Explanatory note on the Elia proposal for a ‘Methodology for the use of Dynamic Line Rating in the capacity calculation’

5 December 2017

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INTRODUCTION

This explanatory note is written to provide information and clarification in the choices made by Elia in a proposal for a "*Methodology for the use of Dynamic Line Rating in the capacity calculation - 05/12/2017*" as introduced for approval by CREG (hereinafter "DLR proposal"). In case of discrepancies between the explanatory note and the DLR proposal, the DLR proposal shall prevail. Terms used in this document are understood as defined in the CACM Regulation.

This DLR proposal follows a constructive discussion with CREG[1] about the most appropriate method to be used to integrate DLR in the capacity following a negative decision of CREG with regards to a first proposal of December 2016. This explanatory note provides further detail of the analysis performed and criteria assessed to build up the current DLR proposal.

CONTEXT

In 2008, in collaboration with Ampacimon©, Dynamic Line Rating (DLR) has been tested for the first time on a 380kV line in Belgium, since then Elia has gradually increased the use of this technology. Elia has been one of the pioneers in Europe by installing such a technology on several lines.

Since December 5th, 2016, Elia also uses the DLR data of Ampacimon to increase the available capacity of several equipped lines in the D2CF, DACF and IDCF files. This accelerated introduction followed previsions of a winter with possible adequacy problems and aimed at maximising the available interconnection capacity within the limits of the security of the grid in line with the legal obligations for Elia as a Belgian transmission system operator. As such – and with the indication that this method would be subject to further evaluation – Elia installed a pre-treatment rule for the raw DLR data of Ampacimon, since using these DLR data without a pre-treatment rule would represent a non-negligible risk for the real-time grid operation.

As described in the DLR proposal, the base principle for increasing available capacity based on forecasts is that said increase has to remain within the limits of an acceptable increase of risks for operational security. Therefore, in the method applied since 5 December 2016, Elia has fixed a cap of 105% with respect to the seasonal limit on the initial ampacity forecasts for the concerned lines and for all time-horizons (D2CF, DACF and IDCF). Moreover, in case of daily averaged negative temperatures, Elia is currently increasing the capping level to 110% with respect to the seasonal limit for all equipped lines and for all time-horizons (D2CF, DACF and IDCF).

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[1] In which all data used by Elia have been fully shared with CREG and where the validity of the data has been confirmed.

Following a negative decision of CREG with regards to a first proposal of December 2016, Elia has engaged with CREG in sharing its experience after almost a year of operation and was able to update its statistical analysis that now is based on an extended dataset[2]. Based on this analysis and the discussions with CREG, a new methodology has been developed in which the current capping levels have been re-evaluated and a differentiation is made between peak and off-peak hours.

METHODOLOGY FOR THE USE OF DYNAMIC LINE RATING IN THE CAPACITY CALCULATION

1. Dynamic line rating versus static line rating

The static line rating, evaluated with deterministic or probabilistic methods, is based on certain rather conventional assumptions regarding atmospheric operating conditions. This approach had been widely accepted and used decades ago when different direct and indirect measurements techniques were not available or were used very seldom.

In last decade, one of the possible options identified to exploit the grid as much as possible is based on dynamic line rating by using several available measurement and forecast techniques. The related data acquisition is very often combined with meteorological measurements. By having both information available line conductor model can be calibrated and used in a subsequent process in order to gain variable transmission line limits by using environmental cooling or heating conditions as one major input factor.

This leads to the following definitions:

- **Static thermal current:** A static thermal current is a current which causes that conductor, operating under presumed atmospheric conditions, designed for certain maximum continuous operating temperature and certain maximum operating sag, reaches one of either limits: the maximum conductor temperature or the maximum sag.
- **Dynamic thermal current:** A dynamic thermal current is a current which causes that conductor, operating under real atmospheric conditions, designed for certain maximum continuous operating temperature and certain maximum operating sag, reaches one of either limits: the maximum conductor temperature or the maximum sag.

