TRACTEBEL ENGINEERING S.A.
Boulevard Simón Bolívar 34-36
1000 - Brussels - BELGIUM
tel. +32 2 773 99 11 - fax +32 2 773 99 00
engineering@tractebel.engie.com
tractebel-engie.com

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TRACTEBEL ENGINEER NG S A. - Registered office: Boulevard Simón Bolívar 34-36, 1000 Brussels - BELGIUM
VAT: BE 0412 639 681 - RPM/RPR Brussels: 0412 639 681 - Bank account BAN: BE74375100843707 - BIC/SW FT: BBRUBEBB

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1. INTRODUCTION

This report aims at describing the methodology and the results of the study of the variation of grid losses and security of supply for the AQUIND Interconnector between Great Britain and France.

First, in Section 0, the variation of grid losses is studied by computing the B5 indicator of ENTSO-E. In Section 2.1, the methodology applied for this study is detailed. Then, in Section 2.2, the results of the model developed by Tractebel are presented. Finally, in Section 2.3, the results obtained are compared with the results of the TYNDP 2018.

Secondly, in Section 3, the impact of the AQUIND interconnector on the security of supply is studied by computing the B6, B7 and B8 indicators. In Section 3.1, the methodology used is detailed. Then, in Section 3.2, the results are presented. Finally, in Section 3.2.3.4, the results obtained are compared with the results of the TYNDP 2018.

2. VARIATION OF GRID LOSSES

2.1. Methodology

The methodology applied to quantify the variation of grid losses and to monetize this variation is based on the approach suggested in the TYNDP 2018 and detailed in the 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects[1].

First, in Section 2.1.1, the methodology for the quantification of variation of grid losses is detailed. Then, in Section 2.1.2, the methodology for the monetization of variation of grid losses is presented.

2.1.1. Quantification of variation of grid losses

2.1.1.1. GENERAL APPROACH

In order to quantify the variation of grid losses due to the AQUIND Interconnector, a grid model representative (regarding the variation of losses) of Europe has to be developed.

Based on this model, an hourly DC load flow with and without the new interconnection is run over a year. The difference of total grid losses between the cases with and without corresponds to the yearly variation of grid losses due to the interconnection studied. The tool used for this study is SCANNER.

SCANNER is a powerful tool developed by Tractebel Engineering used in many economic analyses. Its high-performance was recognized by many observers in Europe and elsewhere in the world. Its purpose is to analyze a composite generation-transmission power system with regards to reliability assessment performance valuation and operating cost estimation. The SCANNER tool is characterized by a sequential Monte Carlo simulator of generation and transmission systems. Monte Carlo simulation is used to consider random forced outages of generating units and transmission elements. For each hour of a year, operating costs are optimized under operating constraints (e.g. thermal rating of transmission elements). Numerous simulations of the behavior of the power system during one year (i.e. different Monte Carlo years) are run with different samples of the uncertain phenomena affecting the system, in order to reach a good statistical accuracy.

The simulation of the economic dispatch of generators by minimizing the operating cost is performed by SCANNER in three steps:

- The first step is the annual allocation of hydrological resources.
- The second step is the daily unit commitment of generators and the optimization of the use of hydrological resources and of storage, performed in day-ahead.
- The third step is the intraday economic dispatch.

[1] ENTSOE, 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects, 27 September 2018,

The scenarios studied are the 2025 Best Estimate and 2030 Sustainable Transition, Distributed Generation and EUCO of the TYNDP 2018 as well as an additional scenario developed by AQUIND for 2030 (2030 AQUIND Market Scenario) and two variants of this scenario (the 2030 AQUIND High Commodities/Renewables and the 2030 AQUIND Low Commodities scenarios).

2.1.1.2. IMPLEMENTATION

The Scanner model developed gathers France, Great Britain, Germany, Belgium and Netherlands. As detailed in Section 2.1.1.2.1, this region is representative of the variation of grid losses linked to the AQUIND Interconnector.

The internal grid is represented for both Great Britain and France, while a market model is used for the other countries (Germany, Belgium and Netherlands), as shown in Figure 1.

