Methodological paper:

Benchmark cross-zonal capacity calculation

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Content

1. Introduction

(1) This document is one of a set of documents describing various methodologies applied in the electricity wholesale markets volume of the annual ACER/CEER Market Monitoring Report (MMR), which is intended to present the results of the monitoring of the performance of the internal electricity market in the European Union (EU).

(2) The Agency regularly monitors the level of cross-zonal capacity offered to the market in Europe. In particular, it monitors the gap between the level of cross-zonal capacity that is currently made available to the market and the capacity (hereinafter benchmark capacity) that could be made available if the Agency's Recommendation on Capacity Calculation Methodologies[1] (CCM) were followed with no (or very limited) deviations.

(3) The aim of this paper is to describe the methodology used to compute benchmark cross-zonal capacity for the existing bidding zone configuration, in line with the following main guidelines, which can be derived from this Recommendation:

- "limitations on internal network elements should not be considered in cross-zonal capacity calculation methods"
- "the capacity of the cross-zonal network elements considered in common capacity calculation methodologies should not be reduced in order to accommodate loop flow"

(4) The Agency extensively consulted with stakeholders, including TSOs and ENTSO-E, in order to elaborate this methodology.

(5) Section 2 introduces the general approach taken, and then section 3 describes the detailed calculation process. Finally, sections 4 and 5, respectively, deal with caveats and data sources.

2. General approach

(6) The Agency's Recommendation assumes that the delimitation of bidding zones addresses all structural physical congestion[2] and that the remaining congestions within bidding zones are addressed via remedial actions. Hence, the benchmark capacity can be calculated assuming that

i. cross-zonal capacity is limited only by cross-zonal network elements

ii. the full capacity of these network elements is available for cross-zonal exchanges.

(7) This is without prejudice to the possibility of applying temporary deviations to the Agency's Recommendation: internal congestion and LFs may be taken into account in cross-zonal capacity calculation if it can be proved that this is needed to ensure operational security and socio-economic efficiency at the EU level, and can be done in a non-discriminatory manner.

(8) The cross-zonal capacity calculation process estimates physical margins on network elements[3], and how much cross-zonal exchanges influence these elements. Figure 1 shows the process of

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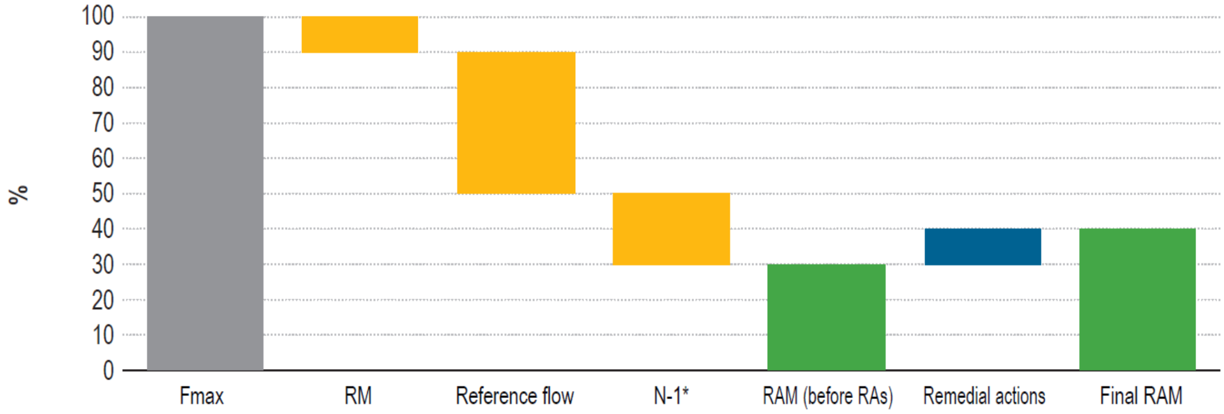
[1] Recommendation of the Agency No 02/2016 of 11 November 2016 on the common capacity calculation and redispatching and countertrading cost-sharing methodologies, available at: https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Recommendations/ACER%20Recommendation%2002-2016.pdf.

[2] In an efficient bidding zone configuration, structural network congestions should lie between bidding zones in order to ensure cost-efficiency and relevance of price signals. According to Regulation (EC) No 714/2009, structural congestions must be addressed by capacity allocation mechanisms.

[3] Allocation constraints may be added in order to reflect other operational constraints

deriving physical margin on network elements. These capacities are then allocated based on market needs.

