. In practice, the maintenance of transmission lines in the area is most likely to be scheduled in line with the maintenance of the nearby Gravelines nuclear power station. Therefore, for planned outages of transmission lines, there are likely to be no incremental costs incurred as a result of the new interconnector. Only unexpected outages of local transmission lines are likely to cause the TSO to incur additional redispatch costs. This would be through TSO enforced adjustments either of the expected running profiles of one of the two interconnectors in the area or the Gravelines power station. As noted previously, this would be the case, even in the absence of the new link.

Issue 3: Voltage constraints

In our view, the presence of the new interconnector is likely not to impose additional costs on TSO when assessing its requirements for reactive power. Indeed, it believes that, through an appropriate choice of converter technology, the new link should be able to contribute positively to the voltage profile in the region.

1 Introduction

STAR Capital Partners (STAR Capital) and Groupe Eurotunnel plan to build a direct current (DC) interconnector between France and Great Britain (ElecLink). The new interconnector shall have a transmission capacity of 1,000 MW. The connection to the French transmission grid shall be established in the same substation where the already existing Interconnexion France-Angleterre (IFA), is connected (Mandarins). IFA has a capacity of 2,000 MW.

The Commission de Régulation de l'Énergie (CRE) has asked ElecLink to provide a study concerning the impact of the planned interconnector on the continental European transmission system (in particular the French system including its interconnectors to Great Britain and Belgium). In a letter dated 13 January 2012 CRE has described the scope of the requested study.

Within that outline CRE asked for investigations regarding the technical repercussions determined by ElecLink in terms of system stability after an outage in the transmission grid (especially in the transient time period), compliance with network security requirements such as the (n-1)-criterion and the voltage situation in the transmission grid influenced by increasing import/export capability between France and Great Britain. The analyses shall focus on the French 380/220-kV-grid including interconnections with neighbouring systems, in particular with Belgium.

ElecLink has requested Consentec, to provide qualitative and quantitative results regarding the different aspects. We set out our findings in this report.

The report has the following structure:

- Chapter 2 provides some background details of our company;
- chapter 3 sets out our approach;
- chapter 4 presents our results; and
- chapter 5 describes our conclusions.

2 Introduction to Consentec

We, Consentec GmbH, are a specialist consulting and software firm focusing on engineering, economic and regulatory issues related to energy supply, with a special focus on gas and electricity networks on all transmission and distribution network levels. Consentec was founded in 1999 in Aachen by Dr. Wolfgang Fritz (Managing Director) and Prof. Dr. Hans-Jürgen Haubrich, the former Director of the Institute of Power Systems and Power Economics (IAEW) of RWTH Aachen University, and is fully independent of the interests of any specific institutions, companies and associations.

Consentec's clients are mainly ministries, regulatory authorities, network operators, industry associations, IT providers and equipment manufacturers based in European countries. Consentec supports its clients by consultancy, technical and economic investigations, software solutions (both individual and standardised), training, and expert reports. Consentec's staff members and founders can draw upon profound knowledge and long-standing professional experience in the field of system engineering and economics of power and gas supply, as well as a comprehensive international contact network to the companies and institutions involved in operation and regulation of the energy supply sector.

3 Our approach

In this section we describe our approach for the three main areas of analysis requested by CRE. In turn we set out our approach for:

- Stability constraints;
- Thermal constraints; and
- Voltage constraints.

3.1 Stability constraints

To our understanding this section refers to an analysis of the dynamic system behaviour after faults in the vicinity of the converter station.

The assessment of impacts of any fault in the transmission system requires a substantial quantitative analysis in order to derive requirements for the design and set-up of the protection of the DC link and, potentially, network and/or generation facilities in its vicinity. Such an investigation has to be based on a real model of the transmission and generation system (e.g. including actual technical parameters of lines and transformers as well as generator data) and appropriate calculation software.

Typically, such calculations are in the sole responsibility of the TSOs themselves because only they have access to a detailed and a real load flow model of the continental European transmission grid (which is confidential data in possession of the TSOs) and the required calculation software.

Thus, we set the focus on the assessment of faults on the new interconnector and discuss the repercussion on the rest of the transmission system on a qualitative basis.

3.2 Thermal constraints

We possess a load flow model of the continental European transmission system that has been derived from public information sources and hence is free from third parties' intellectual property rights. While the model by principle cannot yield the same level of accuracy as a TSO's model, we are convinced that it is sufficient for the given task, for two reasons. Firstly, the impact assessment is performed by a comparison of the situation with and without the new interconnector, i.e. emphasis is on the incremental effect rather than on absolute measures of network loading etc. Secondly, it is reasonable to assume that any relevant impact on the load flow situation (and hence on thermal constraints) can only occur in a geographically limited region around the converter station. The proof of the latter aspect by means of numerical examples is part of our assessment.