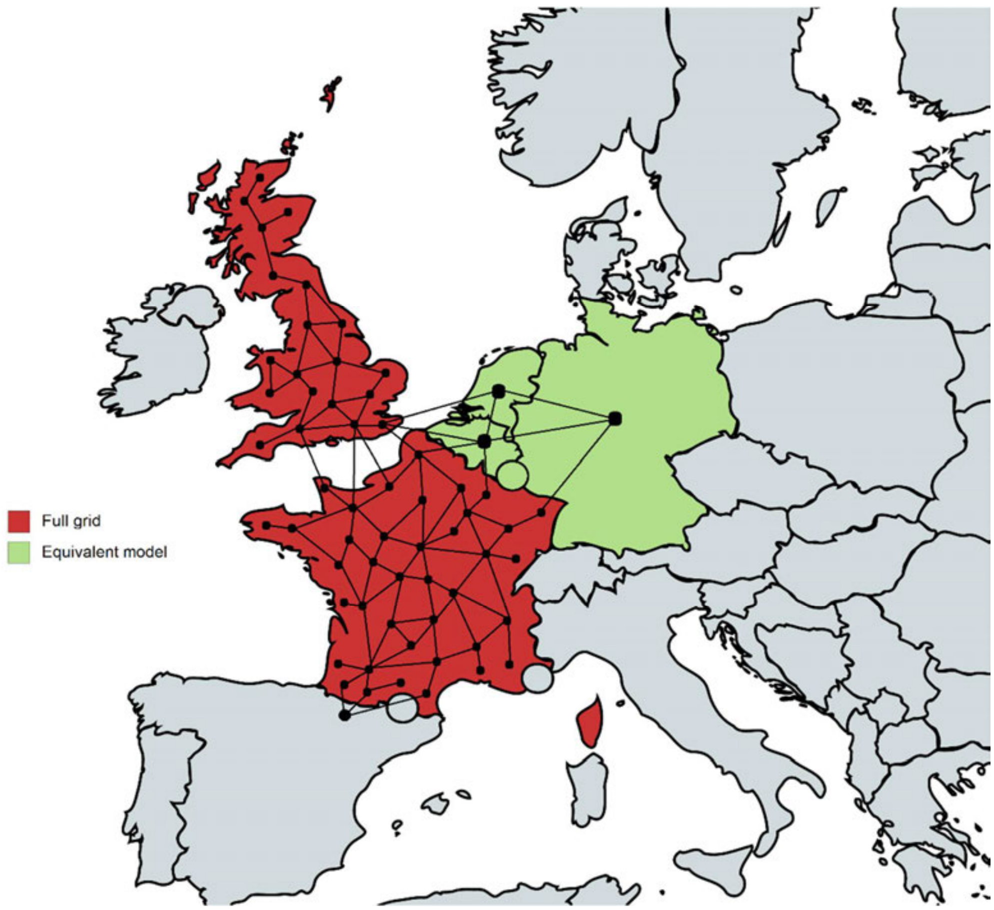

Figure 1 : Representation of the grid model developed by Tractebel.

In the variation of grid losses, are thus taken into account :

- The losses on the AQUIND interconnector.
- The internal grid losses of Great Britain and France.
- The losses on the other interconnections (excluding AQUIND) between Great Britain and France.
- The losses on the interconnections between Great Britain and Germany, Belgium and Netherlands.

The modelling parameters used for the AQUIND Interconnector and the other interconnections between Great Britain and Continental Europe are detailed in Section **Error! Reference source not found.**.

2.1.1.2.1. Zone of interest

A first approximation of the variation of grid losses was conducted on an internal SCANNER model of the CWE network in order to justify the modelling hypotheses presented here above.

It was computed that the variation of internal grid losses in Germany is 30 times lower than the variation of France and, in Belgium and Netherlands, the variation is 40 times lower than in France.

The lower variation of losses in the neighboring countries is justified by the lower variation of dispatch compared to France. Indeed, the variation of annual generation dispatch between the case with and without the AQUIND interconnector is 2.8% in France compared to 0.3% in Germany.

In regard of the results presented here above, one can affirm that the impact of the internal losses of the neighboring countries can be neglected.

Only these three neighboring countries were considered and are modelled with and equivalent node because they are the more likely to influence the internal dispatch of France and Great Britain. Indeed, there is a strong interconnection between France and Belgium as well as between France and Germany, and the Netherlands are strongly interconnected with Belgium and Germany. Moreover, an interconnection already exists between Netherlands and Great Britain, an interconnection between Belgium and Great Britain is under construction and one between Germany and Great Britain is under study.

In order to study the impact of Spain on the model, a market model of Spain was added to the AQUIND Market Scenario. The variation of the variation of grid losses between the case with and without Spain observed was small (less than 10%) and in the uncertainty range. It was therefore decided not to include Spain in the model. However, an interconnection between France and Spain is included as well as an equivalent generation capacity in Spain, in order to reach the desired level of adequacy.

2.1.1.2.2. **Location of the generation**

The location of the generation units is a key factor in the study of the variation of grid losses. In the 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects, it is stated : "*Furthermore, losses are sensitive to the precise location of generation units.*"[2].

The location of the generation units of France and Great Britain was partially transmitted by Baringa for the different scenarios. The location of the rest of the generation has been determined by Tractebel. The new thermal generation has been first located at the location of the decommissioned units. The new renewable production has been located keeping the same key of repartition as the existing renewable units.

It is worth mentioning that the location of the generation may differ from the location of the generation of the model of the TYNDP which can lead to variation between the results.

2.1.2. Monetization of variation of grid losses

As detailed in the 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects, the grid losses should be monetized at the marginal price of the system for each hour :

$$Cost\ of\ losses = \sum_i \sum_h s_{h,i} P_{h,i}$$

With i, a market zone, h a given timestep, $s_{h,i}$, the marginal cost of zone i at timestep h and $P_{h,i}$ the losses in the same zone for the same timestep.

The monetization of the variation of losses is thus :

$$Variation\ cost\ of\ losses = \sum_i \sum_h s'_{h,i} P'_{h,i} - \sum_i \sum_h s_{h,i} P_{h,i}$$

with $s'_{h,i}$ and $P'_{h,i}$ the marginal cost and total losses for the timestep h of zone i with the AQUIND interconnector and with $s_{h,i}$ and $P_{h,i}$ without the AQUIND interconnector.

To monetize the losses on the interconnections, half of the losses is allocated to one zone and the other half to the other.

[2] ENTSO-E, 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects, 27 September 2018, page 34.

2.2. Study results

2.2.1. 2025 Best Estimate

Table 1 gathers the results for the variation of grid losses and the monetization of the variation of losses for the 2025 Best Estimate scenario. The results are detailed for the AQUIND interconnector, the internal grid of France and Great Britain, the other interconnections between France and Great Britain (without AQUIND) and the other interconnections between Great Britain and Continental Europe.