Figure 1 : Estimate of remaining available margins (RAMs) on network elements within the capacity calculation process



Source: ACER (2018).

Note: Reliability margins (RMs) account for uncertainties (e.g. related to the capacity calculation process). Reference flows (F_0) describe flows on network elements when no cross-zonal exchanges occur within the CCR; these flows stem from internal exchanges (and exchanges from outside the CCR). N-1 contingencies are usually assessed by adding critical network elements with contingency (CNECs), rather than by decreasing the physical margin of network elements. Finally, remedial actions (RAs) are individually assessed for each CNEC, and increase the margin on some elements. The RAM describes the capacity made available for cross-zonal exchanges.

(9) In order for the benchmark capacity to be a realistic target, the following basic assumptions are adopted:

a. Only thermal limits of network elements are considered. Other operational security limits (e.g. voltage stability, dynamic stability), which may additionally decrease the level of cross-zonal capacity under some circumstances[4], are not considered.
b. The thermal capacity of all individual cross-zonal network elements is reduced by 15% to cope with RM[5] and F_0.
c. The methodology for calculating benchmark capacity respects the N-1 security criterion.
d. Remedial actions are approximately and empirically taken into account.
e. NTCs should be simultaneously feasible within a capacity calculation region (CCR)[6]

(10) Compared to operational capacity calculation processes, the benchmark capacity calculation is aimed at estimating a few representative sets of cross-zonal capacities, instead of many hourly (short term) calculations. Therefore, when computing benchmark values, the impact of the availability of generation[7] and remedial actions or the likely import/export directions are estimated based on average (representative) network conditions.

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[4] The frequency of these occurrences may differ greatly per border and should be justified by the respective TSOs on an ad-hoc basis. Moreover, such constraints may also be overcome without decreasing cross-zonal capacity (e.g. using a static VAR compensator).

[5] For more information about the various capacity calculation parameters, see section 3.1 of the 2016 MMR

[6] CCRs are designed so that capacity calculation processes may be run independently in each CCR

[7] And its related impact on generation shift keys (GSKs). GSKs describe how a change in a given bidding zone net position is reflected in nodal electricity injections (and withdrawals).

3. Calculation process

3.1 Benchmark capacity in the context of calculating coordinated NTC (CNTC)

(11) The methodology for calculating benchmark capacity in a CNTC context must allow for a comparison between the currently available capacity (actual NTC) and the benchmark NTC values on a national or regional basis. The benchmark should correspond to a maximum secure NTC capacity. Furthermore, benchmark capacities on different borders must be simultaneously feasible[8].

(12) This simultaneity requirement is difficult to achieve in highly meshed networks: in the CNTC method, the physical flows on network elements are fundamentally defined by a set of net positions of bidding zones, whereas CNTC values are only an indirect attempt to limit the net positions via limitations of exchanges on individual borders. In the case of small bidding zones in highly meshed networks, calculating a set of CNTCs that are simultaneously feasible is particularly difficult, and relies on a set of arbitrary choices. For such regions (e.g. the Core Region[9]), the FB methodology should urgently be applied, and benchmark NTC values should be handled with care.

3.1.1 The problem of the interdependency of CNTC values in meshed networks

(13) In meshed networks, NTC values are interdependent. The capacity allocated on one border will create physical flows on other borders. Capacity calculation on one border must thus take account of the part of the physical capacity on that border that will be 'consumed' by cross-zonal capacity on other borders, i.e. the share of the physical capacity on that border necessary to provide commercial cross-zonal capacity on other borders.

(14) To that end, the physical capacities of network elements must be divided into quantities reserved for each commercial border. This division is based on a number of assumptions, more or less arbitrary[10]. The Agency suggests relying on assumptions similar to those described in the CCMs of various CCRs. These methodologies essentially spread capacity among borders in a homogeneous fashion, no matter whether one border exchange may be more valuable than another. Starting from initial zero NTCs, these values are gradually scaled up based on remaining available margins on network elements in order to ensure simultaneity at CCR level.

3.1.2 Calculation steps for CNTC values

(15) Based on the main principles introduced above, the benchmark bidirectional CNTCs are calculated by means of the following process:

a) **Select a representative network situation**. The whole capacity calculation process is aimed at maximising cross-border capacity while ensuring operational security in a given configuration. A common grid model (CGM)[11] describes such a situation. Representative seasonal CGMs will be used in the following. As line thermal limits tend to be lower in summer than in winter, benchmark cross-zonal capacities computed for both winter and summer would probably be slightly lower than benchmark capacities computed only with a winter CGM. The

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[8] By contrast, in FB capacity calculation methods, the maximum bilateral exchanges are not simultaneously feasible.

