CWE Enhanced Flow-Based MC feasibility report

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EXECUTIVE SUMMARY

Background

The Memorandum of Understanding of the Pentalateral Energy Forum on market coupling and security of supply in Central Western Europe (CWE), was signed on the 6th of June 2007 and sets as an objective the analysis, design and implementation of a flow-based market coupling between the five countries of the CWE region.

Flow-Based Market Coupling allocates capacity by optimizing the global market of the different coupled spot markets' order books while granting that the physical limits of the grid are respected.

In 2008, a market analysis on CWE FBMC (Flow-Based Market Coupling) was performed based on non-operational FB data and some issues were detected which seemed to be linked to the data quality. At that time it was decided to start with ATCMC (ATC Market Coupling) in CWE as an intermediate facilitation of the market and to study a FBMC in parallel. After that decision, some major steps have been made and milestones accomplished, as listed hereunder:

- The TSOs developed the CWE coordinated ATC mechanism in order to facilitate the CWE ATCMC.
- TSOs and PXs successfully launched the CWE ATCMC on November 9, 2010.
- The TSO Flow-Based Working Group (FB WG) continued the improvement and fine-tuning of the CWE flow-based capacity calculation.
- The TSO FB WG together with the TSO & PX FB Validation Taskforce (FBV TF) prepared the FB parallel run; so that the market impact of FBMC could be simulated, based on TSOs FB input data and PXs ATCMC order books, as soon as the ATCMC was live.

CWE FB Capacity Calculation feasibility report

The 2008 CWE FB "classical" method has been improved and fine-tuned during the TSO FB WG experimentation in 2010. The development of the CWE coordinated NTC/ATC mechanism and the corresponding industrial tools/services to realize this, greatly facilitated the work in this field. The resulting process is identified with 'CWE enhanced FB', in order to make clear that significant improvements in the FB process have been established since 2008.

CWE enhanced FB improves the ATC methodology as FB increases the proposed capacity offered to the market

For a given Security of Supply domain, the NTC/ATC domain is only a part of this security domain (because of the capacity splitting between borders made by the TSOs) while the FB domain is the full security domain itself.
As such, the FB mechanism will offer more trading opportunities to the market, which is indeed confirmed during the FB experimentation.

CWE enhanced FB improves the ATC methodology in terms of Security of Supply concerning unusual market directions

Security of Supply (SoS) for the usual market directions remains unchanged irrespective of the coordinated NTC or FB method. For the unusual market directions, however, the SoS under FB is improved as under FB no assumptions need to be made for those unusual market directions.
Flow-based gives a more accurate description of the SoS domain.

CWE enhanced FB improves the current capacity calculation methodology (ATC) as FB improves the cooperation between TSOs, which allows an increase in coordination between TSOs

The FB description is closer to the reality of the grid, which induces a natural need for increased cooperation and information exchange between the CWE TSOs in the FB operational process. This is in contrast to the opacity and lack of physical meaning of the NTC values.
Furthermore an increase in the level of coordination between the TSOs is facilitated.
Under FB, interdependency of the cross-border exchanges is reflected from the beginning of the process for all the directions of the capacity space. This is in contrast to the current coordinated NTC process where the first step (initial local TSO computation) is not coordinated.

The CWE enhanced FB addresses transparency requirements and concerns on market players understanding

The non-redundant FB parameters containing PTDF factors and margins associated to the critical branches will be communicated to the market before allocation. Additionally, in order to ease the transition from ATC and to provide market players with more grips on the FB domain, a simplified description of the FB domain can be supplied: it could consist in figures representing maximal bilateral exchanges and net positions allowed by the FB constraints.

The CWE enhanced FB operational process has been experimented during 2010 by the FB WG, **proving its feasibility** from an operational point of view. Furthermore it is **compatible with the following adjacent capacity calculation processes**:

- **Intraday ATC computation**: as long as FB is not implemented in intraday, FB for D-1 must be compatible with the current intraday ATC usage for allocation. This compatibility is granted, as it is always feasible to compute non-negative ATCs for intraday allocation usage after FBMC.
  CWE TSOs recommend an initial coordinated splitting of the FB domain, proposed to the market in D-1, followed by a further local increase/decrease based on DACF merged files and validated by a coordinated verification of all the TSOs (same verification process as currently applied in D-1).
  The implementation of this option is linked with resource availability for TSOs for the ID coordinated verification step. In case not enough operational resources are available, bilateral intraday capacity increase should not be allowed.

