Transitional solution for calculation and allocation of intraday cross-zonal capacities for continuous trading in the Intraday timeframe

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ENERGINET.DK SVENSKA KRAFTNÄT FINGRID Statnett

Abbreviations:

AAC	Already Allocated Capacity
ATC	Available Transfer Capacity
ATCE	ATC Extraction
BZ	Bidding Zone
CC	Capacity Calculation
CCM	Capacity Calculation Method
CNE	Critical Network Element
D-1	1 Day before delivery date
D-2	2 Days before delivery date
DA	Day-Ahead
FB	Flow-Based
ID	Intra-Day
MC	Market coupling
NP	Net position
NTC	Net Transfer Capacity
PTDF	Power Transfer Distribution Factor
RAM	Remaining Available Margin
SE1-SE2	Swedish border between bidding zone SE1 and bidding zone SE2, containing both directions of SE1→SE2 and SE2→SE1
SE1→SE2	Direction from bidding zone SE1 to bidding zone SE2
TP	ENTSO-E Transparency Platform
TSO	Transmission System Operator
XBID	Intra-Day continuous trading platform
z2z	Zone-to-zone
z2s	Zone-to-slack

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1 Background and purpose

Article 20 of the Nordic DA CCM, approved on October 14, 2020, describes a transitional solution for the calculation and allocation of cross-zonal capacities for the intraday timeframe. Article 20(1) states the need of calculating ATC-values based on the FB domain for the intraday market until the single intraday coupling is able to support FB parameters[1]. Article 20(2) prescribes an optimization approach to facilitate this calculation. Article 20(3) requires the Nordic TSOs to publish the optimization approach and the parameters used, including their descriptions, purpose, and effect two months before the application of this transitional solution (i.e. two months before the Nordic DA FB go-live). The NRAs and stakeholders shall be informed along the development process of the optimization formulation, and they may provide comments duly to be taken into account in development work.

This document aims at fulfilling the article 20(2) and 20(3) by elaborating the optimization formulation that is currently being investigated in the Nordic CCR and is intended to be used at the start of the parallel runs. As such, this document is a living document that will be aligned to the latest development of the ATC extraction (ATCE) along the Nordic CCM parallel run.

Article 20 requires the calculation of 'ATC' values from the 'final FB domain'. The calculation is referred as the ATCE method. Because the final DA FB domain is used as input to the ATCE, the outcome of this calculation is 'ATC' values, corresponding to the NTC values that is calculated based on the DA FB domain. Chapter 3 elaborates more on the terminology of the ATCE on in the Nordic context.

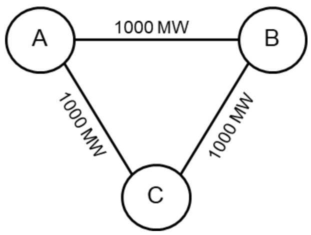
2 High level comparison between FB and NTC

This chapter illustrates the relationship between the FB and NTC given the same grid topology and conditions for the two approaches. Considering the following example depicted in Figure 1, a power grid consisting of three bidding zones (BZs), and three identical lines with the physical capacity of 1000 MW each. Each line is considered a Critical Network Element (CNE).

The physical characteristics of this grid can be linearized and represented by a matrix of "zone to slack" PTDFs (z2sPTDFs) and Remaining available margins (RAMs). Each BZ has a specific z2sPTDF for each CNE that tells us how much of one MW injected in this BZ shows up on a particular CNE. Each RAM shows the maximum allowed flow on each CNE. In this simplified case, the capacity of each connecting line (or CNE)

[1] 'Until the single intraday coupling in accordance with Article 51 of the CACM Regulation is able to support the allocation of cross-zonal capacities based on FB parameters, the CCC shall transform the final FB parameters as referred to in Article 19 into available transmission capacity ('ATC') values on bidding zone borders of the Nordic CCR and bidding zone borders of neighbouring CCRs if the latter are included in capacity calculation pursuant to Article 18. For each market time unit, one set of ATC values shall be calculated.'

is the RAM for that CNE, and C is the chosen “slack zone"[2] in the system. The matrix of RAMs and z2sPTDFs are shown in figure 3 below[3].