[9] Currently flow-based capacity calculation applies to only a small part of the Core Region, which is the Central-West (CWE) Region.

[10] See for example, the proposal for available transfer capacity (ATC) for shadow auctions in the Core CCR (Article 20), https://consultations.entsoe.eu/markets/core-da-ccm/supporting_documents/Core%20CCR%20TSOs%20proposal%20for%20the%20regional%20design%20of%20DA%20FB%20CC_PC_FV.pd

[11] CGMs are grid models shared among TSOs when performing operational capacity calculation processes.

impact of this overestimate (or underestimate) is probably limited[12]. Finally, some small topological actions are performed in order to maximise cross-border capacity: all interconnectors are switched on, and the network topology is updated for a few borders[13].

b) **Compute a FB domain representing the network situation** for each CCR.

   i. **Define critical network elements (CNEs) and contingencies (in order to take the N-1 criteria into account)**. CNEs are 220 and 400 kV cross-border lines[14]. Contingencies consist of the individual[15] outage of any network element which is found to significantly[16] impact flows on CNEs. Additionally, CNEs without contingency should be added to the list. As a result, the following individual contingencies are considered[17]

      i. all internal lines within the country currently considered
      ii. interconnectors in neighbouring countries
      iii. all interconnectors from the country currently considered[18]

   ii. **Estimate PTDFs:** PTDFs estimate the linear impact of any cross-zonal exchange on any CNEC. The PTDF calculation is made by using GSKs proportional to the generation output in the CGM, relying on a DC[19] load flow approximation. As a result, the generated PTDFs are subject to significant uncertainty.

   iii. **Set RMs, F_0, and RAMs:** RMs and F_0 (coming from residual LFs) are assumed to amount to 15% of the maximum admissible flow (Fmax). As a result, the RAM on each CNEC is set to 85% of Fmax[20].

   iv. **Empirically consider remedial actions:** remedial actions play a crucial role in capacity calculation, as they alleviate constraints related to contingencies. However, it would be very difficult and time consuming to assess in detail the availability[21] and impact of each remedial action on each border. Therefore, in addition to the temporary overload allowed for some contingencies, an empirical approach was taken, assuming that, for a given year, all hourly NTC sets were safe, including remedial actions. When a set of hourly NTCs lay outside the FB domain, the domain was slightly expanded[22] to include this set of NTCs. Moreover, remedial actions would likely be available (and more economically efficient) to handle low PTDF values[23]. As a result, PTDFs below 5% were also ignored[24].

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[12] For example, on the French-Spanish border, where there are relevant differences between winter and summer thermal limits, the overestimate when computing based on a winter CGM only would probably be 5-7%. On other borders with less winter-summer thermal differences, the overestimate is probably smaller.

[13] For example, between Denmark and Germany, France and Spain, and in Slovenia for the 2017 MMR.

[14] In line with current network operations, the 220kV interconnection network was ignored for Slovenian cross-border lines, i.e. on the AT > SI, HR >SI and IT > SI borders.

[15] Multiple simultaneous contingencies are ignored

[16] More than 5%

[17] Contingencies related to bus bars are ignored

[18] With a flow adjustment value implying that, often, for these interconnectors, a remedial action will be taken in the event of contingency, so that, before remedial action, a temporary 10% overload may be acceptable (in line with current TSOs practices), in addition to using the RM. The overload would then be solved by the remedial action.

[19] Due to limitations mentioned by ENTSO-E TSOs related to the UCTE file format, no AC calculation was made.

[20] For some contingencies, temporary overloads were allowed; see footnote 18.

[21] Moreover, here, only the average availability of a given remedial action needs to be estimated

[22] The Fmax was slightly increased, and PTDFs for CNECs with contingency were slightly altered to be closer to base case PTDFs. As a result, the set of NTCs would lie at the border of the updated FB domain. See annex for more information.