- **Long Term ATC computation:** the compatibility is granted if the long term capacity domain offered to the market is fully included in the FB domain. Practically this means that there should be no negative capacities (no 'precongestions') before the market coupling (In 2010 experimentation, no precongestion has been observed).

- **D-1 NTC computation of the non-CWE borders** is compatible and feasible with introducing FB capacity calculation and allocation on the CWE borders. Switching to FB on the CWE borders, can influence the computation process of NTCs on other borders of the CWE TSOs.

CWE FBMC price and market impact analysis

Simulations comparing ATC constraints and FB constraints on a short period (2 times 2 weeks in winter) showed that Day-Ahead Market Welfare and convergence indicators are significantly better with FB constraints than with ATC, whatever the coupling method used (FBMC or FBIMC). Overall, the market impact analysis concludes that FB constraints have a positive impact on the market compared to ATC.

The FBV TF recommends continuing to monitor the impact on the market while the project is ongoing in order to confirm the observations on representative simulation periods. It will also allow configuring the coupling algorithm through deciding between FBMC and FBIMC and helping to determine whether the ramping constraints for bidding areas should be activated. More precisely, non intuitive situations were found in FBMC. Using FBIMC removes these situations without unacceptable deterioration of other indicators. The impact of FBMC on market resilience should also be monitored.

CWE FBMC interaction with coupling to other initiatives

CWE FBMC coupling with other initiatives is feasible, whatever the type of extension (AC or DC cable connected area, using FB or ATC constraints and implicit or explicit coupling).
Indeed, among the different possible scenarios of coupling, no blocking problems are identified:

- Compatibility between different allocation methods is ensured: CWE FBMC is compatible with neighbouring explicit auctions or with another region under implicit auctions.
- Compatibility between different capacity calculation methods is ensured: in target solutions of single price coupling, the algorithm can take into account both FB and ATC constraints, and ensures compatibility between FB areas and ATC areas.

Besides, in the hybrid price coupling combining both FB and ATC constraints, a special attention should be paid to the impact of one model over another: indeed, ATC transactions influence the flows on critical branches of the FB area (and thus use a part of their physical available margins), and this influence could be taken into account directly in the coupling algorithm.
This would avoid to take this influence into account ex-ante (before the coupling) by booking some physical margin of the critical branches in the FB area: this is sub-optimal since it requires to take constraining hypothesis of ATC transactions in order to guarantee the SoS, and potentially induce to give less capacity than the level which could have been given if the realized ATC transaction influence was directly taken into account in the coupling algorithm (and not the ex-ante hypothesis).

When FB/ATC hybrid price coupling projects will emerge, CWE TSOs and PXs recommend, from a theoretical point of view, to consider the possibility of taking into account the impact of ATC exchanges in the FB model.

General conclusion

During the 2010 CWE FB TSO experimentation it was proven that the enhanced FB capacity calculation and allocation:

- is feasible from an operational point of view;
- increases the proposed total capacity offered to the market when compared to ATC;
- improves the Security of Supply in unusual market directions and TSO cooperation compared to the CWE coordinated ATC method;
- addresses transparency requirements and concerns on market players understanding;
- is compatible with the adjacent capacity calculation processes:
    - D-1 NTC computation of the non-CWE borders,
    - Long Term ATC computation,
    - ATC intraday computation.

The theoretical improvements of FB vs ATC have been confirmed during the 2010 CWE FB experimentation. From the capacity calculation point of view, CWE TSOs recommend continuing describing the details of a FB implementation for CWE MC.

Overall, through simulations comparing ATC constraints and FB constraints on a short period (2 times 2 weeks), the market impact analysis concludes that FB constraints have a positive impact on the market compared to ATC.

CWE FBMC coupling with other initiatives is feasible, whatever the type of extension (AC or DC cable connected area, using FB or ATC constraints and implicit or explicit coupling).

Next steps

The CWE TSOs and PXs recommend continuing to monitor the impact on the market while the project is ongoing in order to confirm the observations on representative simulation periods and to configure the market coupling algorithm. Non-intuitive situations in FBMC have been found and will continue to be monitored as will the effect of their removal through FBIMC on the other indicators.