Line (CNE)	Max flows	PTDFs for BZ A	PTDFs for BZ B	PTDFs for BZ C (slack)
A -> B	1000 MW	33 %	- 33 %	0
B -> C	1000 MW	33 %	67 %	0
A -> C	1000 MW	67 %	33 %	0

Figure 1. 3-bidding zone example and its z2sPTDFs

There are two approaches for calculating capacity for the market coupling based on this linearized modelling of the grids, NTC or FB. In FB, the capacity is provided to the market directly in the form of the z2sPTDF matrix above. The market algorithm determines prices and Net Positions (NPs) of the bidding zones as market coupling outcome. Essentially, the FB market coupling algorithm tries to increase NPs (with an objective/intention to maximize the socio-economic welfare of the market coupling bidding zones in Europe) until a limit on one (or several) of the CNEs are reached. The domain of all possible combinations of NPs allowed in the FB market complying to the matrix above, defines the "FB domain". The FB domain for the matrix above is illustrated in Figure 2 (in two dimensions only).

In NTC, capacities are provided as values for each direction for each individual bidding zone border. These values can be extracted from the linearized grid description above in such way that the resulting NTC domain respects the linearized grid description and its limits. As for the FB domain, the NTC domain includes all possible combinations of NPs that is allowed in the NTC market, complying to the physical limits of the grid. The NTC domain is illustrated in Figure 2.

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[2]The slack zone is the reference point in the z2sPTDF matrix in the sense that all power injections is extracted in this zone. Thus, all z2sPTDFs for the slack zone are zero (see Figure 1 and Footnote 3 for details). The slack zone is a necessary mathematical construct, but the choice of slack zone has no influence on the results.

[3] The z2sPTDF of BZ A on the CNE (A->B) can be interpreted/computed by the following. First, run a load flow calculation, on the grid without any modification, to obtain the power flow on the CNE (A->B), denoted as ‘F_AB_original’. Second, modify the grid condition by injecting 100 MW power at A, and consuming the 100 MW power at C (i.e. being the slack). Run the load flow again in this modified setup to obtain the power flow on the CNE (A->B), denoted as ‘F_AB_new’. The z2sPTDF of BZ A is then computed by (F_AB_new – F_AB_original)/100, where the 100 in the denominator refers to the 100 MW power injection. Similarly, to compute z2sPTDF of BZ B, the logic remains the same except that the modification in the second step injects 100 MW at BZ B. Finally, to compute z2sPTDF of BZ C, the injection and the consumption both happen at BZ C. Thus, the ‘F_AB_original’ and ‘F_AB_new’ in this case are the same, resulting z2sPTDF of BZ C on CNE (A->B) being 0.

In NTC, the physical limitation of CNE (A->C) being 1000 MW with a z2sPTDF of 67%, causing the export capacity of BZ A to be limited to 1500 MW (i.e. 1000 MW / 0.67 = 1500 MW) (see Figure 2). The import capacity for BZ A, will equally have to be limited to 1500 MW due to the physical limitation of CNE (A->C) being 1000 MW as well with a z2sPTDF of –0.67 (-1000/-0.67). Similar arguments also hold for BZ B and bidding zone C, which also will face import- and export limits at 1500 MW. In this manner, NTC is a capacity calculation and market approach that limits the import- and export capacity for each bidding zone.

The way the limits are implemented, is by distributing the import/export limits to the different borders. However, the distribution itself can be done in a multitude of different ways, only requiring that the correct export and import limitations for each bidding zone are maintained. Returning to our 3-BZ example above, the 1500 MW limitations may for example cause the TSOs to ex-ante decide 750 MW in each direction for border A->B and A->C and B->C equally. A different, but equally valid distribution of NTCs, will be to put NTCs for A->B at (1500,0), B->C at (1500,0) and A->C at (0, 1500). This will also provide 1500 MW as import and export limits for all 3 bidding zones. Thus, the two distributions are only two different representations of the same NTC domain. In fact, all distributions of NTCs resulting in the 1500 export/import limits are different representations of the same NTC domain.