[23] See MMR 2017 section 3.3.2

[24] In its bidding zone review report (see: https://docstore.entsoe.eu/Documents/News/bz-review/2018-03_First_Edition_of_the_Bidding_Zone_Review.pdf), when trying to conduct a similar exercise, ENTSO-E also stated (p. 118) that

v. As a result, an FB domain described by PTDFs and RAMs is derived

c) **Compute simultaneously feasible NTCs** within the FB domain for each CCR.

i. Start from zero NTCs

ii. For a given CNEC

  i. Compute the RAM[25]

  ii. Spread it uniformly[26] among the borders which influence it significantly[27]

iii. For a given border, take the minimum increase over all CNECs (as all constraints need to be simultaneously fulfilled) and update the NTC

iv. Iterate from ii until no further NTC increase is possible.

v. The resulting NTC values account for the uneven distribution of flows on individual interconnectors, which defines the maximum exchanges at which one interconnector is being congested first while others are not.

vi. Finally, NTCs are capped to the thermal capacity of the border to avoid unrealistically high values. In order to derive more realistic benchmark capacities for the borders North of Italy[28], the total benchmark NTC on these borders is spread proportionally to their share of historical NTCs. As a result, ratios of NTC to benchmark at regional level are more realistic within the Italy North and Swiss border regions. Other interdependent borders are mainly located within the same CCR, so that no other benchmark NTC reshuffling is needed.

(16) As a final result, the calculated NTCs ensure that

- The Agency's recommendations[29] on CCM are fulfilled.
- Flows on cross-zonal network elements remain within acceptable margins in the event of contingencies, taking remedial actions into account
- NTCs in a given CCR are simultaneously feasible

3.2 Benchmark capacity in the context of FB capacity calculation

The initial assumption for calculating benchmark capacity in an FB context is that the historical operational FB parameters provide the best framework for calculating the theoretical maximum capacity. These include the PTDFs, Fmax and other technical characteristics of CNECs.

In FB, no single value limits bilateral cross-zonal exchanges. Instead, a set of constraints defines a domain of possible net positions compatible with the physical limits of the network. Therefore, the calculation of benchmark capacity is equivalent to building a new theoretical domain, whereby:

a) Only cross-zonal network elements are considered as CNEs, whereas internal CNEs and allocation constraints are discarded

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"Small PTDFs can even constrain exchanges far away, leading to extreme outcomes.

One reason for this phenomenon is the considerable geographical scope of the Bidding Zone Review and the large number of bidding zones, which multiply the number of PTDFs per CBCO, with some of them being very small. A threshold below which PTDFs are not considered was introduced in order to resolve this issue. However, there is some degree of discretion, which might potentially distort the comparison between different configurations."

[25] For each CNEC, the RAM is the minimum margin available under various sets of exchanges. It is derived from the set of oriented exchanges which loads the CNEC the most.

[26] There are many possible ways to spread the RAM: uniformly, based on expected price spread, based on PTDFs… Such a spread choice is arbitrary. As a result, individual NTC values should be handled with care, but the sum of NTCs at bidding zone or CCR level is more robust.

[27] i.e. which PTDF is higher than 5%

[28] AT – IT, CH – IT, FR – IT, SI - IT

[29] See footnote 1

b) CNEs are assumed to provide their full physical capacity for the FB domain

This process is consistent with the calculation of benchmark capacity under CNTC. Both the issues of contingency and uncertainty are treated as follows:

c) Contingency (N-1 criterion) is accounted for, as CNECs do already account for this aspect;
d) Reliability and residual UFs can be treated in the same way as in CNTC, i.e. by considering that RM and F_0 (15% of Fmax) are deducted from Fmax when setting the RAM

(17) For FB capacity calculation, the size of the FB domain (i.e. its 'volume') based on the assumptions listed above, can be considered as the benchmark capacity, since this volume represents all the simultaneous possibilities of cross-zonal exchanges within a region. In order to account for the market welfare coming from this volume, the benchmark directional[30] volume is compared to the actual directional volume[31].

(18) Also, in regions currently relying on NTC values, but where FB is envisaged, the domain resulting from actual NTCs is compared to the benchmark FB domain, which results from the calculation step 3.1.2 b) described above[32].

4. Caveats

(19) When applying the methodology described above, the following caveats and considerations apply:

- Computing FB parameters based on a network configuration is subject to a number of assumptions (GSKs, AC or DC load flow calculation…)

- Only line thermal limits are considered, whereas other security limits (such as, for example, dynamic security limits) requirements may also be taken into account, and could further limit capacity under specific circumstances.

- Benchmark capacities are computed only where robust CGMs are available.