November 2011, a key decisional milestone is scheduled to formally take an investment decision for FB implementation. This decision will be based at least on the following main deliverables which will be provided in September 2011:

- TSO’s feasibility report based on 2010 Experimentation, including interaction with development of intraday (current report);
- Price/Market impact analysis and analysis of the interactions with the coupling to other initiatives performed jointly by PXs/TSOs (Current report, updated in July with more data based on approximately one week of simulation each month);
- FRM assessment / model quality study, PRB and computation time analysis, sensitivity analysis, eg. PTDFs (July 2011).
- Implementation details (timings, backups, fallback, …)
- Answers to the received questions of external stakeholders to the present document

Pending the above mentioned key decisional milestone, CWE PX & TSO FB MC Go live target date is foreseen for last quarter 2012.

Contents

Glossary

ATC	Available Transfer Capacity
ATCMC	ATC Market Coupling
CB	Critical Branch
CC	Capacity Calculation (ATC or FB)
CEE	Central Eastern Europe (Austria, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia)
CGM	Common Grid Model
CSE	Central South Europe (Austria, France, Germany, Greece, Italy, Slovenia)
CWE	Central Western Europe (Belgium, France, Germany, Luxembourg, Netherlands)
D-1	Day Ahead
D-2	Two-Days Ahead
D-2CF or D2CF	Two-Days Ahead Congestion Forecast
DA	Day Ahead
DACF	Day-Ahead Congestion Forecast
DAMW	Day-Ahead Market Welfare
ENTSO-E	European Network of Transmission System Operators for Electricity
FB	Flow Based
FBMC	Flow-Based Market Coupling
FBIMC	Flow-Based Intuitive Market Coupling
FBV TF	Flow-Based Validation Task Force (joint group CWE PX & CWE TSO)
FB WG	Flow-Based Working Group (CWE TSO group only)
FRM	Flow Reliability Margin
FTR	Financial Transmission Right
GSK	Generation Shift Key
ID	Intraday
IDCF	Intraday Congestion Forecast
ITVC	Interim Tight Volume Coupling
LT	Long Term
MC	Market Coupling
NP	Net Position (sum of commercial exchanges for one bidding area)
NTC	Net Transfer Capacity
NWE	North Western Europe (CWE countries + Denmark, Finland, Norway, Sweden, United Kingdom)
PCR	Price Coupling of Regions
PDCA	Plan > Do > Check > Act
PTDF	Power Transfer Distribution Factor
PST	Phase-Shifting Transformer
PX	Power Exchange
RAM	Remaining Available Margin
R4CA	Regional Coordinated Capacity Calculation and Capacity Allocation
RCA	party Responsible for Common Activities
SN	Snapshot
SoS	Security of Supply

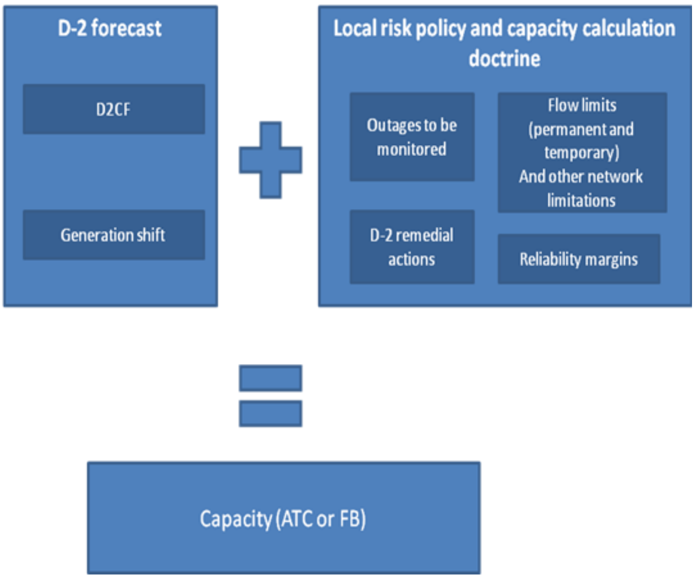
SWE	South Western Europe (France, Portugal, Spain)
TF	Task Force
TRM	Transmission Reliability Margin
TSO	Transmission System Operator
TS	Timestamp (hourly)
TTC	Total Transfer Capacity
UCTE	(formerly) Union for the Coordination of Transmission of Electricity (today integrated into ENTSO-E)
UIOSI	Use It Or Sell It
WG	Work Group