	ΔE [GWh/year]	ΔCost [MEUR/year]
AQUIND	326.5	16.2
France	117.0	51.7
Great Britain	239.7	-4.7[3]
Interco. FR – GB (w/o AQUIND)	-38.4	-1.3
Other interco. GB – Cont. Europe	-9.8	-2.1
Total	634.9	59.7

Table 1 : Variation of grid losses and monetization, 2025 Best Estimate.

From the model developed, the AQUIND interconnector leads to an increase in grid losses of **634.9 GWh/year** and an increase of the cost of the losses of **59.7 MEUR/year** for the 2025 Best Estimate Scenario. One notices that a major part of the losses occurs on the interconnector itself, at a rate which is normal for HVDC interconnectors.

2.2.2. 2030 Sustainable Transition

Table 2 gathers the results for the variation of grid losses and the monetization of the variation of losses for the 2030 Sustainable Transition scenario.

	ΔE [GWh/year]	ΔCost [MEUR/year]
AQUIND	173.9	11.3
France	11.1	21.0
Great Britain	149.6	5.1
Interco. FR – GB (w/o AQUIND)	-38.4	-2.8
Other interco. GB – Cont. Europe	-18.1	-1.9
Total	278.1	32.7

Table 2 : Variation of grid losses and monetization, 2030 Sustainable Transition.

[3] It is noticeable that, in this case, in Great Britain, the cost of the losses decreases with the interconnection while the losses increase. This is explained by the important decrease of marginal price in Great Britain with the interconnection.

2.2.3. 2030 Distributed Generation

Table 3 gathers the results for the variation of grid losses and the monetization of the variation of losses for the 2030 Distributed Generation scenario.

	ΔE [GWh/year]	ΔCost [MEUR/year]
AQUIND	169.4	11.1
France	64.0	18.3
Great Britain	167.9	6.3
Interco. FR – GB (w/o AQUIND)	-32.8	-2.2
Other interco. GB – Cont. Europe	-15.6	-1.7
Total	353.0	31.8

Table 3 : Variation of grid losses and monetization, 2030 Distributed Generation.

2.2.4. 2030 EUCO

Table 4 gathers the results for the variation of grid losses and the monetization of the variation of losses for the 2030 EUCO scenario.

	ΔE [GWh/year]	ΔCost [MEUR/year]
AQUIND	211.6	8.0
France	224.5	18.9
Great Britain	201.7	-21.2
Interco. FR – GB (w/o AQUIND)	-25.7	-2.4
Other interco. GB – Cont. Europe	10.3	-0.6
Total	622.5	2.8

Table 4 : Variation of grid losses and monetization, 2030 EUCO.

2.2.5. 2030 AQUIND Market Scenario

Table 5 gathers the results for the variation of grid losses and the monetization of the variation of losses for the 2030 AQUIND Market scenario.

	ΔE [GWh/year]	ΔCost [MEUR/year]
AQUIND	472.1	18.8
France	521.4	21.7
Great Britain	313.6	-16.1
Interco. FR – GB (w/o AQUIND)	-28.8	-4.5
Other interco. GB – Cont. Europe	2.6	-1.1
Total	1280.9	18.7

Table 5: Results of variation of grid losses, 2030 AQUIND Market scenario.

2.2.6. 2030 AQUIND High Commodities/Renewables Scenario

Table 6 gathers the results for the variation of grid losses and the monetization of the variation of losses for the 2030 AQUIND High Commodities/Renewables scenario.

	ΔE [GWh/year]	ΔCost [MEUR/year]
AQUIND	361.4	15.4
France	369.2	11.7
Great Britain	262.0	-11.7
Interco. FR – GB (w/o AQUIND)	-41.4	-5.4
Other interco. GB – Cont. Europe	1.6	-1.2
Total	952.8	8.8

Table 6: Results of variation of grid losses, 2030 AQUIND High Commodities/Renewables scenario.

2.2.7. 2030 AQUIND Low Commodities Scenario

Table 7 gathers the results for the variation of grid losses and the monetization of the variation of losses for the 2030 AQUIND Low Commodities scenario.

	ΔE [GWh/year]	ΔCost [MEUR/year]
AQUIND	512.4	18.5
France	453.8	29.6
Great Britain	289.2	-3.0
Interco. FR – GB (w/o AQUIND)	-26.7	-2.3
Other interco. GB – Cont. Europe	6.2	-0.5
Total	1234.9	42.2

Table 7: Results of variation of grid losses, 2030 AQUIND Low Commodities scenario.

2.3. Comparison with results of the TYNDP 2018

Table 8 compares the results of the model developed by Tractebel to study the variation of the grid losses for the AQUIND Interconnector with the results of the TYNDP 2018.

	2025 Best estimate		2030 Sustainable Transition		2030 Distributed Generation		2030 EUCO	
	TYNDP	Tractebel	TYNDP	Tractebel	TYNDP	Tractebel	TYNDP	Tractebel
Variation of grid losses [GWh/year]	400	635	889	278	391	353	694	623
Variation of grid losses [MEUR/year]	22	60	110	33	15	32	46	3

Table 8 : Comparison of the variation of grid losses and monetization with the results of the TYNDP 2018.

One can notice strong differences between the results obtained by Tractebel and the results of the TYNDP. This is explained by the different modelling hypotheses and the variability of the results of the TYNDP, as detailed in Section 5.2. Moreover, ENTSO-E indicated the possible overestimation of the monetization of the losses, also detailed in Section 5.2.