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[2] Please note that all statistical results in this document are based on a dataset from 1/01/2015 up to 30/06/2017. Considering that Forecasts 1h are relevant only if the flows on a given line are superior to about 30% of the nominal ampacity, depending on the specific line there were only between 3000 and 7000 valid hours retained for the statistical analysis. It is often said that a dataset of minimum 3 years (i.e. 26280 hours) becomes statistically reliable when meteorological forecasts are involved. The lines most recently equipped with Horizon forecast are not included in this analysis because Ampacimon needs several months to accumulate enough data in order to adjust correctly its forecast Horizon.

2. Ampacimon technology

2.1. Types of Ampacity: Real-time and forecasts

The Ampacimon technology makes use of small modules installed on the most critical spans of a line. Those modules measure continuously the line sag and this allows Ampacimon to calculate the maximum permanent flows that the line can support.

The modules are powered by induction of the current flowing on the line. Due to technical limitations, if those flows are smaller than about 30% of the nominal capacity then the modules are not activated and the ampacity falls back to a degraded value based only on temperature measurements. This limit has been chosen since at that moment at least 70% of the line capacity is still available and the added value of DLR is then negligible. The values received by Ampacimon are then processed by Elia and the limitations of other elements of the line in the bays are then taken into consideration.

2.1.1. Real-Time (RT) Ampacity

The RT Ampacity gives the permanent maximum ampacity of the line. It makes use of real-time measures of the line sag from each of the Ampacimon modules installed on a line. This RT ampacity is accurate and refreshed every 5 minutes. The RT ampacity gives high ampacity values but is too volatile to be used in real-time grid operation (local climate conditions vary continuously).

2.1.2. Forecast 1h

This is the ampacity used in real-time by Elia in the grid security calculations. It gives the maximum ampacity of the line which can be used with sufficient certainty for the next hour[3]. As a consequence the forecasted ampacity 1h is more stable and thus suitable to be used in real-time grid operation.

2.1.3. Forecast Horizon[4]

The Forecast Horizon gives an estimation of the ampacity of a line for the coming 60 hours. It requires an additional license. This forecast makes use of weather forecasts and the historical link between weather conditions and measured line-sagging. It is refreshed every 6 hours when new weather forecasts are available. In this document we will use the following convention: the forecast “xx” hours in advance will be noted “Fxx”. Each time the Forecast Horizon is refreshed at a given time “t”, we make use of the following grouping:

- F6 represents the forecast of the the hours t+1 until t+6;
- F12 represents the forecast of the hour t+7 until t+12;

[3] 98% of the time the Forecast 1h will not be overestimated even if climate conditions vary.

[4] All the results presented in this document make use of the F48 as reference for Horizon values for D2CF process. In reality, the F54, F48, F42 and F36 are used in the D2CF but one must choose one of those to make a coherent statistical analysis.

Please note that for a given business date and time there are practically no differences between the ampacity F54, F52, etc. This is due to the fact that temperature is the main parameter in the Forecast Horizon algorithm. In Belgium, temperature forecasts are relatively accurate over a 3 days' time horizon. Below the ampacity forecasts is shown for 3 time-horizons for the 22/10/2015 on line 380.11. This is a typical shape showing a lower ampacity forecast during daylight (temperature effect).