As regards an analysis of the impact on the regional transmission grid around the converter station, we have analysed realistic (also including extreme) cases of network utilisation. CRE has requested an assessment of the first five years after commissioning of the new interconnector (foreseen for 2016). This is covered by numerically analysing the target year 2016 and a rather qualitative outlook to the period after 2020.

Fig. **Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.**.1 below illustrates how input data and calculation steps intertwine.

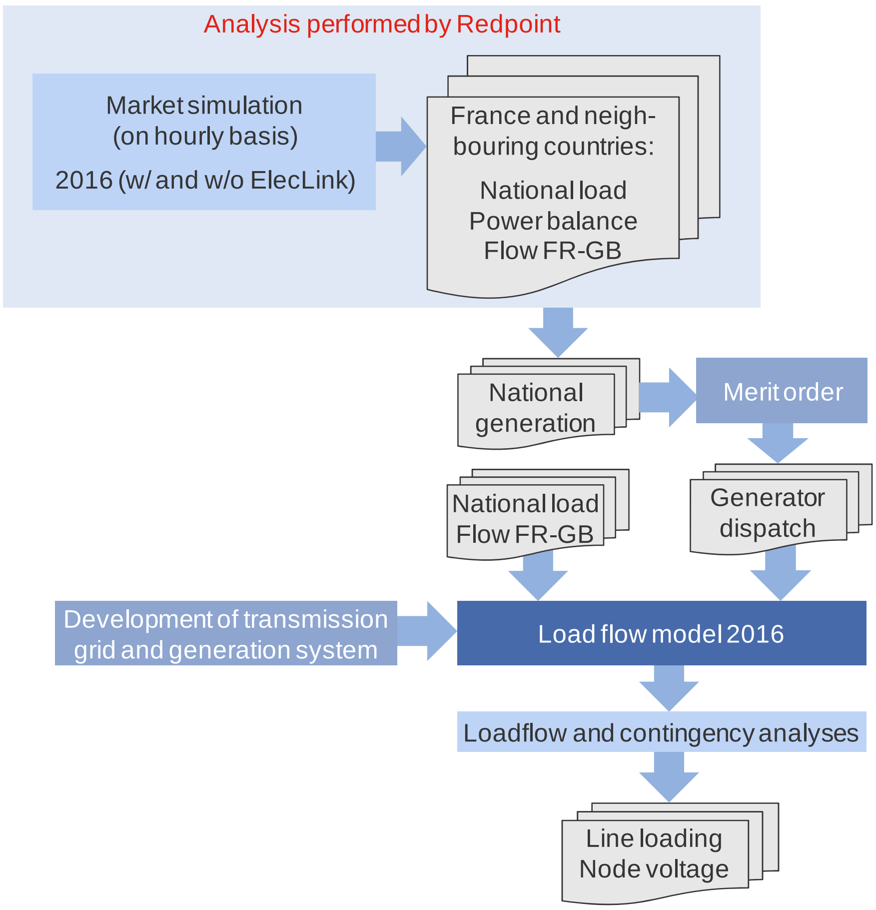

Fig. ***Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.****.1: Workflow for quantitative assessment*

We set up our grid model according to official network development plans (in particular, TYNDP by ENTSO-E) in order to reflect the situation in 2016 where ElecLink is expected to go in operation. In the relevant area around the converter station in France no network extension projects are listed (except for an increase of the operating voltage from 225 to 400 kV by 2017 on the line Avelin-Mastaing[1] at the French-Belgium border), so that the main development until 2016 and between 2016 and 2020 relates to national demand and the generation system.

As regards the planned extension of wind energy capacity within France we have assumed a realistic development based on historic ratio of additionally installed capacities per year. The amount of installed offshore wind energy capacity and its connection points to the grid have been derived from public information regarding the first call for bids issued by the French government in 2011.[2]

Further planned projects of new conventional generation units (especially the extension of the nuclear power plant in Penly and diverse gas-fired power plants in the relevant region) will very probably not be in operation before 2020. Hence, these projects have not been considered in the analyses.[3]

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1 We also understand from our discussions with RTE that further transmission investment in the area is planned: a second reinforcement of Gavrelle-Avelin and Vesle-Lonny (expected to be operational in 2016/17 referring to the ENTSO-E TYNDP 2012-2022) as well as further planned reinforcement of interconnection with Belgium in 2018/19. However, to be conservative we have not included this additional transmission investment in our network modelling taking into account potential delays in permission procedure and construction phase.

2 As the planned offshore wind parks are mainly located at the North-Western coast the impact of line loadings in the vicinity of the converter station Mandarins is negligible.

3 We note that this approach contrasts with our understanding RTE's approach which we consider adopts excessively conservative assumption. For example, in RTE's network modelling it includes all future generation projects (as listed in the *fil d'attente)* as if they are operational in 2016. Therefore it assumes that the extension of the Penly nuclear power station is operating in 2016 – in practice it is not likely to be operational until 2035. Similarly, RTE is overly conservative in its approach to transmission investment, assuming in its modelling that there will be no additional transmission investment after 2016 – that is despite having well developed plans for further reinforcement of the network towards the end of the decade.