3. SECURITY OF SUPPLY

The security of supply provided by a power system is related to its reliability. Traditionally, the reliability of a power system is decomposed into two fundamental aspects: **adequacy** and **security**. Adequacy relates to the existence of sufficient facilities (e.g. generation, transmission, distribution facilities) within the system to supply the consumer demand while satisfying operational limits. Adequacy is therefore associated with static conditions which do not include system disturbances. On the other hand, security can be defined as the ability of the system to withstand disturbances arising from faults and unscheduled removal of equipment without further loss of facilities or cascading failures. Security is therefore associated with the response of the system to these disturbances.

In order to analyze the security of supply linked to a project, ENTSO-E proposes three indicators :

- **B6 – Adequacy to meet demand**
- **B7 – System Flexibility**
- **B8 – System Stability**

These indicators will be presented and computed for the AQUIND interconnector, following the structure defined hereunder.

First, the methodology applied for the study is detailed. Section 0 presents the methodology for the indicator B6, Section 3.1.2 for the indicator B7 and Section 0 for the indicator B8.

Secondly, in Section 3.2, the results of the model developed by Tractebel are presented.

Then, in Section 3.2.3.4, the results obtained are compared with the results of the TYNDP 2018.

3.1. Methodology

The methodology applied to compute the B6, B7 and B8 indicators is based on the approach suggested in the TYNDP 2018 and detailed in the 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects.

The scenarios studied are the same as for the Variation of grid losses : the 2025 Best Estimate and 2030 Sustainable Transition, Distributed Generation and EUCO of the TYNDP 2018 as well as an additional scenario developed by AQUIND for 2030 (2030 AQUIND Market Scenario) and two variants of this scenario (the 2030 AQUIND High Commodities/Renewables and the 2030 AQUIND Low Commodities scenarios).

3.1.1. B6 Security of supply: Adequacy to meet demand

As stated in the ENTSO-E Guidelines :

*“**Adequacy to meet demand** is the ability of a power system to provide an adequate supply of electricity in order to meet the demand at any moment in time, i.e. that a sufficient volume of power is available and can be physically delivered to consumers during all time steps (e.g. hours).”*[4]

This indicator is thus linked to the adequacy of the power system.

The benefits of adequacy of an interconnection project can be quantified as :

- The decrease of Expected Energy Not Served (EENS) of the system
- The peak generation capacity the project could save while keeping the same adequacy standards

ENTSO-E proposes to take the decrease of yearly EENS for the B6 indicator and conduct a sanity check by assessing the maximum peak generation capacity the project could save.

In order to quantify and monetize the decrease of EENS with the interconnection, the methodology is :

- Remove the interconnection project from the grid model
- Adapt the portfolio of the regions to reach the generation adequacy standard
- Run the model with various forced outage patterns and calculate the EENS
- Add the project to the model, run the model and calculate the EENS
- Multiply the change in EENS by the Value of Lost Load (VoLL)

The grid model used is the SCANNER model presented in Section 2.1, run using a multi-area approach.

As detailed in Section 2.1.1.1, the SCANNER tool is characterized by a sequential Monte Carlo simulator of generation and transmission systems. Random forced outages of generating units are sampled by SCANNER, on the basis of probability laws (Weibull laws) describing the times to failures and the times to repair. By simulating different outage patterns selected according to Monte Carlo methodology, statistically correct results are obtained.

The generation adequacy standard is set at a Loss of Load Expectation (LOLE) of 3 hours for France, Great Britain, Germany, Belgium and Netherlands. The VoLL used by ENTSO-E is 10 000 EUR/MWh. The same value is used for this study.

If the interconnector brings significant benefits to the two interconnected regions, the maximum save of peak generation capacity is twice the installed capacity of the interconnector. Indeed, if there are no coincident scarcity events, the interconnector would effectively be as beneficial as the same level of conventional generation installed in each of the two interconnected regions.

[4] ENTSO-E, 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects, 27 September 2018, page 36.

The save of peak generation capacity is then monetized by ENTSO-E taking the value of 40 000 EUR/MW/year.

The B6 indicator is taken as the minimum between the monetized value of the decrease of EENS and the monetized value of the peak generation capacity the project could save.

3.1.2. B7 Security of supply: System flexibility

As stated in the ENTSO-E Guidelines :

*"**The System flexibility indicator** (B7) seeks to capture the capability of an electric system to accommodate fast and deep changes in the net demand (load minus intermittent RES) in the context of high penetration levels of non-dispatchable electricity generation."*[5]

The B7 indicator is quantified by use of the transmission capacities to indicate the level of cross-border assistance to ramping that the new interconnector can provide.

Definitions :

- **Residual load :** difference between load and renewable production.
- **Maximum hourly ramp of residual load, $\boldsymbol{R_{0,max}}$** : maximum absolute value of the hourly ramping of residual load in MW at the 99.9 percentile.
- **Existing Grid Transfer Capability, $\boldsymbol{GTC_{old}}$**: maximum power flow that can occur across a boundary.
- **Remaining maximum hourly ramp of residual load, $\boldsymbol{R_{r,max}}$** :
$$R_{r,max} = R_{0,max} - GTC_{old}$$
- **$\Delta\boldsymbol{GTC}$ for the new project** : increase of GTC thanks to the project.