Although the equal split of the 1500 MW export capacity on CNE (A->C) and CNE (A->B) is a valid NTC solution to facilitate the trades in the market, one may also observe that the FB method/domain can offer more capacities in terms of trading possibilities. With FB, one potential market outcome is 1000 MW export in BZ A and B at the same time, allowing C to import 2000 MW. This market outcome is at the 'edge/intersection' of the FB domain but still within FB. Consequently, by providing the FB domain to the market (i.e. asking the market allocation algorithm to find an optimal solution within the FB domain for the European market coupling), the market allocation outcome may end up at this market point. On the contrary, this 'FB feasible' market outcome is not within the previously described NTCs. Consequently, by providing the NTC domain to the NTC market allocation (i.e. asking the market allocation algorithm to find an optimal solution within the NTC domain for the European market coupling), the market allocation outcome can never find this 'FB feasible' market point as a market coupling solution.

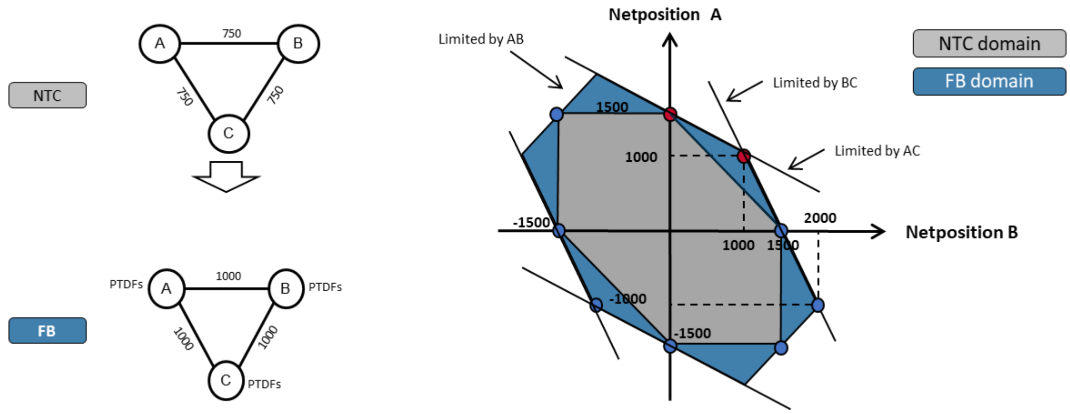

Figure 2 FB and NTC domain comparison

Note that BZ C is not explicitly shown in Figure 2. Because the 3-BZ example is considered a balanced and closed system, the sum of export of BZ A and B must equal to the import of BZ C.

3 ATCE in the Nordic context

3.1 Background

After the DA market clearing at 13:00 and before 14:00 D-1 (one day before delivery date), the TSOs need to calculate ID capacities for the ID gate opening at 15:00 on D-1.

At the time of DA FB go-live in the CCR Nordic, XBID is technically not yet able to process the FB format (i.e. PTDFs and RAMs on the CNEC level), but the NTC/ATC-format (i.e. the capacities between bidding zones on the cross-zonal border level). The ATCE method is designed as a transitional solution to solve this compatibility issue[4]. Specifically, the required inputs of the XBID platform, foreseen at the DA FB go-live in the Nordic CCR, are DA NTC and DA AAC (AAC=Already Allocated Capacity), corresponding to the equation below.

$$ID\ ATC = DA\ NTC - DA\ AAC$$

To facilitate the ID trading activities, the TSOs shall provide the capacities corresponding to the DA NTC term and the DA AAC term, as inputs for the ID timeframe to the XBID platform, such that XBID automatically generates the ID ATC for the ID continuous trading. In a nutshell, the ATCE optimization method computes the capacity that corresponds to the DA NTC values in the equation above from the

[4] Based on a given FB domain (PTDF and RAM on the CNE level), the ATCE method provides an 'optimal' set of NTC values (capacities on the cross-zonal border level).

DA FB domain, together with the DA AAC (i.e. from the DA MC results, not computed by the ATCE optimization, but computed by NEMOs), as input to the XBID platform for the ID gate opening. For the sake of simplicity and explanation, from this point on the DA NTC in this document refers to the outcome of the ATCE, if not specified otherwise.