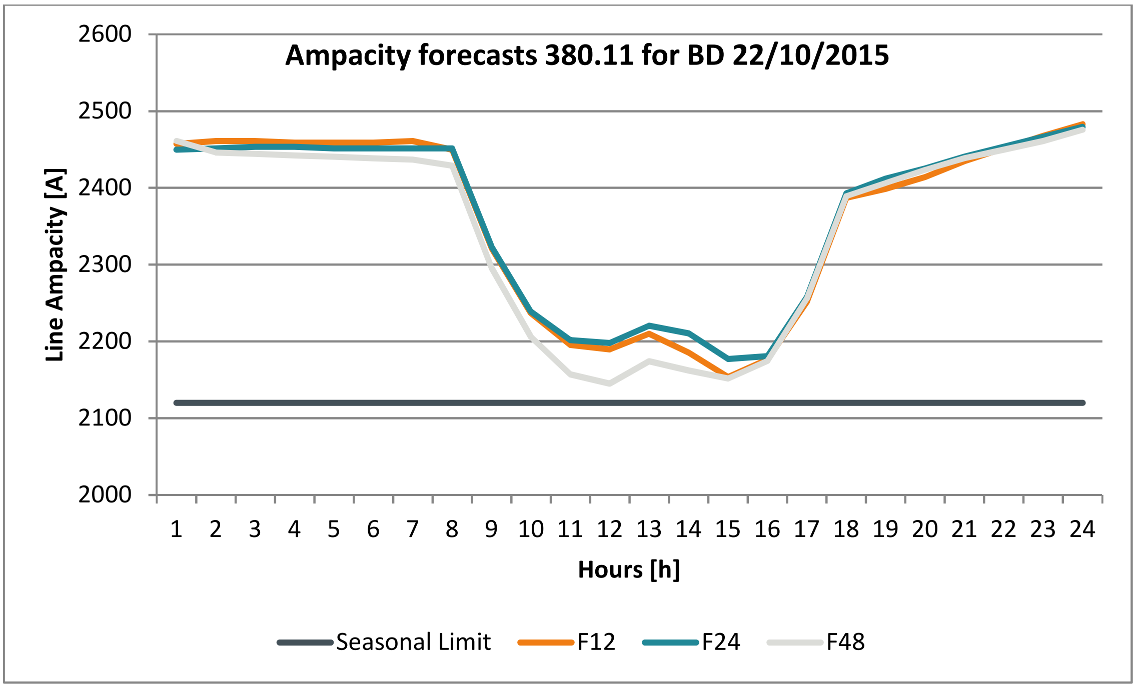

Figure 1: Ampacity forecasts on line 380.11 for three time horizons.

2.2. Use of Ampacimon modules on the Elia transmission grid

In a close collaboration between Elia and Ampacimon©, the Dynamic Line Rating has been tested for the first time on a 380kV line in 2008. After 3 years of tests and improvements of this prototype, in 2011 two 150kV-lines in the Belgian coastal region were equipped with Ampacimon modules and a Forecast 1h in the framework of the Twenties project. After 3 years of return of experience of these first 'production modules', Elia has decided in 2014 to install Forecast 1h on the most critical overhead lines of the Elia grid. As such, Elia has been one of the pioneers in Europe by making use of this technology for the operational management of the grid.

Since then Forecast 1h has helped Elia during several critical moments on the Elia grid. Some lines have been highly loaded thanks to the DLR demonstrating the utility, reliability and efficiency of this technology for the real-time management of the grid.

In its constant search to increase the use of the Ampacimon modules, In 2015, Ampacimon developed for Elia a new algorithm, the Forecast Horizon, in order to provide an ampacity forecast on overhead lines up to 60 hours in advance. Elia decided to install such licenses on the five most limiting 380kV tie-lines due to the adequacy situation at that time in Belgium.

The table below shows the different Ampacimon modules and different forecasting licenses that Elia will have as of 1/01/2018.

Line ID	Line Name	Forecast 1h license	Horizon license
380.23	Meerhout-Van Eyck	YES	-
380.27	Van Eyck-Maasbracht	YES	-
380.19	Achène-Lony	YES	YES
380.25	Doel-Zandvliet	YES	YES
380.11	Lixhe - Gramme	YES	
380.91	Van Eyck - Lixhe	YES	YES
380.12	Van Eyck - Gramme	YES	YES
380.28	Van Eyck-Maasbracht	YES	YES
380.79	Avelgem-Mastaing	YES	YES
380.29	Zandvliet-Kreekrak	YES	-
380.30	Zandvliet-Kreekrak	YES	-
380.80	Avelgem-Avelin	YES	YES
380.26	Doel-Zandvliet	YES	YES
380.73	Mercator - Horta	YES	YES
380.74	Mercator – Horta	YES	YES
380.101	Horta – Avelgem	YES	YES
380.102	Horta – Avelgem	YES	YES
220.513	Aubange - Moulaine	YES	YES
220.514	Aubange - Moulaine	YES	YES
150.5	Brugge-Langerbrugge	YES	-
150.6	Brugge-Langerbrugge	YES	-
150.15	Brugge-Slijkens	YES	-
150.16	Brugge-Slijkens	YES	-
150.313	Baudour-Chièvres	YES	-
150.314	Baudour-Chièvres	YES	-
70.49	Moucron - Tournai	YES	-