The increase of system flexibility is given by comparing the variation of GTC linked to the project :

$$\boldsymbol{B7} = \frac{\Delta \boldsymbol{GTC}}{\boldsymbol{R_{r,max}}}, \text{ if } \boldsymbol{R_{r,max}} > \boldsymbol{0}$$

$$\boldsymbol{B7} = \boldsymbol{0}, \text{ if } \boldsymbol{R_{r,max}} = \boldsymbol{0}$$

A high value of the B7 indicator indicates thus that the new interconnection improves strongly the system flexibility, while a value close to 0% indicates that it does not influence significantly on the system flexibility.

[5] ENTSO-E, 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects, 27 September 2018, page 38.

3.1.3. B8 Security of supply: System stability

As stated in the ENTSO-E Guidelines :

*"**Power system stability** is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance. Examples of physical disturbances could be electrical faults, load changes, generator outages, line outages, voltage collapse or some combination of these."*[6]

This indicator is thus linked to the security of the power system.

The assessment of the system stability requires important additional simulations and complex models. Only a qualitative assessment of the system stability regarding the Transient Stability, the Voltage Stability and the Frequency Stability is presented, in line with the standard ENTSO-E CBA methodology. The benefit from black start services is also analyzed.

3.2. Study results

3.2.1. B6 Security of supply: Adequacy to meet demand

For the case studied, the maximum save of peak generation capacity is equal to 4 000 MW, corresponding to a monetized benefit of 160 MEUR/year. The B6 indicator will thus be the minimum between the monetized value of the decrease of yearly EENS and 160 MEUR.

Table 9 presents the results obtained for the B6 indicator for the seven scenarios studied.

Scenario	EENS saved [MWh/year]	Diminution EENS monetized [MEUR/year]	Sanity Check value [MEUR/year]	Monetization B6 [MEUR/year]
2025 Best Estimate	6615	66	160	66
2030 Sustainable Transition	2539	25	160	25
2030 Distributed Generation	501	5	160	5
2030 EUCO	191	2	160	2
2030 AQUIND Market	1353	14	160	14
2030 AQUIND High Commodities/Renewables	0	0	160	0
2030 AQUIND Low Commodities	5833	58	160	58

Table 9 : B6 SoS: Adequacy to meet demand, results.

[6] ENTSO-E, 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects, 27 September 2018, page 40.

3.2.2. B7 Security of supply: System flexibility

For the case studied, the Existing Grid Transfer Capacity between France and Great Britain, $\boldsymbol{GTC_{old}}$, corresponds to the current interconnection capacity, equal to 2 000 MW. The increase of Grid Transfer Capacity, $\Delta\boldsymbol{GTC}$, is equal to the capacity of the AQUIND interconnector, 2 000 MW.

The value of the remaining maximum hourly ramp of residual load, $\boldsymbol{R_{r,max}}$, and the B7 indicator are summarized in Table 10.

Scenario	Zone	$R_{r,max}$ [MW]	B7 [%]
2025 Best Estimate	France	6804	29
	Great Britain	7065	28
2030 Sustainable Transition	France	9481	21
	Great Britain	7673	26
2030 Distributed Generation	France	10813	18
	Great Britain	7951	25
2030 EUCO	France	6614	30
	Great Britain	8919	22
2030 AQUIND Market	France	10078	20
	Great Britain	8547	23
2030 AQUIND High Commodities/Renewables	France	11926	17
	Great Britain	9276	22
2030 AQUIND Low Commodities	France	7956	25
	Great Britain	7692	26

Table 10 : B7 SoS: System flexibility, results.

3.2.3. B8 Security of supply: System stability

3.2.3.1. TRANSIENT STABILITY

By properly adjusting the converters at the ends of the interconnector during incidents, it is possible that the converters will improve the transient stability of the power system.

3.2.3.2. VOLTAGE STABILITY

The converters used are VSC converters. These allow reactive compensation to be provided and thus improve voltage stability locally.

The connection substation in France is Barnabos. No voltage stability problem has been highlighted by RTE for this substation. Moreover, no future investment in order to improve voltage stability are planned close to this substation in the "Schéma décennal de développement du réseau" (Ten-Year Network Development Plan) of RTE. The new interconnection therefore does not avoid new investments regarding the voltage stability.

The connection substation in Great Britain is Lovedean. In the report of National Grid "SO Submission to Cap and Floor" of June 2017[7], it is stated that the AQUIND interconnector allows benefits from avoiding new shunt reactors or STATCOMS close to Lovedean.

3.2.3.3. FREQUENCY STABILITY

The AQUIND interconnector strengthens the interconnection between two synchronous areas; Continental Europe and Great Britain. It increases the possibility of sharing primary reserve between these zones and therefore supports the frequency stability of the European system.

In the report of National Grid mentioned here above, it was shown that AQUIND is potentially able to provide a benefit to the system by being able to provide frequency response cheaper than the current marginal form of frequency response (commercial frequency response). It this report, it was assumed interconnectors could provide 5-10% of their capacity for frequency response.

3.2.3.4. BLACK START SERVICES

Interconnectors which use Voltage Source Converter (VSC) technology have the potential to offer black start capability. The AQUIND interconnector could thus provide black start services to the power systems. However, numerous new other interconnectors with VSCs are planned between Great Britain and France and, for diversity reasons, all these interconnectors will not be allowed to provide black start services together. The benefits linked to the black start services are thus marginal.