- NTC benchmark is subject to further caveats

    - NTC benchmark capacities are computed based on representative CGM(s), whereas operational NTCs change on an hourly basis following actual operational conditions. As a result, operational calculations rely on more precise forecasts of the likely market direction and system behaviour.

    - Remedial actions (including network topology actions) and base-case topology optimisation are mostly ignored, or are taken into account in an average, empirical manner. Fully taking them into account may increase benchmark capacities.

    - When extracting NTC values from a FB domain, an arbitrary factor spreading power flow capabilities among borders has to be defined.

    - A PTDF threshold is defined to describe exchanges which are ignored (for a given CNEC) when computing simultaneously-feasible capacities.

[30] i.e. the volume in the direction of the realised hourly net positions from the market coupling

[31] To ensure comparability with NTC borders, the cubic root of this ratio is usually displayed

[32] Computing the benchmark FB volume may prove challenging when many borders are involved. As a result, a simplified ratio relying on regions with a limited number of borders, e.g. the Core (CWE) region, may be used. For this region, the simplified ratio relies on the cubic root of the ratio of the shadow auction ATC and FB domains, and is equal to 40% for 2017.

- FB benchmark is subject to further caveats
    - As the operational FB domain provided to the Agency is usually presolved, some constraints (initially redundant at the TSO level) are not provided. When the FB domain is updated, the redundant constraints may become relevant for the benchmark domain, but will not be included (because they were not provided at the outset).

5. Data

Table 1: Data required and sources used for benchmark capacity calculation

Description	Unit	Time granularity	Geographic granularity	Source
Common grid model		Representative market time units (MTUs)	Continental Europe	ENTSO-E
Flow-based parameters: Fmax, FRM, PTDFs	MW, %	MTU	CNEC, allocation constraint	CWE TSOs Experimental data from Nordic TSOs
Shadow auction ATCs	MW	MTU	CWE bidding-zone border	CWE TSOs

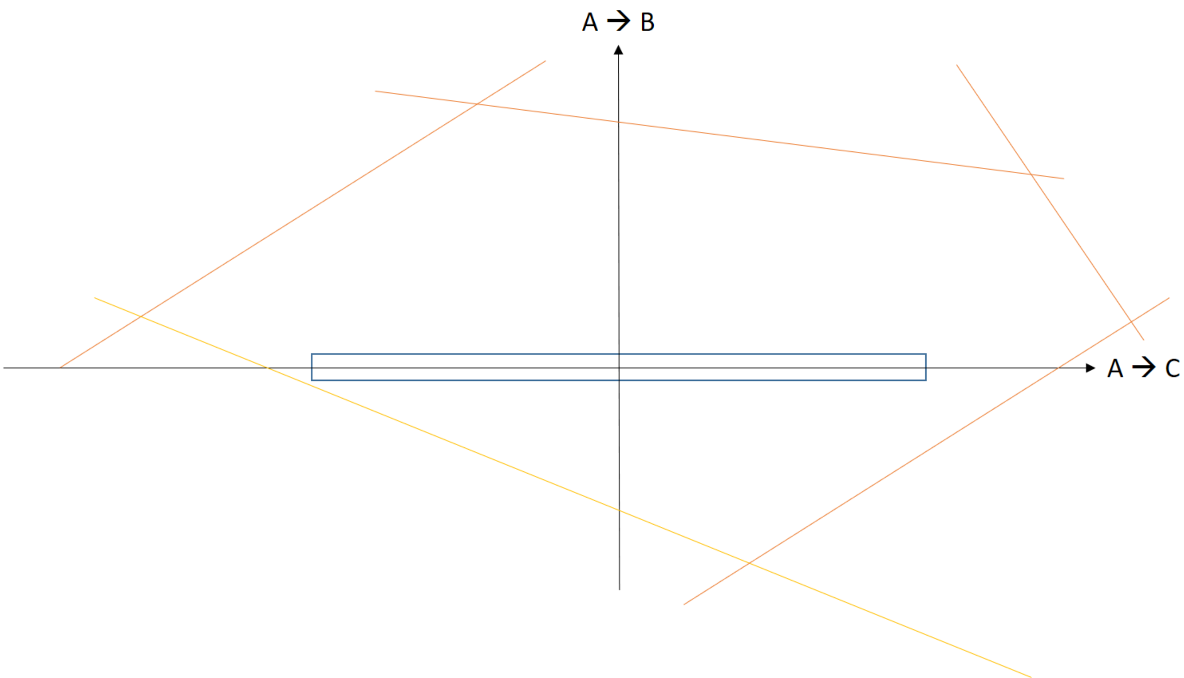
Annex - FB domain expansion to include NTC sets

(20) When computing benchmark NTCs for a given CCR, the methodology extracts NTCs from a representative benchmark FB domain. In order to take remedial actions into account empirically, this FB domain is expanded to include sets of historical NTC values. These NTCs should be safe when taking remedial actions into account; as a result, they should lie inside (or at the border of) the FB domain[33].