The network situations to be considered are described by national load and power balance, in particular for France and neighbouring countries, and the flows on IFA and ElecLink. All required data has been provided by Redpoint, an advisor to STAR Capital.

For each considered situation (5 market situations taking into account the two cases with and without ElecLink, i.e. 10 situations in total) we derived the respective national generation from the load and power balance figures. In order to calculate precise line loadings, we have broken down the national generation into a generator dispatch on the basis of a power plant data base (i.e. a merit order approach taking into account parameters such as fuel type, and year of construction and efficiency factor resulting in unit-specific marginal costs) and entered these generation data into the grid model.

By means of load flow and contingency analysis we have determined the impact of the new interconnector on pre and post contingency line loadings and identified potential cases (situations and locations) of overloading and assessed different ways of remedies (e.g. topology changes, redispatch or network reinforcement).

In addition to that, we have analysed the export/import capabilities in case of a double circuit outage of one of the two 380-kV-connections to Mandarins.

3.3 Voltage constraints

While thermal constraints could be restricting the intended use of the new interconnector for exchanging power between France and Great Britain, voltage issues would rather be a side effect. Moreover, the impact of the interconnector on the voltage situation could be controlled by the choice of technology of the converter stations. This is particularly the case given recent improvements converter technology and the increasing adoption of Voltage Source Converter (VSC) technology. Consequently, we have treated this aspect by conceptual argumentation rather than substantial numerical simulation.

4 Results

In this chapter we set out our results. We consider in turn, our findings on:

- Stability constraints;
- Thermal constraints; and
- Voltage constraints.

4.1 Stability constraints

Faults on a DC interconnection are comparable to the loss of load or generation in the connected systems leading to an increase or decrease of frequency in the transient time period. Such cases are already covered on system level by provision of reserve power and emergency plans. As the possible impact of a fault of the DC line under consideration is far below other critical incidents (like loss of other DC links with higher nominal power or faults in major power plants) we do not expect any critical consequences regarding impacts on system balance.

Another important question is whether disturbances like a loss of the DC link itself or faults of lines or transformers in its vicinity may result in oscillations within the system which might seriously endanger system security. As regards the generators connected to the AC grid, automatic protection systems are installed in order to prevent the equipment from damage. The same accounts for converter stations of DC links which have to consider critical faults for the design of their protection systems.

Further potential repercussions caused by technical failures in the converters of a DC link such as upper harmonics or overvoltage in the AC system after a short circuit can be resolved with automatic control technology or using earthing equipment at both ends of the DC line.

Hence, negative influences on the AC power system due to faults on the DC connection can be avoided by the use of existing technology and protection settings.

There are no (severe) incidents regarding the continental European transmission system in the past to be traced back to faults on DC interconnections, such that it is very likely that any repercussions of faults on new interconnections (such as ElecLink) on the rest of the power system can be effectively avoided. This is also confirmed by the network situation in the area of the Mandarins substation. The highly meshed 380-kV-network with low interior impedances as well as the existence of large generators (nuclear plant Gravelines) in the vicinity of this substation lead to a comparatively high short-circuit power in Mandarins compared to typical 380 kV substations. As short-circuit power is a good indicator for a system's resistance against disturbances in the transient time frame we would not expect stability concerns to be a major issue here.

4.2 Thermal constraints

4.2.1 Overview of grid parameters and generation system in relevant area

In order to determine drivers for the network utilisation in the relevant network region, we have analysed the grid topology as well as the location and technology power plants.

The 380-kV-network in the area close to the converter station for the DC link(s) is dense and provides a high amount of transport capacity. This is mainly driven by the necessity to transmit the power infeed of the nuclear power plant located in Gravelines with an installed generation capacity of 5,700 MW. It is connected to the substation Warande by six 380-kV-circuits with about 12,000 GW of transmission capacity[4]. There is no direct connection to the 220-kV-grid as there are no transformers located in the Gravelines substation.

Thus, the grids are mostly decoupled such that the 220-kV-grid is mainly of distribution nature while the 380-kV-grid has mainly transmission function. The power infeed of the thermal power plant in Dunkerque (800 MW) is used to supply the demand of the large industrial area located at the Dunkerque harbour as well as a backup supply for the Gravelines power plant in an emergency case. Hence, the impact on the line loading in the relevant region is highly limited.

At the substation in Warande the power is transmitted via two 380 kV double-circuits to Weppes and Chevalet in South-East direction. A third 380 kV double-circuit connects Warande with the substation Les attaques in western direction and then reaching the substation Mandarins (DC link converter station). Mandarins is also supplied with a 380 kV double-circuit from the South (substation Argoeuvres). Each circuit can transmit about 1,800 MW,

[4] There are also two 220-kV-lines between Warande and Gravelines not displayed in the grid map.

i.e. Mandarins is connected to more than 7,000 MW of transmission capacity (fig. **Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.**.1).