3.3. Comparison with results of the TYNDP 2018

3.3.1. B6 Security of supply: Adequacy to meet demand

Table 11 compares the results of the model developed by Tractebel for the B6 indicator of the AQUIND Interconnector with the results of the TYNDP 2018.

[7] National Grid, SO Submission to Cap and Floor, June 2017.

Scenario	EENS saved [MWh/year]		Monetization B6 [MEUR/year]	
	TYNDP	Tractebel	TYNDP	Tractebel
2025 Best Estimate	1538	6615	15	66
2030 Sustainable Transition	5658	2539	57	25
2030 Distributed Generation	2734	501	27	5
2030 EUCO	36	191	0	2

Table 11 : B6 SoS: Adequacy to meet demand, comparison with TYNDP.

One can notice significant differences between the results obtained by Tractebel and those of the TYNDP, but the order of magnitude is similar.

This difference is first explained by the important variability of the results due to the method used. Indeed, a significant variability of EENS saved among the different simulations was observed for certain scenarios. However, the results of the TYNDP always lie in or close to the 95% confidence interval obtained. Moreover, the adaption of the portfolio of the regions to reach the generation adequacy standard may strongly influence the results, but no information on the method used by the TYNDP to adapt the generation was available. Finally, the details of implementation are not fully transparent in the TYNDP. Therefore, there are potential other differences in the assumptions adopted between the models and these differences may explain discrepancies in the results.

3.3.2. B7 Security of supply : System flexibility

Table 12 compares the results of the model developed by Tractebel for the B7 indicator of the AQUIND Interconnector with the results of the TYNDP 2018.

Scenario	Zone	$R_{r,max}$ [MW]		B7 [%]	
		TYNDP	Tractebel	TYNDP	Tractebel
2025 Best Estimate	France	5815	6804	34	29
	Great Britain	7383	7065	27	28
2030 Sustainable Transition	France	7124	9481	28	21
	Great Britain	8258	7673	24	26
2030 Distributed Generation	France	9233	10813	22	18
	Great Britain	9615	7951	21	25
2030 EUCO	France	7899	6614	25	30
	Great Britain	8535	8919	23	22

Table 12 : B7 SoS: System flexibility, comparison with TYNDP.

One can notice that the results obtained by Tractebel are close to those of the TYNDP.

4. CONCLUSIONS

To quantify the variation of the grid losses and the impact on the security of supply of the AQUIND Interconnector, a grid model representative of Europe has been developed using the software tool SCANNER.

Seven scenarios were studied : the 2025 Best Estimate and the 2030 Sustainable Transition, Distributed Generation and EUCO of the TYNDP 2018 as well as an additional scenario developed by AQUIND for 2030 (2030 AQUIND Market Scenario) and two variants of this scenario (the 2030 AQUIND High Commodities/Renewables and the 2030 AQUIND Low Commodities scenarios).

The results of the TYNDP scenarios were compared with the results of the TYNDP and an analysis of the results obtained by ENTSO-E was led.

Table 13 summarizes the results obtained.

Scenario	B5 – Variation of grid losses		B6 - Adequacy to meet demand		B7 – System Flexibility		
	ΔE [GWh/year]	ΔCost [MEUR/year]	EENS saved [MWh/year]	Monetization B6 [MEUR/year]	Zone	$R_{r,max}$ [MW]	B7 [%]
2025 Best Estimate	635	60	6615	66	France	6804	29
					Great Britain	7065	28
2030 Sustainable Transition	278	33	2539	25	France	9481	21
					Great Britain	7673	26
2030 Distributed Generation	353	32	501	5	France	10813	18
					Great Britain	7951	25
2030 EUCO	623	3	191	2	France	6614	30
					Great Britain	8919	22
2030 AQUIND Market	1281	19	1353	14	France	10078	20
					Great Britain	8547	23
2030 AQUIND High Commodities/ Renewables	953	9	0	0	France	11926	17
					Great Britain	9276	22
2030 AQUIND Low Commodities	1235	42	5833	58	France	7956	25
					Great Britain	7692	26

Table 13 : B5, B6 and B7 results summary.

5. APPENDIXES

5.1. Computation of losses on the interconnections

The losses on the AQUIND interconnector gather the losses on the lines and the losses in the converters. The interconnector being composed of two pairs of HVDC cables, with a converter at each end of each pair, the total losses are equal to :

$$P_{losses} = 4 * P_{losses_{line}} + 4 * P_{losses_{conv}}$$

Where $P_{losses_{line}}$ are the losses on one cable and $P_{losses_{conv}}$ the losses in one converter.

The losses on a transmission line are computed as :

$$P_{losses_{line}} = R * I^2$$

Where R is the resistance of the line and I the current.

The current on the line can be derived from the power flow ($P_{flow_{line}}$) on the line :

$$I = \frac{P_{flow_{line}}}{V}$$

Where V is the voltage of the interconnector.

The losses can thus be expressed as :

$$P_{losses_{line}} = R * \left(\frac{P_{flow_{line}}}{V}\right)^2$$

A linearization of the losses is used in Scanner :

$$P_{losses_{line}} = R * \frac{P_{flow\,line}}{V} * \frac{P_{nom}}{V}$$

With P_{nom}, the nominal capacity of the line.

In our case, the resistance of the line is supposed equal to 0.011 Ω/km. The voltage is equal to 320 kV, the nominal capacity of a cable is 500 MW and the length of the cable is 240 km.

For each converter, the losses are equal to 1% of the energy flowing in the converter and the no-load losses are supposed equal to 0.2% of the nominal power of the converter.