(21) This annex describes the FB domain update, in order to include sets of historical NTCs[34]. Each set of NTCs is assessed separately, and may impact the limiting constraints of the FB domain.

(22) The example below depicts a simplified FB domain (for three bidding zones), along with an NTC domain[35]. In this case, the NTC domain lies inside the FB domain.

Figure 2 : Example FB domain, including a given NTC domain



Notes: The NTC domain is depicted in blue, whereas the FB domain is depicted in yellow (base case CNEs) and orange (CNECs). The NTC domain is included in the FB domain, i.e. any point inside the NTC domain is also deemed safe in the FB domain.

(23) When part of the (historical) NTC domain lies outside the FB domain (as shown in the figure below), it means that some remedial actions have probably not been fully taken into account when building the FB domain. As a result, the FB domain needs to be enlarged as little as possible to encompass the full NTC domain.

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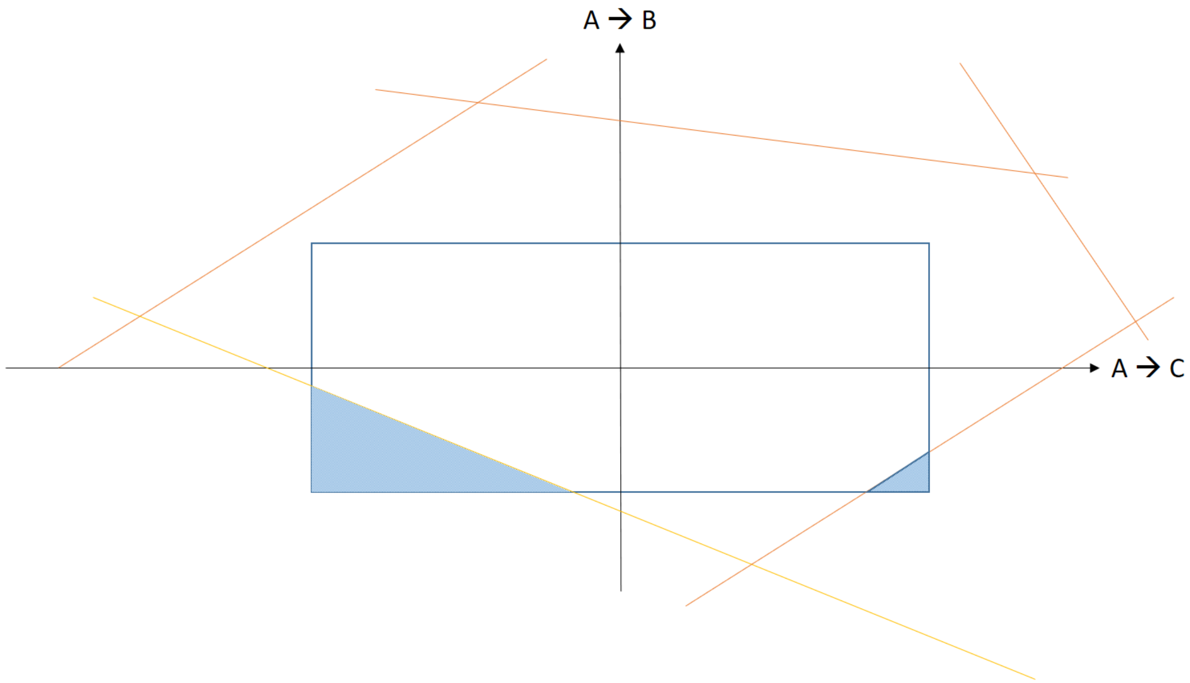
[33] This methodology is somehow similar to the long term allocation (LTA) inclusion process described in the Core CCM methodology (see footnote 20). However, in this methodology, RAs are explicitly defined, so that only RAMs are modified.