Table 1 : overview of Elia lines installed with Ampacimon modules and different forecasting licenses as from 1 January 2018

3. Basic principle by developing the methodology

The basic principle is that by applying a methodology to integrate DLR in the capacity calculations processes for any timeframe, one should aim to maximise the average gain of the capacity increase without going beyond predefined levels of a risk increase for operating the grid in a secure manner.

In order to be able to choose between different methods (of which a capping method and a derating method are the two main approaches), and determine the acceptable levels of risk increase and final values to be integrated, Elia has performed various analyses. These analyses have focussed on the day ahead process and integration into the D2CF values, but can be copied for the DACF and IDCF values.

The result of these analyses concluded that the optimal rule in D2CF is to insert an upper cap at max 105% of seasonal rating for peak hours and an upper cap at max 10% of seasonal rating for off-peak hours, while maintaining the values of the of seasonal rating as lower limit (➔ minimum = 100% of seasonal limit).

4. Description of the performed analyses

4.1. Reliability Analysis for Forecast Horizon

In order to asses a possible increase in operational risk by applying the Ampacimon Forecast Horizon (48h) values, Elia compared them with the Forecast 1h values (i.e. the values that Elia uses in real-time grid operation). The conclusion of this comparison is that the forecast Horizon 48h provided by Ampacimon is not 100% of the time higher than the Forecast 1h. Sometimes the Horizon values are higher than the values used in real-time in the security analysis (i.e. Forecast Horizon > Forecast 1h for a given date and time, referred to in this document as "operational risk").

It is the responsibility of Elia, as a TSO, to fulfil the N-1 criteria for all hours of the year. As a consequence, a 'pre-treatment' rule to apply to the raw data of the Forecast Horizon values is necessary in order to manage the associated operational risks.

As stated before, one of the basic principles for increasing available capacity based on forecasts is that said increase has to remain within the limits of an acceptable increase of risks for operational security. Therefore Elia needed to set the level of the acceptable increase of operational risks and currently defined this as 0.1% (i.e. +/- 9h per year)

4.2. Analysis of different options for a pre-treatment rule for Forecast Horizon values

Different options exist to develop a rule that on the one hand maximizes the average ampacity used in D2CF, DACF and IDCF while minimizing the operational risks (<0,1%) that those values would be higher than the Forecast 1h used in real-time operation of the grid.

Since December 2016, Elia applies a "capping rule method" to attain this goal. In its decision of 5 October 2017, CREG suggested to apply a "derating rule method" to be able to increase the capacity. The analysis below compares both methods

4.2.1. Capping rule method

Since December 5th 2016, Elia is using a capping rule for all hours of the day with:

- A lower cap equivalent to the seasonal rating;

- An upper cap equivalent to 105% of the seasonal rating if daily averaged forecasted temperature >0°C;
- An upper cap equivalent to 110% of the seasonal rating if daily averaged forecasted temperature <0°C.

This results in an average ampacity of 104.3% with respect to the seasonal rating and an operational risk of about 0.07%. Of course, the upper cap could be adapted and this would result in different average gains and risks as shown on the graph below.