3.2 DA AAC in ATCE

For the ID gate-opening capacity computations, the DA AAC refers to the DA market outcome of the scheduled exchanges.

On D-1 around 12:45, the EU market coupling algorithm (known as Euphemia) provides the market coupling outcome, in terms of price and net position per bidding zone. At further, the scheduled exchanges per bidding zone border are computed by the NEMOs using the 'Flow-determination' method that transforms the net positions of all Nordic bidding zones into the scheduled exchanges of all Nordic bidding zone borders as part of the market coupling outcome[5].

Because the DA scheduled exchanges are part of the DA market outcome, computed by NEMOs and published to the market participants, the TSOs have adopted the DA scheduled exchanges as the DA AAC to be fed into the XBID as the required input for the ID gate-opening capacity calculations. Again, for the sake of simplicity and explanation, from this point on the DA AAC in this document refers to the DA scheduled exchanges / the outcome of the flow determination method, if not specified otherwise.

There are two applications of the DA AAC in ID ATC calculation at gate-opening. One is to feed into XBID as input, and the other is to be used as the 'minimum guaranteed capacity' when performing the ATCE, and section 3.3, 3.4 and 4.2 explain more in terms of the reasons and its implementation.

3.3 DA NTC in ATCE

To ensure there is sufficient ID ATC at the gate opening, ID ATC is designed to be always larger or equal to 0. This further implies that the DA NTC term needs to be always larger or equal to the DA AAC term according to the equation of ID ATC = DA NTC – DA AAC. In other words, the DA AAC term is the DA already allocated capacity from the market coupling. The DA NTC term, as an output of the ATCE, should at least guarantee the DA AAC, such that there is always 'sufficient' ID ATC at the ID gate-opening[6].

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[5] Calculation is based on DA scheduled exchanges methodology in accordance with Article 43 of the CACM regulation.

[6] The TSOs are developing a suitable method and the associated business process to cope with the situation when an unplanned outage occurs between the MC starts and the ID gateopening.

3.4 Conceptual example

Suppose SE1→SE2 DA AAC is 4000 MW[7] (being the NEMOs' flow determination outcome). This implies that the minimum-guaranteed capacity of the DA NTC of SE1→SE2 border is 4000 MW. Mathematically speaking, this 4000 MW is the lower bound of the 'to-be-extracted' DA NTC of this border. Suppose that the optimization program obtains 4300 MW DA NTC on this direction, in this case the TSOs shall provide 4300 MW as DA NTC and 4000 MW as DA AAC to XBID. The XBID platform further determines the ID ATC of this SE1→SE2 direction, using the equation ID ATC = DA NTC – DA AAC = 4300 – 4000 = 300 MW. Similarly, the SE2→SE1 direction DA AAC is -4000 MW (from NEMOs) and let's suppose the DA optimal NTC is 1500 MW (from ATCE). The TSOs shall provide DA NTC of 1500 MW and the DA AAC of -4000 MW to XBID. The XBID platform computes the ID ATC of this direction, being 1500 - (-4000) = 5500 MW.

4 General implementation description of ATCE algorithm

This chapter describes the optimization formulation, including the description, purpose and effect of the parameter(s) used in the optimization. Mathematically, constrained optimization is the process of optimizing an objective function with respect to some variables in the presence of constraints on those variables.

Figure 3 show the schematic overview of the ATCE prototype tool. Essential building blocks are

- objective function (see section 4.1)
- constraints (see section 4.2)
- mathematical solver/problem overview (see section 4.3)
- threshold parameter (see section 4.4)

[7] The numbers in the example are fictitious and only for illustration purposes.