[34] Due to some assumptions (e.g. the fact that internal lines are ignored), benchmark NTC values will be symmetrical (i.e. are the same for both directions of a given border), so that average bidirectional historical NTCs are used throughout this annex.

[35] The NTC domain is obtained by combining extreme import and export NTCs on the various borders.

Figure 3 : NTC domain not fully included in FB domain



Notes: the NTC domain is depicted in blue, whereas the FB domain is depicted in yellow (CNEs) and orange (CNECs). The parts of the NTC domain which lie beyond the FB domain are highlighted in blue.

(24) Limiting FB constraints may be slightly relieved, either by increasing the RAM level (through negative FAV), or by decreasing (absolute) PTDF values. Increasing RAM levels would, for example, mimic preventive remedial actions or possible temporary overloads before a curative remedial action is applied, whereas decreasing PTDFs may describe changes in the network topology.

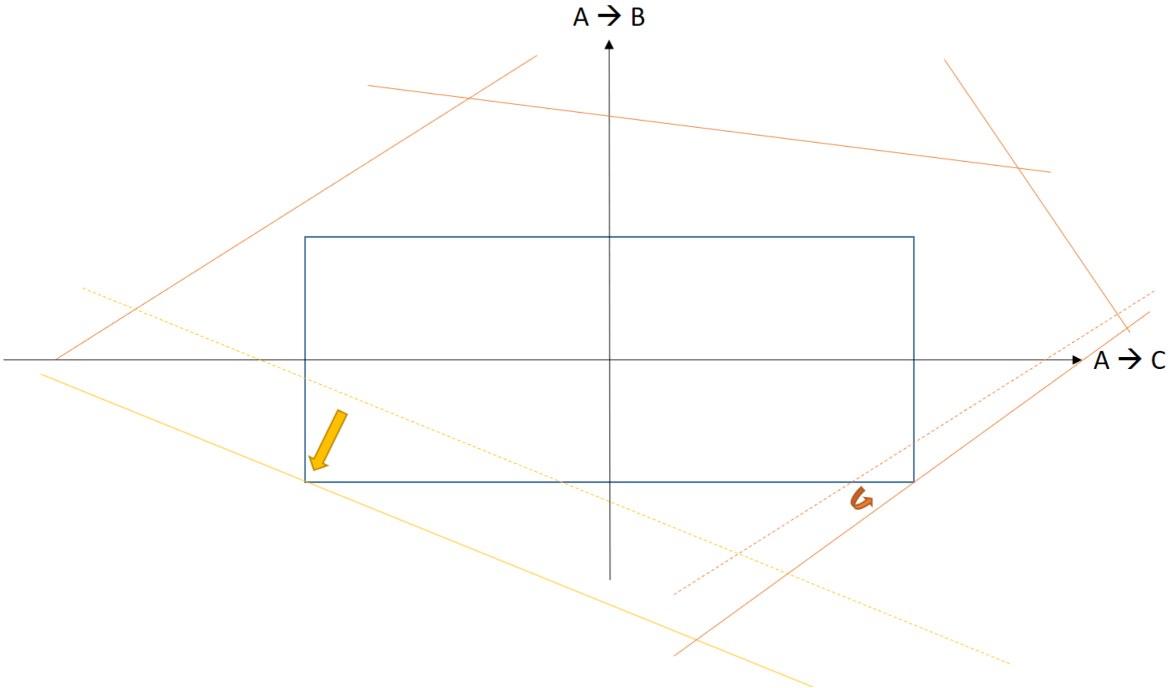
(25) The limiting[36] FB constraints are updated as follows:

- For base case CNEs, it is assumed that topological actions have a limited impact (because the network is usually meshed), so that the (negative) FAV is increased.
- For CNECs, it is assumed that a combination of topological and other remedial actions is possible. As a result, some PTDFs may be reduced (but not below the PTDFs of the associated base case CNE PTDFs), and the (negative) FAV may be increased. Half of the overload is solved through PTDFs reduction (when possible), and the remaining overload is solved through FAV.

(26) The resulting FB domain includes the set of historical NTCs, and is depicted below.

[36] Non-limiting constraints remain unchanged

Figure 4 : Updated FB domain



Notes: The NTC domain is depicted in blue, whereas the FB domain is depicted in yellow (CNEs) and orange (CNECs). Dashed lines depict limiting FB constraints before update. CNE constraints are shifted parallel to the original constraint, whereas CNEC constraints are both shifted and rotated.