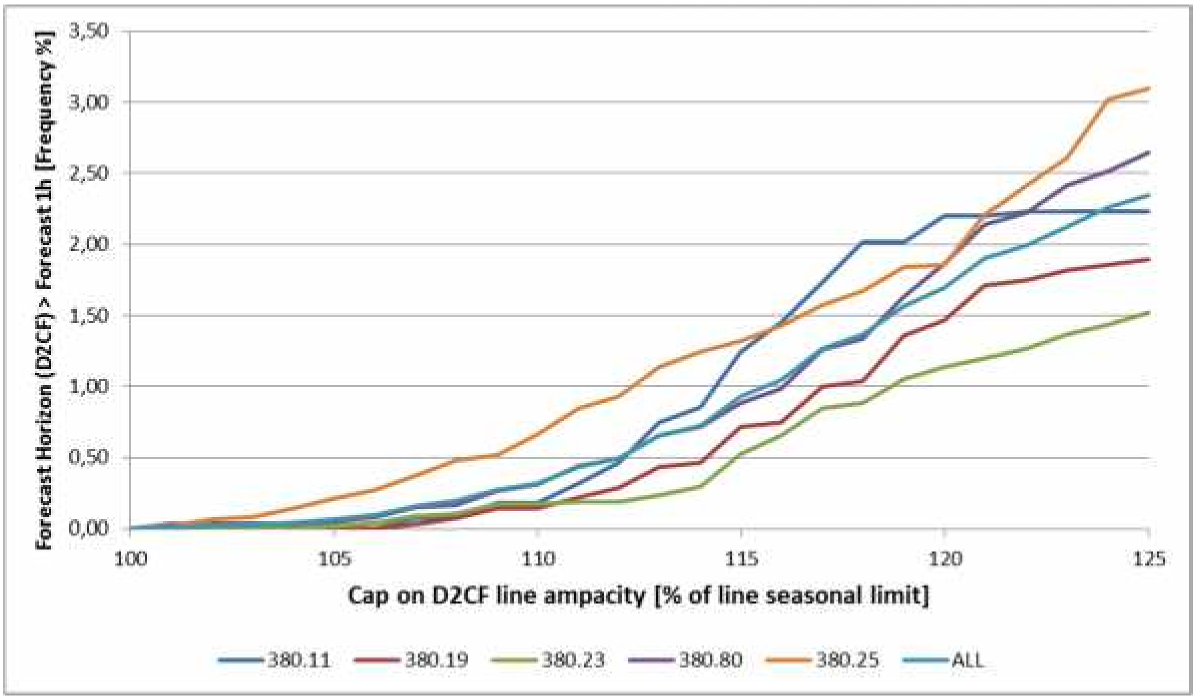

Figure 2: Occurrences when the Forecast Horizon 48h is higher than Forecast 1h (y-axis) in function of the capping levels (x-axis).

4.2.2. Derating rule method

CREG suggested in its decision B1636 to investigate the possibility to make use of derating rule method instead of a capping rule. The derating rule would consist of simply reducing the Forecast Horizon by a certain percentage for all hours of the day.

CREG suggested using a derating factor of 95%. Applying this derating factor results in an average ampacity of 108.7 % with respect to the seasonal rating and an operational risk of about 1.38%. Of course, the derating factor could be adapted and this would result in different average gains and risks as shown on the table below.

x % of F48	Av. Gain	Risk
85	97,3	0,11
86	98,4	0,14

87	99,6	0,17
88	100,7	0,22
89	101,9	0,31
90	103,0	0,38
91	104,2	0,50
92	105,3	0,66
93	106,5	0,86
94	107,6	1,08
95	108,7	1,38
96	109,9	1,68
97	111,0	2,09
98	112,2	2,55
99	113,3	3,23
100	114,5	4,27

Table 2 : Average risk and ampacity gain with a derating rule method

4.2.3. Comparison of both methods

In order to be able to compare the performances of the capping rule with respect to those of the derating rule it is necessary to have a look at the operational risks in function of the corresponding average ampacities as shown in the graph below, since this is considered as the main determining element in establishing a DLR methodology.