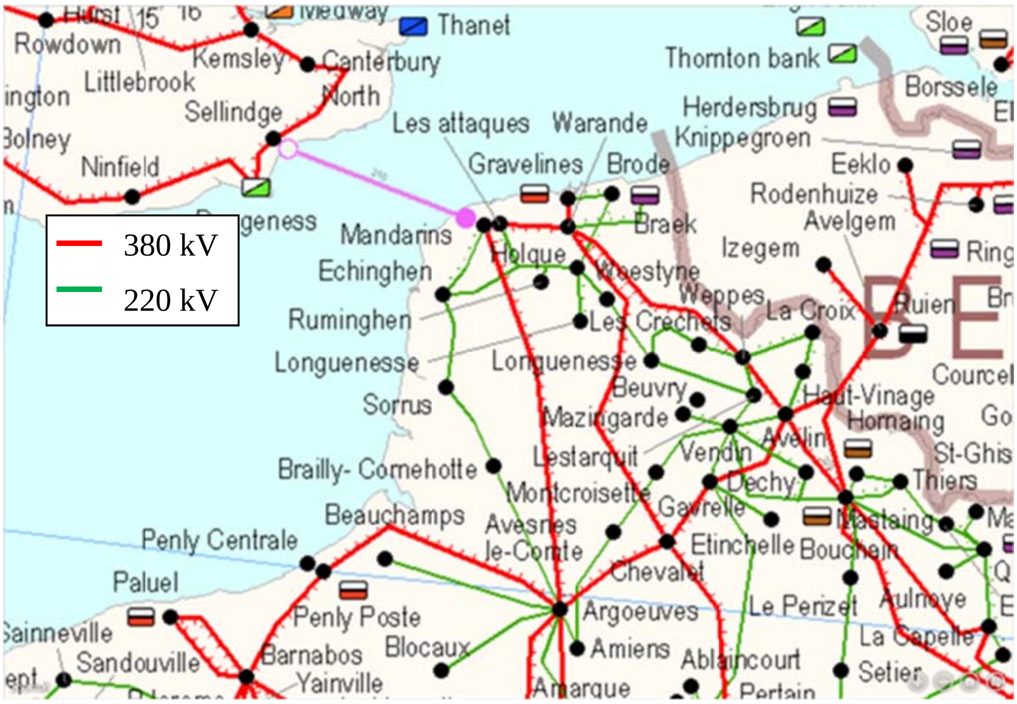

Fig. ***Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.****.1: Transmission grid and generation facilities in vicinity of French converter station Mandarins (source: ENTSO-E)*

As the nuclear power plant in Gravelines can be assumed to be in operation in every demand situation, it can be concluded that the network utilisation is more or less determined by the operation of the DC link(s) (i.e. flows from or to Great Britain) while the impact of the overall market situation has less impact.

Thus, in a situation without the new interconnection between France and Great Britain power infeed of about 7,700 MW (5,700 MW generated in Gravelines plus 2,000 MW via IFA) has to be transported. With ElecLink the transmission requirements reach about 8,700 MW.

4.2.2 Considered scenarios

We have analysed a number of different market situations in order to cover a realistic bandwidth of network utilisation scenarios[5]. These scenarios also contain rather extreme (but still realistic) cases leading to potentially high line loadings. Scenarios 1 and 2 reflect situations with peak load in France combined with a high demand of energy imports (including imports from Great Britain). Scenario 3 indicates a situation with rather high demand but more or less neutral power balance where France is exporting to Great Britain. Scenarios 4 and 5 represent medium load situations with high French export capacities reflected by a clear positive power balance resulting, amongst others, to export flows from France to Great Britain (fig **Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.**.2).

[5] It is worth stressing that, for the purposes of this analysis, we only consider the commercial implications of ElecLink’s connection to the French network in terms of the possibility of additional costs to be incurred by the TSO to manage congestion. We are aware of no particular technical impediments regarding ElecLink’s connection to and use of the French transmission network – rather, it is very similar in nature to any other medium sized connection to the transmission network. As such we do not believe that ElecLink represents any particularly unusual technical challenges for RTE.