1. Introduction to capacity calculation and CWE market coupling

1.1 Capacity Calculation

The main steps of a capacity calculation process as defined by the ENTSO-e AHAG Capacity calculation project are the following:

- Each TSO creates a forecast file (D2CF) describing its part of the grid in the best way
- In addition, each D2CF file has to be accompanied by the respective Generation Shift Key (the GSK maps an import / export position to an altered output power of the generating units)
- Based on local risk policy[1], each TSO defines and monitors critical branches: internal or cross-border elements that are significantly impacted by cross-border trade, under N situation or N-k outages
- As defined by local procedures, remedial actions allowed in D-2 are taken into account while ensuring a secure power system operation i.e. N-1/N-k criterion fulfilment
- For each situation the operational limits have to be respected (thermal limits, voltage limits, dynamic stability...)
- Based on local risk evaluation/policy, TSOs hedge themselves against real time changes and uncertainties due to a D-2 calculation, through reliability margins
- The result of this process is the **Security of Supply domain** which can be expressed in two main ways:
    - By using available transfer capacities (ATCs): the maximum allowable commercial exchange that pushes a critical branch to its maximum flow
    - By using the physical constraints of the grid elements (FB): the available physical margin and the influence factors on critical branches.
- Capacity (both under ATC and Flow-based representation) is given to the MC system in order to be allocated.

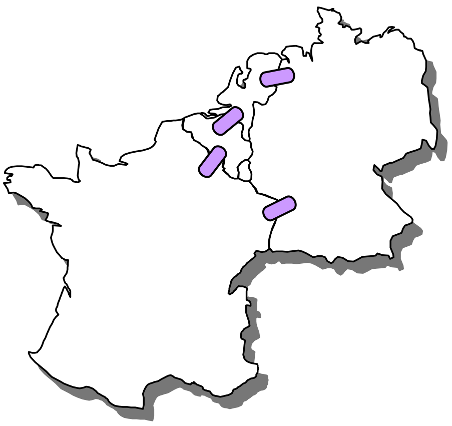


The formal recommendation of the ENTSO-e AHAG Capacity calculation project for Day-Ahead is Flow-Based for meshed grids, while ATC could be used for borders where distribution of power flows over the interconnecting lines is only slightly influenced by non-adjacent bidding areas.

[1] Different contingencies may appear: tripping of a single line is one of the most probable events which could happen during operation. Busbar tripping or simultaneous tripping of several lines or loss of a whole substation is generally less probable. Dimensioning the system for all possible events, even those with very low probability of occurrence, would lead to very high costs. Therefore, it is a matter of system risk policy to take into account the probability of system failures, and their consequences, in order to find an acceptable trade-off between costs and level of security, respecting compliance with security criteria established in Network Codes.

1.2 CWE area

Hereunder the CWE[2] area is shown, for which the CWE TSOs perform the cross-border capacity calculation.



CWE bidding areas:
- Belgium
- France
- Germany
- Netherlands

Physical interconnectors between:
- Belgium & Netherlands
- Netherlands & Germany
- Germany & France
- France & Belgium

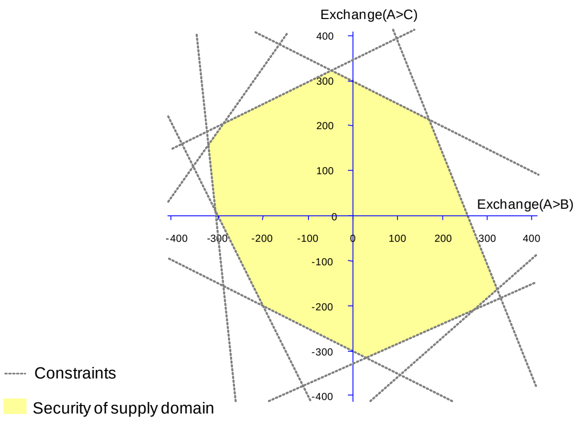
So **no** physical interconnectors between Germany & Belgium