Example

In the case of a power flow of 2000 MW, considering 1000 MW on each pair of cable and 500 MW on each cable, the losses on a cable are equal to :

$$P_{losses_{line}} = 0.011 * 240 * \frac{500}{320} * \frac{500}{320} = 6.45\ MW$$

The losses in a converter are equal to :

$$P_{losse_{conv}} = 0.01 * 1000 = 10\ MW$$

The total losses on the interconnector are thus equal to :

$$P_{losses} = 4 * 6.45 + 4 * 10 = 65.78\ MW$$

For each other interconnection between Great Britain and Continental Europe, the same methodology is followed. An equivalent resistance has also been computed, keeping the value of to 0.011 Ω/km. The losses of the converters are taken into account, keeping the value of 1% of the energy flowing and no-load losses equal to 0.2% of the nominal power of the converter. This method and parameters may differ from the one of the TYNDP, leading to variation of the results.

5.2. Analysis of the results of the TYNDP

As mentioned in Section 2.3, the results of the TYNDP regarding the variation of losses and its monetization are subject to variability and ENTSO-E indicated the possible overestimation of the monetization of the losses.

In the TYNDP 2018 project sheet of the AQUIND Interconnector, it is stated :

"*In the TYNDP 2018, ENTSO-E used a new approach to monetize losses associated with each project described in a new Cost Benefit Analysis methodology, discussed with stakeholders and approved by the European Commission. The methodology was followed rigorously and correctly*.

However, it appeared that the final results were unexpectedly highly impacted for some projects by the difference in granularity of input variables or by projects different sensitivity to climate conditions (same conditions have been applied to all projects). The steps necessary to amend the approach, including amending the methodology, discussing it with stakeholders and implementing it was impossible in the time-frame of the TYNDP 2018 development. This has led to what may be considered as too high monetized losses values that would not occur in reality. ENTSO-E acknowledges these facts and recommends to use the results of losses computation with cautiousness when conducting any sort of financial analysis to estimate the project profitability and feasibility."[8]

Moreover, ENTSO-E shared a note regarding the B5 indicator with the project promoters to explain the results of the TYNDP for this indicator. In this note, it is stated :

"After all the calculations were done, the TYNDP experts noted that for some projects assessed in TYNDP 2018, the results of losses variation monetized (B5) seemed unrealistic. Therefore, ENTSO-E conducted an investigation on the reasons for such unexpected results."

The following points were highlighted by ENTSO-E :

- The influence of climatic conditions on the hourly marginal costs, used for monetization of losses results.
- The influence of market modelling software tools on the hourly marginal costs, used for monetization of losses results.

[8] ENTSO-E, Project 247 – AQUIND Interconnector, https://tyndp.entsoe.eu/tyndp2018/projects/projects/247, consulted on May 22, 2019.

- The possible overpricing of the losses due to monetization of the losses using 100 Points in Time for the Great Britain power system.

This note highlights the possible overestimation of the monetization of the losses of the TYNDP 2018 but also allows to estimate the variability of the variation of the grid losses and its monetization regarding different parameters, as detailed in the following subsections.

In addition, and as mentioned in Section 2.1.1.2.2, ENTSO-E also indicated in the 2nd ENTSO-E Guideline For Cost Benefit Analysis of Grid Development Projects that the location of the generation units is a key factor in the study of the variation of the losses.

The different influencing parameters and hypotheses mentioned here above explain the differences in results presented in Section 2.3.

5.2.1. Influence of climatic conditions

The climatic profiles used for the monetization of the losses of the TYNDP 2018 are the climatic conditions of 2017, while for the calculation of the market CBA indicators three climatic years were used (1982, 1984 and 2007). In the note, the results of the variation of grid losses for the climatic conditions of 2017 are compared with the ones obtained for the climatic conditions of 1982 and 1984 for four interconnection projects (P16, P228, P276 and P285).

A variation up to 56% is observed between the climatic years for the variation of grid losses, and up to 181% for the monetization of the variation of losses[9].

5.2.2. Influence of market modelling software tools

For the calculation of the market CBA indicators, ENTSO-E used three market modelling software tools in order to avoid outlying results, the final results being the average of results for all market modelling tools (weighted average for three climatic conditions for each market modelling software tools). However, only one market modelling tool was used for the monetization of losses.

In the note, the results of the variation of grid losses for two market modelling tools (Antares and PowrSym) are compared for four interconnection projects (P16, P228, P276 and P285).

A variation up to 54% is observed between the two software tools for the variation of grid losses and up to 126% for the monetization of the variation of losses, for a given climatic year.

[9] The variation is computed as the absolute value of the difference of the two results divided by the smallest of the two results.

5.2.3. Exceptional case of monetization of losses using 100 Points in Time

In the TYNDP 2018, a representative hour monetization has been utilized for the calculation of losses and their monetization for the Great Britain power system, using a sequential every 87th hour market price for monetization of losses. This has led, in some cases, to serious increase in monetized value of losses, according to ENTSO-E. A correction has been made to take into account the average price of each 87 time steps but still leaving a range of risk in terms of high price of losses monetization.

5.3. B6 indicator : Disaggregation of energy not supplied

Due to the way the B6 indicator is computed (i.e. optimization problem minimizing the overall amount of load shedding), it is not relevant to have a disaggregation of the variation of energy not supplied between countries. Indeed, if there is a general electricity scarcity situation, the exact location of load shedding has no impact on the objective function as long as there is no congestion.