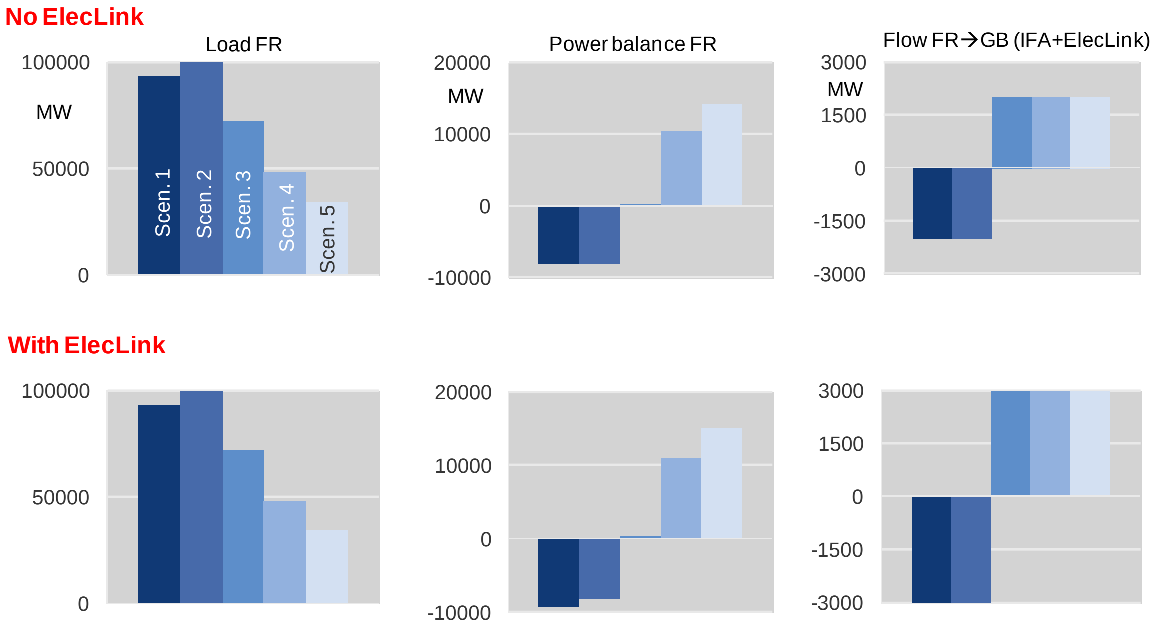

Fig. ***Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.****.2: Main parameters of considered scenarios for target year 2016 (based on Redpoint data)*

The respective national generation can be derived from the given load and power balance figures, which is distributed among the single generation units according to their respective position within the merit order.

4.2.3 Contingency analysis

Generally, our analyses show that the impact of the new interconnector on the flows in (n-1)-case decreases rapidly with the distance between the observed line and the converter station. Accordingly, high loading in the French grid outside the closer vicinity of the converter station (including for instance the French-Belgian border) is not notably originated by the new DC link. Thus, the focus in the following presentation of results is set on the 380-kV- and 220-kV-lines connected to the substations Mandarins, Les attaques and Warande.

Furthermore, we have found out that the outage of the interconnection between France and Great Britain (be it IFA and/or ElecLink) does not cause problems in terms of network loading or available generation capacity.[6]

In the following we discuss the impact of the market situation, the target year and the existence of ElecLink on the network loading separately.

Impact of market situation

In order to assess the impact of the market situation on the network loading, we have calculated the line-specific maximum (n-1)-loading of selected 380- and 220-kV-lines in the relevant network region. The results given in fig. **Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.**.3 refer to the target year 2016 without ElecLink.

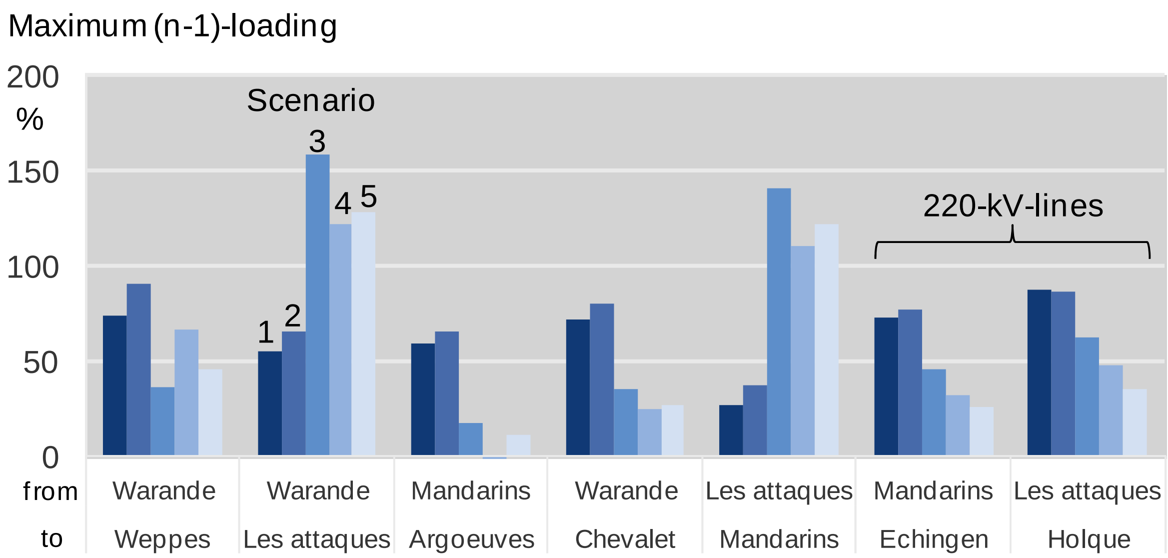

Fig. ***Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.****.3: (n-1)-loading of selected lines for considered market situations (target year 2016 without ElecLink)*

[6] An outage of the DC link(s) would cause a generation deficit or surplus in the connected system depending on the flow direction on the interconnection. In the analysis we have focused on the French system and investigated if the required generation increase/decrease can be performed with the generation capacities in the respective situation and verified the load flow situation after modifying the generation dispatch in France according to the assumed merit order.