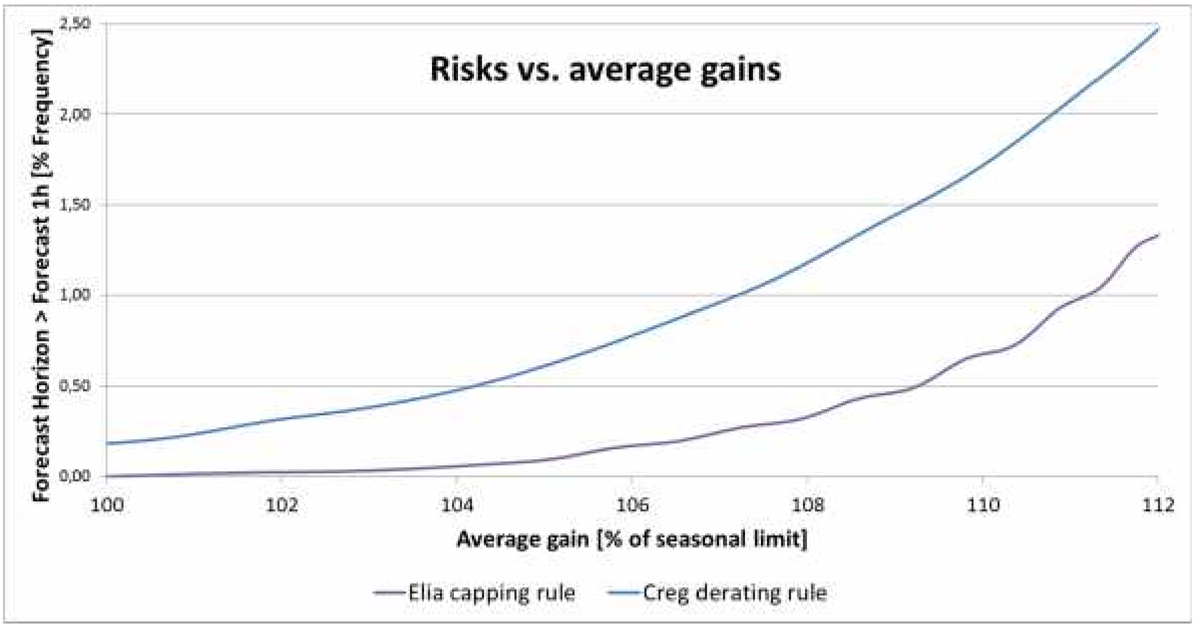

Figure 3: Comparison of the operational risks (y-axis) in function of the average ampacity gains (x-axis) for both pre-treatment approaches.

The Figure 3 above clearly shows that for similar average gains, the risk level is much lower for a capping rule in comparison with a derating rule. This fact demonstrates that a capping rule approach is better to manage operational risks in comparison with a derating rule for the same average gain of capacity.

Based on the above analysis, the proposed Methodology for the use of Dynamic Line Rating in the capacity calculation is based on a capping rule method.

4.3. Characteristics of the DLR methodology

4.3.1. Peak vs. Off-peak

After some exchanges with the CREG when analysing the results of both rules in detail, it became clear that for the same capping level, the associated operational risks appeared to be higher during the day than during the night.

Based on the observation that ampacity gains are systematically higher at night than during the day[5], the logical conclusion is that the current applied capping rule of Elia could be improved by making use of two different upper capping rules that differentiates between night and day. A choice has been made to base this differentiation based on the well-known principles of peak hours and off-peak hours during market coupling.

The relationship between operational risk increase and ampacity gain for both peak and off-peak hours can be calculated as follows:

1. The first step is applying a given capping level to the cleaned historical dataset of the Forecast Horizon of a given line
2. Secondly the number of hours when this capped forecast is larger than the Forecast 1h is counted
3. The third and final step is to calculate the operational risk for this given line by dividing this number of hours by the total number of hours in the used dataset.

This three step procedure is performed for each line equipped with the Forecast Horizon for which sufficient historical data is available to be correctly calibrated by Ampacimon. A weighted average over the equipped lines can then be calculated in order to result in the operational risk we refer to. The weights reflect the size of the cleaned dataset of each line.

This process is repeated for each capping level. The results of this process is shown in the table below. Please note that peak hours correspond to the following period: [9:00 – 20:00] and off-peak period to [00:00 - 9:00[+]20:00 – 24:00].

Cap (%)	All hours		Peak hours		Off-peak hours	
	Av. Gain	Risk	Av. Gain	Risk	Av. Gain	Risk

[5] Temperatures are lower during the night which increases the cooling of overhead lines.