Indeed, for example, in a situation with two zones : Zone A and Zone B. Zone A has a demand of 400 MW and an available generation capacity of 600 MW. Zone B has a demand of 600 MW and an available generation capacity of 300 MW. The interconnection between the two zones has a capacity of 300 MW. This situation is represented in the following figure.

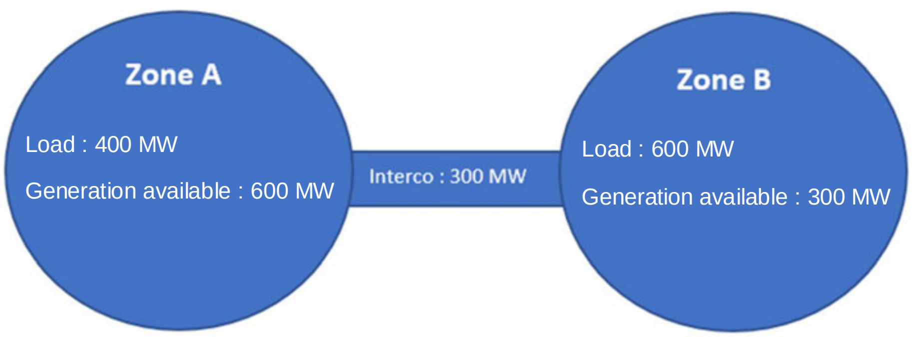

Figure 2: B6 indicator : disaggregation of energy not supplied, example 1.

In this case, the two flollowing solutions (Figure 3 and Figure 4) lead to an identical value of the objective function if the VoLL is identical in the two zones and the losses are not taken into account.

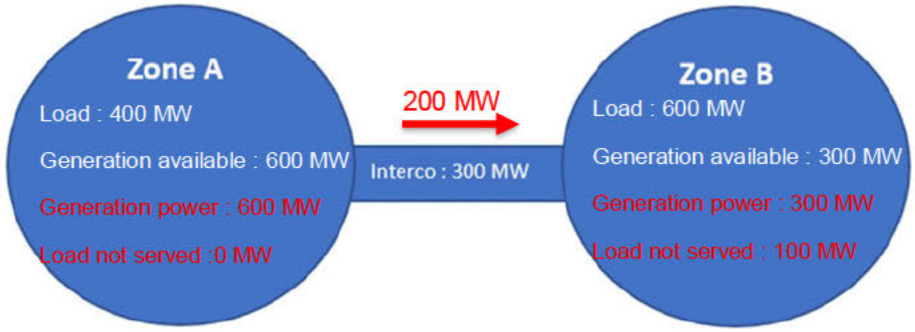

Figure 3: B6 indicator: disaggregation of energy not supplied, example 1, solution 1.

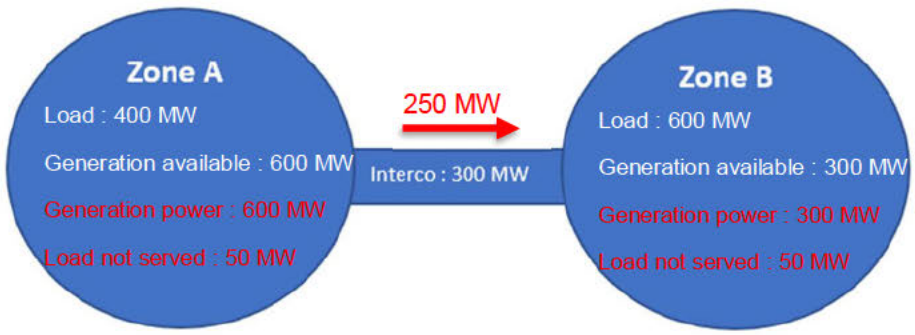

Figure 4: B6 indicator: disaggregation of energy not supplied, example 1, solution 2.

This multiplicity of equivalent solutions implies that the exact amount of load shedding in Zone A and the exact amount of load shedding in Zone B is “random”, depending on the solver used, even if the total amount is well defined. For this reason, it is not possible to disaggregate the load not served between the different zones of the system studied, but only to give the total energy not served in the system.

Remark :

In the example, if the capacity of the interconnection is equal to 100 MW, there is only one optimal solution, due to the congestion of the interconnection:

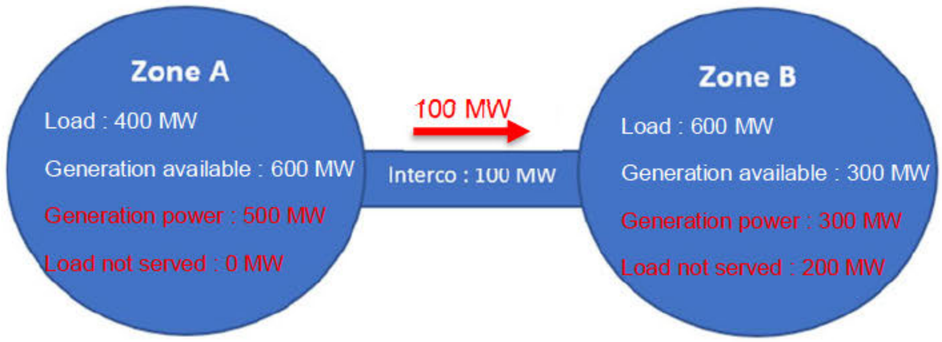

Figure 5: B6 indicator: disaggregation of energy not supplied, example 2, solution.