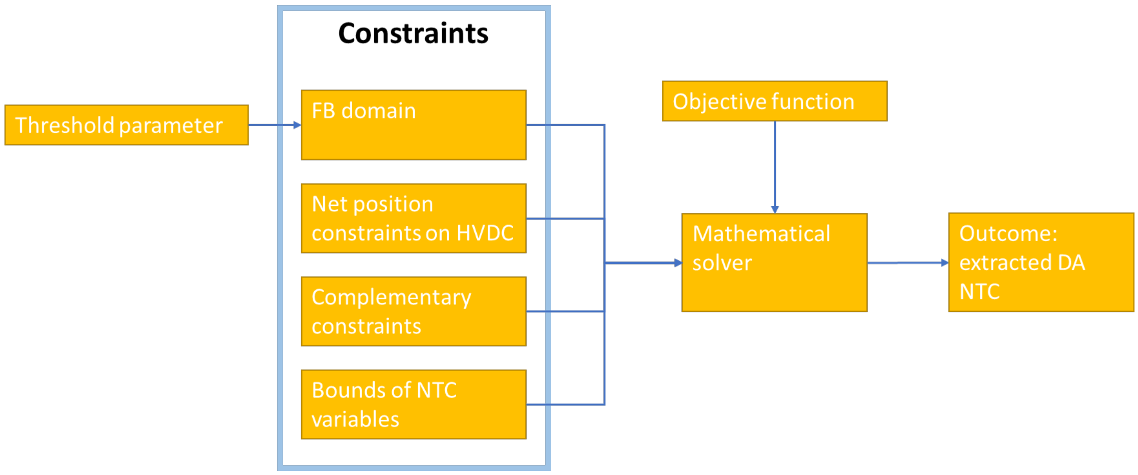

Figure 3 Overview of the ATCE

4.1 Objective function

$$O = \prod_{n} C_n \,, \qquad where\ C_n = \hat{C}_n + \hat{C}_{n,o}$$

In general, an optimization problem consists of an objective function that is a means to maximize or minimize something. In the Nordic ATCE context, the objective function is defined to maximize the total Nordic (bidding zone border) cross-zonal capacities. The mathematical modelling is given in the equation above.

For each bidding zone border, there are two transfer capacities representing the two opposite directions, denoted as $\hat{C}_n\ and\ \hat{C}_{n,o}$, where 'n' is the number of borders and 'o' refers to 'opposite'. Each of the directional capacities is a variable in the optimization formulation. The sum of the two opposite capacities of the same border forms the 'total' capacity of the border, denoted as C_n in the equation above, e.g. the SE1-SE2 total border capacity is (NTC(SE1→SE2) + NTC(SE2→SE1)), reflecting $\hat{C}_n + \hat{C}_{n,o}$. The objective function maximizes the total Nordic bidding zone border capacities by multiplying all individual Nordic bidding zone border total capacity. To write it more explicitly, the objective function looks like Maximize[(SE1-SE2 total capacity) * (NO1-NO5 total capacity) * (other AC borders total capacity…) * (FennoSkan total capacity)) * (other DC borders total capacity…)].

4.2 Constraints

A constraint in the optimization formulation is a condition that the solution must satisfy. In the context of the Nordic ATCE approach, the constraints can be classified as below,

- FB constraints: the physical flows on the CNECs induced by the extracted DA NTC must be smaller than or equal to the DA FB RAM of these CNECs.
- Net position constraints: If net position constraints are present on the HVDC links to limit the import and export of the HVDC links as part of the DA FB capacity calculation (CC) inputs to the DA FB market coupling (MC), they are also considered in the ATCE.
- Complementary constraints
    - The HVDC capacity at the sending end of an HVDC cable (i.e. the extracted DA NTC at the sending end of an HVDC cable) should be equal to the capacity at the receiving end of the cable (i.e. the extracted DA NTC at the receiving end of the cable).
    - The objective function formulation allows the extracted DA NTC value to be negative. The Nordic TSOs further limit the total capacity of a border (i.e. the sum of the directional capacities of the same border) to be positive.
- Bounds of NTC variables: The optimization variables contain DA NTC of AC borders and the DC borders.
    - AC border: Using the AC border SE1-SE2 as an example, the variables are NTC(SE1→SE2) and NTC(SE2→SE1). The upper bound of the variable NTC(SE1→SE2) in the optimization formulation is infinity. 'Infinity' implies that the TSOs do not explicitly set the upper boundary to the DA NTC on this direction. The lower bound of DA NTC(SE1→SE2) is the DA AAC of this direction as the minimum-guaranteed capacity.
    - DC border: Using FennoSkan as an example, the upper bound of FennoSkan(SE3→FI) is not infinity, but the capacity defined by the TSOs, either as its nominal capacity or explicitly defined in the net position constraints. The lower bound of this directional capacity is the DA AAC of FennoSkan(SE3→FI).