Physical interconnectors

1.3 CWE Market coupling

A power exchange is a market place where the demand and supply bids for the day ahead of a country, or group of countries, are collected and matched. In a market coupling of several countries, all the bids of the (national) power exchanges are brought together in order to be matched. This will result in one price and a net import (demand) or export position (supply) per country for all the coupled countries.
However, the results of the market coupling should be feasible in the grids of the TSOs of the countries involved. Therefore, the TSOs need to assess the capacity that they can provide to the day-ahead market coupling algorithm, so that they facilitate the market in their best way, while safeguarding the Security of Supply.
The market coupling algorithm is therefore a constrained optimization problem; the market welfare is maximized, while respecting the constraints provided by the TSOs. When one or more of the constraints is hit by the market coupling, different market prices result in the coupled markets; congestion income, paid for the scarce capacity, is then collected by the TSOs. By contrast, when no constraint is hit, the market prices are identical for all countries.

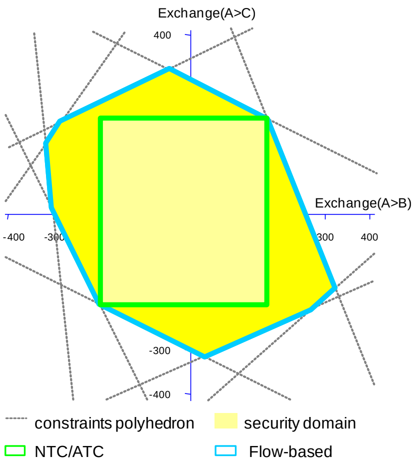
The constraints that are provided by the TSOs are either ATC or FB constraints, respecting the Security of Supply (SoS) domain. The SoS domain can be determined by making assumptions with regard to the foreseen grid situation and by performing contingency analyses. If we imagine a country A, that is interconnected with country B and country C, the SoS domain of country A could look like the figure in the graph below. On the x-axis the commercial exchange from country A to B is varied, while on the y-axis the commercial exchange from country A to C is varied.



In the figure, the SoS domain is colored yellow and is bounded by several physical constraints. We can see from the figure that a 100 MW commercial exchange from A to B and a 100 MW commercial exchange from A to C is within the SoS domain; this combination of exchanges is feasible. A commercial exchange of 400 MW from A to B is always outside the SoS domain and is not allowed.

[2] Luxembourg is part of CWE, but there is no specific Luxembourg bidding area.

By providing FB constraints to the MC system, the TSOs provide the SoS domain as illustrated above, as the domain itself is delimited by the FB constraints.
When a TSO provides ATC constraints to the MC system, he needs to make a choice on how to split the capacity among its borders (A to B and A to C). One of the possible choices is shown by the green rectangle in the figure below.
It is evident from this figure that the ATC domain (or ATC search space) that can be provided to the MC system by the TSOs, without violating the SoS, is more restrictive than the FB one.



In the CWE region, the figures are not as simple as they are illustrated here. Nevertheless, these simple figures can give a good insight of the concepts that will be highlighted in this document.
In the coordinated ATC mechanism, for example, the concept of ‘corners’ is introduced. These corners are nothing more than the corners of the ATC search space; in the figure above the 4 corners of the green rectangle.
When the FB search space is discussed, the concept of ‘vertices’ is used. The vertices are the corner points of the FB domain; in the figure above the vertices are the corner points of the blue polygon.

Although the benefits of FB are obvious from a theoretical point of view, the 2008 market analysis on CWE FBMC (Flow-Based Market Coupling) was performed based on non-operational FB data and some issues were detected which seemed to be linked to the data quality. At that time it was decided to start with ATCMC (ATC Market Coupling) in CWE as an intermediate facilitation of the market and to study a FBMC in parallel. Since then, the 2008 CWE FB “classical” method has been improved and fine-tuned during the CWE TSO experimentation in 2010. The development of the CWE coordinated NTC/ATC mechanism and the corresponding industrial tools/services to realize this, greatly facilitated the work in this field and provided a proper reference to compare ATC and FB in terms of SoS (and not only in terms of welfare). The resulting process is identified with ‘CWE enhanced FB’, in order to make clear that significant improvements in the FB process have been established since 2008. It is the purpose of the report to present the benefits of FB when compared to ATC, not only from a theoretical point of view but also from a practical one.

2. CWE Flow-Based capacity calculation feasibility report

2.1 Introduction

This chapter presents the Enhanced FB capacity calculation which is the result of the FB experimentation.