In scenarios 1 and 2 (where flows on the interconnection between France and Great Britain are in direction France) the (n-1)-loading on the considered lines is always below 100 %. In scenarios 3-5 France exports to Great Britain using the whole IFA capacity of 2,000 MW. In these cases two 380-kV-lines can be observed (Warande→Les attaques and Les attaques→Mandarins) where the (n-1)-loading exceeds the 100 %-limit with a maximum of more than 150 %. These line loadings are the consequence of the export situation France to Great Britain, because then the total power infeed of the nuclear power plant in Gravelines (5,700 MW) and partly the infeed of the natural gas plant in Dunkerque (provided that it is in operation) is transported to a high extend in direction Mandarins while in an import situation (i.e. flows from Great Britain to France) the flows mainly caused by the Gravelines infeed is partly displaced. Thus, in case of French export towards Great Britain critical (n-1)-loadings in the 380-kV-grid may occur.

For both lines being overload the loss of the parallel circuit constitutes the critical outage. Thus, we have further analysed the line loadings in case that after the outage of one circuit the second system is switched off (be it automatically by a line protection setting or manually as countermeasure). In this case the network loading in the relevant region is below 100 % (for the considered scenarios and the given input database).[7] This seems to be reasonable as even in todays' framework, situations are likely where Gravelines has maximum output and at the same time the existing DC link is fully used in direction of Great Britain. Hence, the transmission grid as it is today has to be capable to cover such network situations[8].

The results also show the different qualities of impact as regards market situation and flow direction on the interconnection France-Great Britain. The (n-1)-loading differ significantly between scenarios 1-2 (France importing from Great Britain) and 3-5 (France exporting to Great Britain) due to the reasons mentioned above. For scenarios with identical usage of the DC link the (n-1)-loadings especially in the 380-kV-grid differ only gradually underlining that the usage of the DC link is the dominating driver.

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7 This behaviour could be observed also for the situation with the new interconnector. However, in some of the scenarios the (n-1)-loading are close to the 100 % limit.

8 Note that a similar solution as described above could also be reached by switching measures which will limit the influence of the infeed of the Gravelines plant on the line Warande – Les attaques

Impact of target year

Regarding the time period after 2020 it seems to be realistic, that most of the planned investment projects in the relevant network region (Gavrelle-Avelin-Mastaing and Vesle-Lonny) will be finished. As a consequence, it is likely that the load flow situation will ease such that possible limitations regarding the operation of ElecLink could be mitigated or even eliminated. Hence, we conclude that the first few years of operation after completion of ElecLink is the most critical time period with respect to potential repercussion to the French transmission grid being the trigger to reduce the transmissible capacity via ElecLink.

Impact of new interconnector ElecLink

The planned new interconnector ElecLink shall have a capacity of 1,000 MW. As discussed in the sections above, in a situation without ElecLink power infeed of already 7,700 MW (5,700 MW generated in Gravelines plus 2,000 MW via IFA) has to be transported. With ElecLink the transmission requirements indeed increase to about 8,700 MW but stay in the same dimension.

For scenario 5 (maximum French export)[9] in target year 2016, the (n-1)-loading on the lines Warande→Les attaques and Les attaques→Mandarins further increase as expected for the case with ElecLink (fig. **Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.**.4).

[9] In this scenario a local demand in the relevant network region of about 1,300 MW has been assumed. The major part (approx. 750 MW) is located at the Dunkirk harbor area.