4.3 Non-linear optimization problem

Given the objective function of the optimization formulation, being the product of the total cross-zonal transfer capacity of each bidding zone border, the optimization problem of the ATCE is a non-linear problem, which requires a non-linear solver to solve it.

4.4 z2zPTDF, filter and threshold parameter

4.4.1 Forms of PTDF and FB domain

The FB parameters, or FB domain, in this document refer to the PTDFs and RAMs. PTDF, the power transfer distribution factor, has two forms, namely the zone-to-slack PTDF[8] (z2sPTDF) and the zone-to-zone PTDF[9] (z2zPTDF).

The translation between the two forms of PTDFs is straightforward, using the equation below.

$$z2zPTDF(A \rightarrow B) = z2sPTDF(A) - z2sPTDF(B)$$

z2zPTDF(A->B) denotes the z2zPTDF from bidding zone A to bidding zone B. Physically, it describes the impact of power flow on a CNE, when there is an exchange from bidding zone A to bidding zone B.

Example: Suppose that A, B, and C are three fictitious bidding zones connecting each other. Let's assume the z2sPTDFs of CNE X are shown below.

	z2sPTDF(A)	z2sPTDF(B)	z2sPTDF(C)
CNE X	0.3	0.28	-0.2

Correspondingly, the z2zPTDFs of CNE X are shown below, applying the equation above,

	z2zPTDF(A->B)	z2zPTDF(B->A)	z2zPTDF(A->C)	z2zPTDF(C->A)	z2zPTDF(B->C)	z2zPTDF(C->B)
CNE X	0.02	-0.02	0.5	-0.5	0.48	-0.48

Because of the two forms of PTDFs, a FB domain can also be described in two different equations/forms, namely,

$$\boldsymbol{z2sPTDF} \times NP \leq \boldsymbol{RAM}, \text{ and}$$

$$\boldsymbol{z2zPTDF} \times Exchange \leq \boldsymbol{RAM}$$

These equations/forms reflect the PTDF definition in the footnotes 8 and 9. Again, the FB domain is the same, but with two forms of expression and application. Specifically, the single market coupling algorithm, commonly known as Euphemia, takes the form of z2sPTDF and RAM as inputs to perform the DA market coupling. For the ATCE purposes, the form of z2zPTDF and RAM, transformed from z2sPTDFs, is needed.

8 'zone-to-slack $PTDF$' means the PTDF of a commercial exchange between a bidding zone and the slack

9 'zone-to-zone $PTDF$' means the PTDF of a commercial exchange between two bidding zones

4.4.2 Positive z2zPTDF filter

From the example above, the z2zPTDFs of the CNE X appear to be both positive and negative with the same magnitude.

The same z2zPTDFs are shown below,

	z2zPTDF(A->B)	z2zPTDF(B->A)	z2zPTDF(A->C)	z2zPTDF(C->A)	z2zPTDF(B->C)	z2zPTDF(C->B)
CNE X	0.02	-0.02	0.5	-0.5	0.48	-0.48

The positive z2zPTDFs impose the loading effect on the CNE X, whereas the negative z2zPTDFs have the relieving effect on the CNE X. The loading effect means that for a given exchange from A to B of 1000 MW, 20 MW of the CNE X capacity is used/loaded by this exchange (i.e. 1000 MW * 0.02 = 20 MW). Similarly, the relieving effect of an exchange of 500 MW from C to A can be computed by 500 * (-0.5) = -250 MW, indicating the loading of CNE X will be relieved/off-loaded by 250 MW, if a 500 MW exchange from C to A occurs.