The CWE enhanced FB method that is presented in this chapter, fulfils all the targets mentioned below as will be highlighted in the corresponding section:

- Enhanced FB capacity calculation is operationally feasible (section 2.2)
- Enhanced FB increases the proposed capacity offered to the market when compared to ATC (section 2.3)
- Enhanced FB improves the Security of Supply in unusual market directions and TSO cooperation compared to the CWE coordinated ATC method (section 2.4)
- Enhanced FB addresses transparency requirements and concerns on market players understanding (section 2.5)
- Enhanced FB implementation for CWE MC is compatible with the adjacent capacity calculation processes (section 2.6)

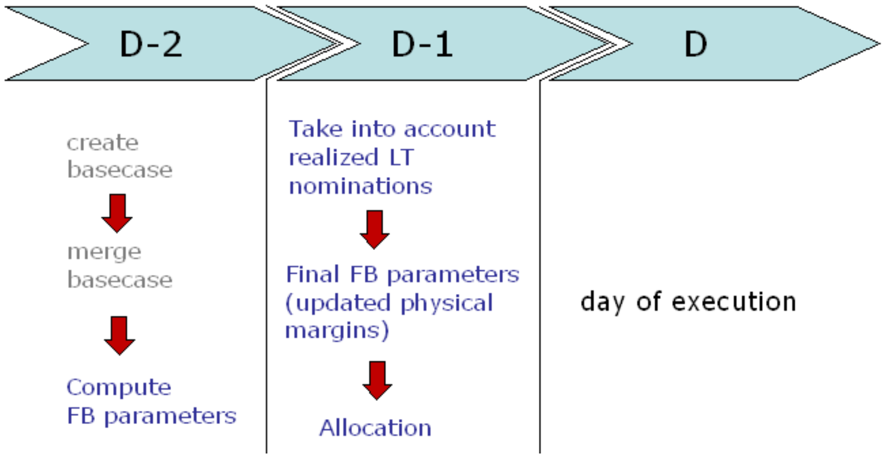
2.2 CWE Enhanced FB operational process

This chapter aims at describing the CWE Enhanced FB operational precoupling process[3], which was experimented during one year to prove its feasibility.

The final output of this precoupling process are the 24 sets of anonymized presolved FB parameters, adjusted to LT nominations, that are to be used by the market coupling algorithm (these technical terms will be detailed in the following chapters).

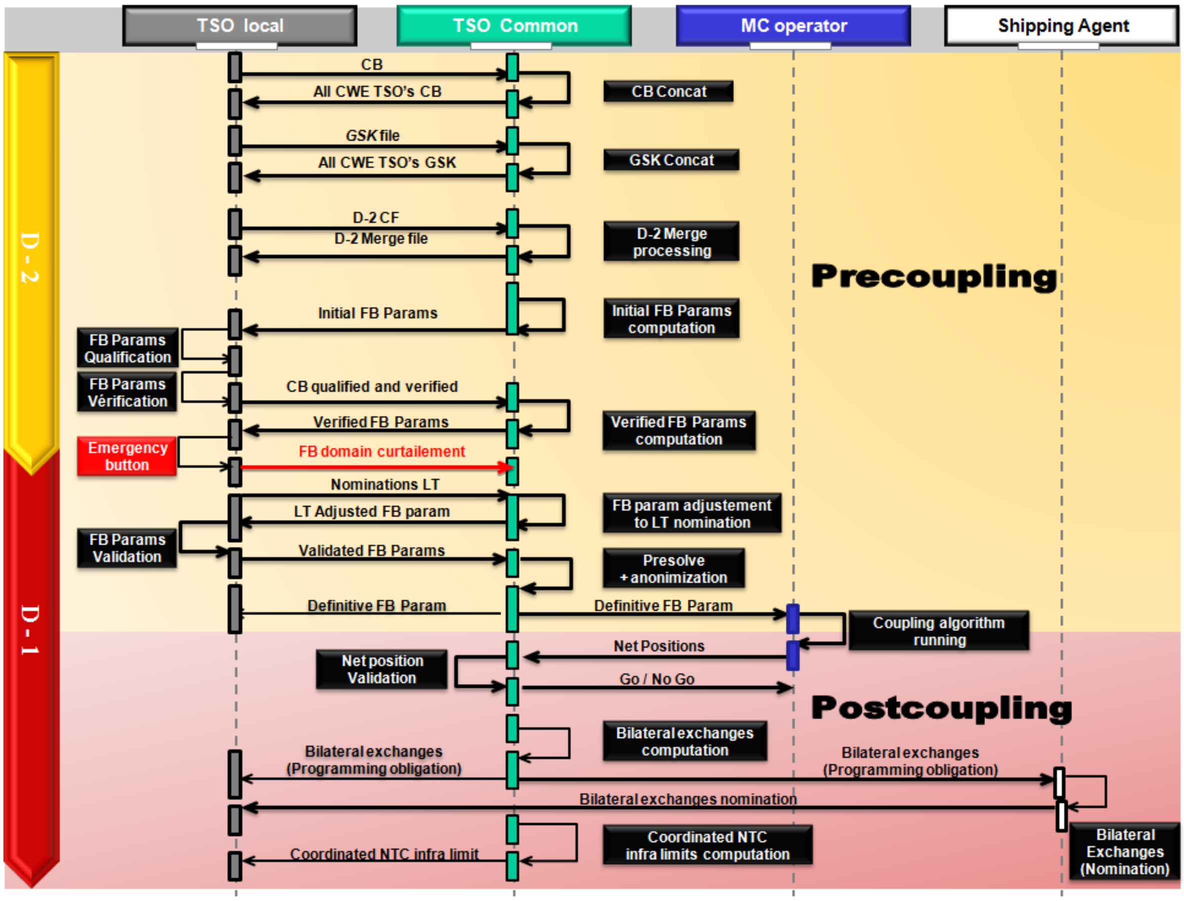
2.2.1 CWE Enhanced FB operational process overview