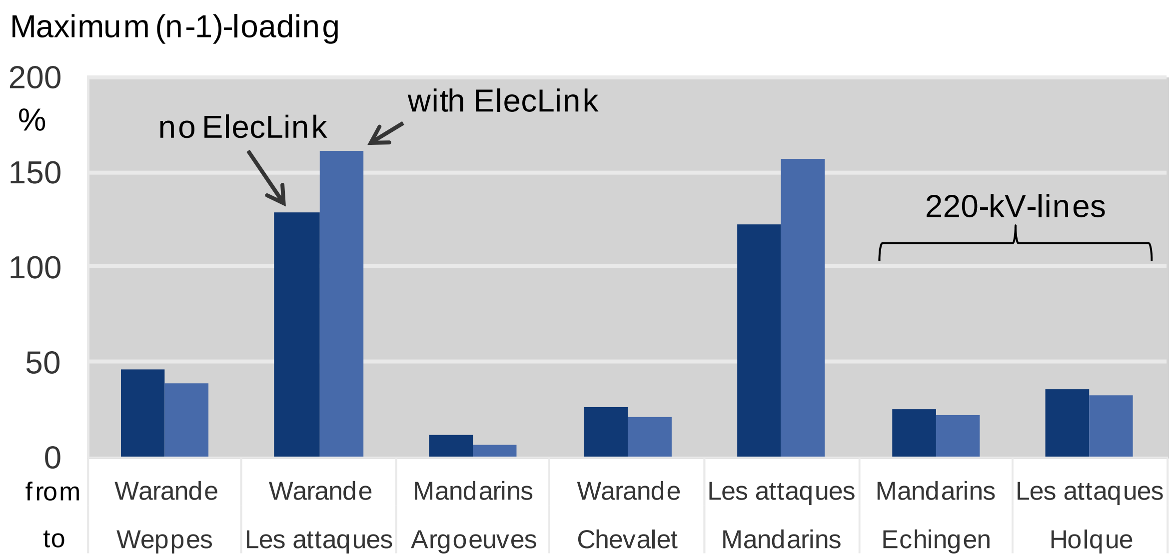

Fig. ***Error! Use the Home tab to apply Überschrift 1 to the text that you want to appear here.****.4: (n-1)-loading of selected lines for case with and without ElecLink (target year 2016, scenario 5)*

The additional loading of about 25 % turns out to be manageable, i.e. in case after the outage of one circuit the second system is switched off (be it automatically by a line protection setting or manually as countermeasure), the network loading in the relevant region stays below 100 % (as already discussed in the previous sections). Furthermore, the probability of such situations to occur is not notably influenced in case that ElecLink is realised. Thus, in case of high (n 1)-loadings with ElecLink countermeasures as today (mainly network topology modifications by switching measures) are likely taken, such that the necessity to modify the generation dispatch (so-called “redispatch”) is not originated by building the new DC interconnection.

Although the flows may increase in some of the considered scenarios, the realisation of the new interconnection does not cause additional critical network situations and overloads compared to the situation without ElecLink.

4.2.4 Import/export usability between France and Great Britain

In addition to analysing the impact of different drivers for potentially high network loading, we have investigated a specific situation with a weakened 380-kV-grid connected to the converter station Mandarins against the background of the usability of import/export capacity between France and Great Britain.

Relevant in this context are cases where either the double-circuit Mandarins-Les attaques or the double-circuit Mandarins-Argoeuves is out of operation (e.g. for maintenance reasons).

Assuming a complete utilisation of the import or export capacity between France and Great Britain (regardless of considering the transmission capacity of ElecLink) the transmission grid would be substantially overloaded in case of an outage on the remaining 380 kV double circuit connected to the converter station Mandarins (for both of the topologies taken into account). In this exemplary calculation we have identified an overload of about 560 MW in the 220-kV-grid on the connection between Ruminghem and Echingen.

Consequently, the transmission capacity between France and Great Britain or the energy infeed of the nuclear power plant in Gravelines might be reduced in order to fulfill network security requirements in situations where both circuits of one of the aforementioned lines are affected by planned or unplanned outages. In the aforementioned example a reduction of export capacity from France or Great Britain of about 1,700 MW would be necessary. Similar relieving effects would be created by redispatch measures inter alia reducing the energy infeed of Gravelines by almost 5,500 MW. (Note that relieving effects of network topology measures such as opening of busbar couplings have not been taken into account.)

As such cases are rather rare[10] and large maintenance work is normally coordinated in order to avoid potentially critical network situations, the aforementioned countermeasures would be more or less taken only in exceptional cases. It is important to mention, however, that with ElecLink the situation changes only to limited extent. Hence, (n-1)-overloadings in the described situation will also occur without ElecLink and similar measures might be necessary even today.

[10] Maintenance of double-circuit lines is usually undertaken sequentially (that is, one line at a time). Therefore for both circuits to be not operational would require the planned outage of one line (on maintenance) and the unplanned outage of the other line. Given the infrequency of both network maintenance and of unplanned outages, the coincidence of both these events would be expected to occur once in a time period of several years at the most.

4.3 Voltage constraints

The voltage level at the substations mainly depends on the overall loading of the transmission grid, i.e. the higher the line loading, the higher the voltage drop between beginning and end of the line. In order to ensure an appropriate voltage level in each situation, the output of reactive power in the generation units is controlled according to the respective conditions. In addition to that, the network topology influences the voltage level because the network elements in operation consume reactive power and the electrical distance between a substation and reactive power source (i.e. mostly power plants) is affected.

In the context of a DC interconnection, an appropriate voltage level at the converter station is required due to the demand of reactive power for commutation, especially as regards the usual use of line-commutated converters with thyristors as switching elements, such as the IFA.

In order to estimate the voltage level at the 380-kV-substation in Mandarins, we have analysed a network situation with the following parameters:

- Situation with high demand of about 75 GW in France
- France exporting to Great Britain (2,000 MW without or 3,000 MW with ElecLink, respectively)
- Double-circuit Mandarins-Les attaques out of operation

In this case the supporting impact of reactive power generated in the nuclear power plant in Gravelines on the voltage level in Mandarins is strongly limited as the direct network connection is interrupted. Instead, the voltage level in Mandarins depends on the voltage level at the neighbouring 380-kV-substation in Argoeuves and the voltage drop over the (quite long) 380-kV-line between these two network nodes.