100	100,0	0,00	100,0	0,00	100,0	0,00
101	100,9	0,01	100,8	0,03	101,0	0,00
102	101,8	0,02	101,6	0,05	102,0	0,00
103	102,6	0,03	102,3	0,05	103,0	0,00
104	103,4	0,04	103,0	0,08	103,9	0,00
105	104,3	0,07	103,7	0,12	104,9	0,01
106	105,0	0,09	104,3	0,16	105,9	0,02
107	105,8	0,16	104,9	0,27	106,8	0,04
108	106,5	0,20	105,4	0,30	107,8	0,08
109	107,2	0,27	106,0	0,43	108,7	0,10
110	107,9	0,32	106,4	0,47	109,6	0,15
111	108,6	0,43	106,9	0,61	110,5	0,23
112	109,2	0,49	107,3	0,71	111,4	0,25
113	109,8	0,65	107,7	0,86	112,2	0,42
114	110,4	0,73	108,1	0,96	113,0	0,47
115	110,9	0,93	108,4	1,09	113,7	0,75

Table 3 : Average Ampacity gains with respect to seasonal ratings and associated operational risks in function of the capping levels.

Based on above table one can see that in order to keep the operational risk <0,1% it is possible to use a cap of +/- 105% during peak hours and +/- 109% during off peak hours, which are the values Elia has proposed in the methodology for 2018.

The exact values of the caps will be fixed every year by recalculating table 3 and choosing the caps that equal an increase in operational risk of 0.1%. These values will be published on the Elia website and via an Urgent Market Message, in line with the transparency obligations..

4.3.2. Low temperatures and cold spells

The same reasoning used in the previous section might be applied for low temperature situations. Indeed when temperatures drop to an exceptionally low level with respect to seasonal averages then for a same capping level, the associated operational risks are lower than in a normal situation. It has been proven impossible to build a statistically relevant table similar to Table 3 in section 4.3.1 due to the lack of data representing those exceptional situations[6]. In case of such a cold spell, Elia will increase the caps for both peak and off-peak

[6] There are only 800 valid hours (about 160 valid hours per line) with temperature below zero in the statistical sample.

hours to 110% of the seasonal limit, until we gather sufficient data to perform a statistical relevant analysis.

Elia would like to stress that – independent of the DLR proposal – the seasonal limit is upgraded to the high-winter rating in the D2CF, DACF and IDCF if the corresponding business days are forecasted to be in a cold spell situation[7]. This is only applied to 380kV lines and it corresponds to an increase ranging from 7 to 10% with respect to winter ratings in function of the considered lines.

4.3.3. Relationship of the lower limit with the seasonal thermal limits

The above analysis shows that the Horizon Forecast might be higher than the Forecast 1h. Based on this an upper cap has been set for both peak and off-peak hours. On the other hand, it happens that the Forecast Horizon is lower than the static rating. When this happens, Elia decided to use the static rating as lower limit because in practice, the Forecast 1h practically never goes below the static seasonal limits even during the hottest days of the years[8]. Indeed, when temperatures reach more than 30°C, seasonal thermal ratings are manually adapted to 90% with respect of the "summer rating" as defined in the exploitation criteria of Elia. This reduction is applied on the D2CF, DACF, IDCF files as well as in the real-time monitoring tools. As a consequence, Elia can safely use the seasonal rating as lower limit in its pre-treatment rule of the Forecast Horizon values.

In applying this methodology, below seasonal static limits for 380kV/220kV lines will be used during the periods indicated.

Season	seasonal limit [% of Inom]	Start	End	Duration
Winter	112%	16 November	15 March	4 months
Spring	106%	16 March	15 May	2 months
Summer	100%	16 May	15 September	4 months
Fall	106%	16 September	15 November	2 months
High Winter	~120%	Average daily temperature <0°C	Average daily temperature ≥0°C	/
High Summer	90%	Temperature >30°C	Temperature <30°C	/

[7] For Belgium, a cold spell is described as a period where the daily temperature is lower than -2 °C for at least 7 consecutive days and when at least one of the following conditions is met: i) the low temperature during this period dropped at least twice to below -7 °C; ii) the high temperature remained below 0 °C for 3 days during the period.

[8] 99.95% of the time with an average deviation with respect to static rating of about 50MW.