Hereunder a macro vision of the FBMC process is depicted:



The chronogram below shows in more detail the whole FBMC operational process sequence:

[3] Remark: the 2010 experimentation focused on normal ongoing process and methodological related issues and not on fall-back situations which will be defined and experimented during the implementation.



All FB precoupling subprocesses mentioned above (CB, GSK, D2CF, Merging, FB parameters computation, …) have been experimented during 2010 by the CWE TSOs and will be described in the following sections.

The precoupling tasks comprise both local ones as well as commonly performed ones.

- TSO tasks that are performed locally by each TSO:
  D2CF, GSK, CB file creation, FB parameter qualification, FB parameter verification.
- TSO tasks that are commonly performed:
  - by the party responsible for common activities (RCA): GSK concatenation, Initial FB parameter computation, FB parameter adjustment to LT nominations, presolve + anonimization.
  - by a merging service provider entity (CORESO): D-2 Merge.
- In between, a task that can be performed either locally or centrally: FB parameter validation.

2.2.2 D2CF

The 2-Days Ahead Congestion Forecast files, (D2CF files) provided by the participating TSOs two-days ahead, are a best estimate of the state of the system for day D.
Each TSO produces for its zone a D2CF file which contains:

- exchange programs of a reference day, that are expected to be comparable to that of the execution day[4]
- best estimation for the planned grid outages
- best estimation for the outages of generating units and the output of the running generating units
- best estimation for the forecasted load and its pattern
- best estimation for the forecasted wind generation
- best estimation of the grid topology with respect to the consistency with above assumptions.

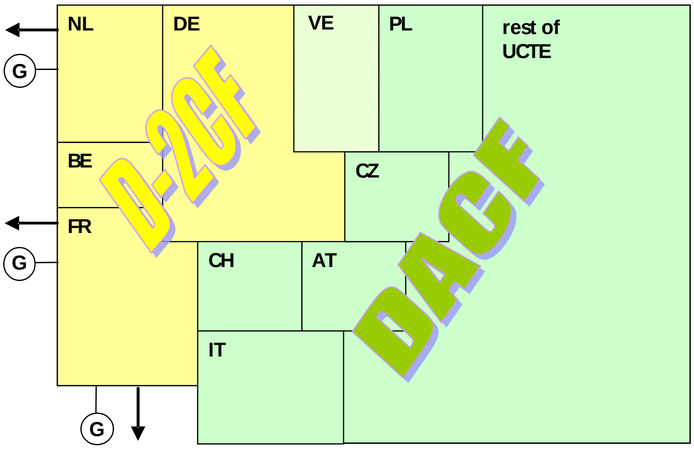
D-2CF files have to be balanced in terms of production and consumption, in coherence with the reference exchanges, i.e. any variation on the loads of a control area must be compensated by a consistent adjustment of the generation output in the same area.