In the exemplary investigation we have assumed a realistic voltage level in Argoeuves of 400 kV. For the given network situation the resulting voltage in Mandarins would be 390 kV in case of 2,000 MW (i.e. capacity of IFA) export to Great Britain and would drop to about 380 kV assuming an export of 3,000 MW (i.e. capacity of IFA+ElecLink[11]).

[11] The calculated node voltage of 380 kV assumes that ElecLink would be designed with the same converter technology as IFA, (i.e. line commutated converter). This is a conservative assumption. ElecLink have re-

Voltage levels of 380 kV or below could be problematic as regards the provision of the required amount of reactive power for the converters.

In case of an alternative design, for instance as self-controlled (voltage source) converters, the reactive power required for commutation is not taken from the AC transmission grid. Such technology is already in operation, e. g. for the Estlink cable between Finland and Estonia.

ElecLink have recently chosen to adopt VSC technology for its converter stations. An implication of this is that the voltage situation will be able to be actively controlled and therefore that ElecLink will certainly not be detrimental to the voltage profile in the region and, in practice, is likely to be net beneficial.

cently chosen Voltage Source Converter technology for the converter stations which has significant voltage control performance improvements relative to the older LCC technology used by IFA

5 Conclusions

In our study regarding the impact of a new DC link between France and Great Britain on the continental European transmission system we have analysed three different aspects of technical constraints, as follows:

- **Issue 1: Stability constraints** - to understand the impact of ElecLink on the dynamic stability of the transmission system close to the point of the connection in the event of faults on the new interconnection.
- **Issue 2: Thermal constraints** - to understand the extent to which the new interconnector will cause congestion on the French electricity network. This might cause additional costs to be incurred by the French Transmission system Operator (TSO) because it would either need:
  - to invest in additional transmission investment to relieve the bottleneck; or
  - to incur redispatch costs in which it adjusts the intended output of generation plants in France to mitigate the congestion and, in so doing, incurs a cost.
- **Issue 3: Voltage constraints** - to understand the extent to which the new interconnector will impact on voltage constraints on the network. Typically, voltage issues are mitigated by reactive power services that are purchased by the TSO.

On **Issue 1 – stability constraints**, our main finding is that repercussions of faults on the new interconnector including the converter stations can be effectively avoided by a proper use of protection technology. An assessment of the impact of faults beyond the interconnector is subject to more detailed studies.

On **Issue 2 – thermal constraints** - our main findings are:

- The network loading is driven by the infeed of the nuclear power plant located in Gravelines (close to the converter station in Mandarins) as well as the flow direction between France and Great Britain. The highest line loadings occur for the case of French export to Great Britain. However, we have found out that more generally the impact on thermal constraints of the new interconnector is driven more by local transmission issues rather than general market supply/demand balance issues.
- Line loadings above 100 % in the (n-1)-case can occur – depending on switching state - on the 380-kV-lines Warande→Les attaques and Les attaques→Mandarins. For both lines

the outage of the parallel circuit constitutes the critical topology. With the new interconnection the maximum (n-1)-loading can increase by about 25 % without causing additional overload in the transmission grid. However, assuming that after the outage of one circuit the second circuit is switched off (be it automatically by a line protection setting or manually as countermeasure) a situation occurs where the network loading in the relevant region is below 100 % regardless of the considered case with or without ElecLink.

- In case of a planned or unplanned outage of both circuits (that is an n-2 scenario) on either the 380-kV-line Mandarins-Les attaques or Mandarins-Argoeuves the transmission capacity between France and Great Britain or the infeed of the nuclear power plant in Gravelines has possibly to be reduced (in both cases with and without ElecLink) in order ensure network security requirements. Based on results of exemplary calculations, such countermeasures might be substantial (up to 1,700 MW reduction of export capacity France to Great Britain, or about 5,500 MW of redispatched power, respectively).

On **Issue 3 – voltage constraints**, for specific network situations (such as high demand in France with full usage of export capacity towards Great Britain together with the double-circuit line Mandarins-Les attaques not available) a low voltage situation can occur at the substation Mandarins that might be problematic as regards the provision of reactive power required for commutation in the converters of the DC interconnection. However, ElecLink's decision to adopt VSC technology for its converter stations means that the voltage profile will certainly not be negatively affected and is most likely to be improved.

We conclude that the realisation of the planned new DC interconnection between France and Great Britain has no severe negative impact on the continental European transmission system concerning the aspects taken into account in this study. This includes both, the local French system as well as the wider North West European transmission system (and our analysis shows that there will be very minimal impact on flows beyond France's borders – for example to Belgium). Any problems that might arise could be managed by the design of ElecLink and the choice of VSC technology. In particular, the realisation of ElecLink would not cause additional investments in the transmission grid (for instance, in order to restore the fulfilment of network security requirements).