Suppose the CNE X has a certain RAM that is subject to be used by any cross-border exchange, the optimization algorithm determines those exchanges that actually load the CNE X, up to the moment that the RAM of the CNE X is exhausted. In other words, each border has two opposite directions with an NTC value corresponding to each direction. For the CNE X, one of the two directional exchanges has the loading effect and the other has the relieving effect. Because the NTC method requires simultaneous feasibility of all exchanges, the worst case, in terms of loading the CNEC X, could happen when the exchange of all borders is in the direction of loading the CNE X. Thus, to ensure the simultaneous feasibility of covering the worst-case scenario, we cannot assume the relieving effect from any exchange in the system. In terms of implementation, the positive z2zPTDF filter removes the effect of the relieving exchanges, mathematically denoted as 'z2zPTDFs with a negative sign', by setting them to zero. The filter ensures that the relieving effect does not interfere with the determination of the exchanges only considering the loading effect. Note that the application of the positive z2zPTDF filter is a methodological implementation in the ATCE algorithm and is not adjustable by the TSOs.

After applying the positive z2zPTDF filter, the z2zPTDFs are shown below,

	z2zPTDF(A->B)	z2zPTDF(B->A)	z2zPTDF(A->C)	z2zPTDF(C->A)	z2zPTDF(B->C)	z2zPTDF(C->B)
CNE X	0.02	0	0.5	0	0.48	0

4.4.3 Threshold parameter: z2zPTDF threshold

The ATCE method introduces one parameter, namely the z2zPTDF threshold. In other words, any 'small' z2zPTDF value smaller than or equal to the threshold are set to zero. Using the PTDF example above, suppose the z2zPTDF threshold = 0.05 or 5 %. Before applying the z2zPTDF threshold, the z2zPTDFs are shown below,

	z2zPTDF(A->B)	z2zPTDF(B->A)	z2zPTDF(A->C)	z2zPTDF(C->A)	z2zPTDF(B->C)	z2zPTDF(C->B)
CNE X	0.02	-0.02	0.5	-0.5	0.48	-0.48

After applying the positive z2zPTDF filter, the z2zPTDFs are shown below[10],

	z2zPTDF(A->B)	z2zPTDF(B->A)	z2zPTDF(A->C)	z2zPTDF(C->A)	z2zPTDF(B->C)	z2zPTDF(C->B)
CNE X	0.02	0	0.5	0	0.48	0

After applying the z2zPTDF threshold, the filtered z2zPTDFs are shown below.

	z2zPTDF(A->B)	z2zPTDF(B->A)	z2zPTDF(A->C)	z2zPTDF(C->A)	z2zPTDF(B->C)	z2zPTDF(C->B)
CNE X	0	0	0.5	0	0.48	0

The z2zPTDF threshold is introduced to filter out the following two scenarios:

- The z2sPTDF and z2zPTDF are computed by power system analysis tools and contain decimal numbers by nature. Due to rounding or computational accuracy, it may happen that 'on paper' the z2zPTDF is 1 % and 'in reality' the effect of such 1 % z2zPTDF is not observed by the TSOs. Such small z2zPTDFs should not limit the cross-border exchanges. By applying the z2zPTDF threshold, the effect of such small z2zPTDFs are eliminated from the ATCE.
- The TSOs may have sufficient remedial actions to alleviate certain amount of overloads, without limiting the cross-border exchanges. Thus, the TSOs decide not to consider these 'minor overloads' being potential reasons to limit the cross-border capacities. By applying the z2zPTDF threshold, such 'minor overloads' become acceptable in the ATCE.

During the Nordic CCM parallel run, the Nordic TSOs will investigate the impact of the threshold parameter on the parallel run results. It is foreseen that the Nordic TSOs will adopt one universal z2zPTDF threshold for the Nordic CCR. According to the DA CCM Article 20(3), the Nordic TSOs will also publish the z2zPTDF threshold parameter used in the optimization approach including their descriptions, purpose and effect, two months before the Nordic FB go-live.

5 Summary

This document describes the ATCE method to be applied for the ID capacity calculation at gate-opening, as a transitional solution until XBID is able to support FB parameters.

[10] The sequence of applying the positive z2zPTDF filter and applying the z2zPTDF threshold does not impact the results.

This document is a living document, that will be aligned to the latest development of the ATCE along the Nordic CCM parallel run, and subject to feedback from the NRAs and stakeholders towards Nordic CCM DA FB go-live.