[4] The reference day is defined with the following rule:

- For Tuesday to Friday: D-1
- For Monday: D-3 (i.e. previous Friday)
- For Saturday and Sunday: D-7
- For bank holidays and specific outages, individual reference days have to be determined and fixed in a separate calendar approved by all CWE TSO

2.2.3 Base case merging (or Common Grid Model creation)

Every participating TSO creates, within its own responsibility, a D-2CF-file, thereby incorporating the before-mentioned information. For the rest of the synchronous continental ENTSO-E grid (former UCTE grid), needed to represent the physical influences of these grids, the DACF-files of the reference day are used. The individual files (D-2CF respectively DACF) are merged together in a centralized way to ensure the creation of a unique common grid model. This is shown in the picture below.



A continental European-wide D2CF file is obtained, referred to as merged D2CF (or common base case, or common grid model) in the rest of the document.

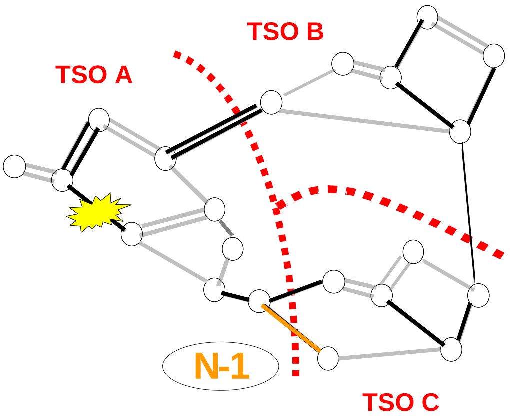
Note: the merging activity is not a fully automatic one and comprises a sanity check (UCTE format compliance, tie-lines status, country balance) of each individual file with a specific operational procedure in case of inconsistencies.

2.2.4 Critical Branches

A **critical branch** (CB) is a transmission link, significantly impacted by cross-border trade, which is monitored under certain operational conditions. The critical branches are determined by each TSO for their own networks and are defined by:

- One line (tie-line or internal line), or one transformer, that is significantly impacted by cross-border exchanges
- An "operational situation": normal (N) or contingency cases (N-1, N-2, busbar faults; depending on the TSO risk policies)

In the graph on the right an example is shown of a CB consisting of a tie-line (orange) that is monitored under N-1 outage of an internal line (yellow)



The parameters that are provided by each TSO for its critical branches are:

- the **maximum allowable flow (Fmax)**: the physical capacity determined by each TSO depending on thermal limits or the relay limiting the power flow.
- the **flow reliability margin (FRM)**: the margin taken on the maximum allowable flow to take into account:
  - the uncertainties inherent to a D-2 capacity calculation process,
  - the real time unintentional flow deviations due to operation of load-frequency controls
  - Uncertainties in data collection and measurement

  (see also FRM in section 5.7).

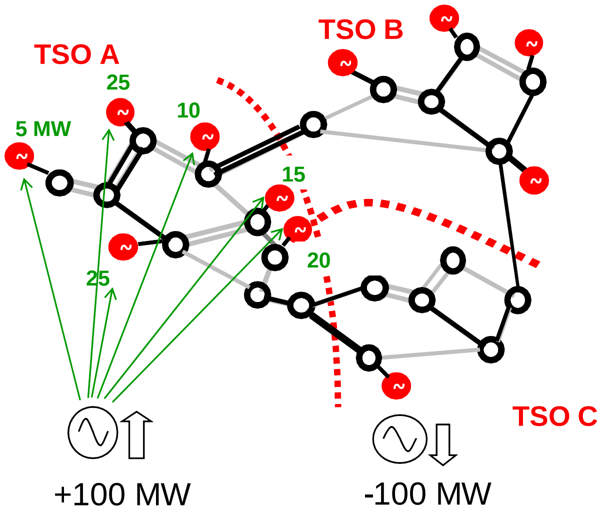
Besides critical branches, which are active power flow-related limits only, other specific limitations are necessary to guarantee a secure grid operation such as the ELIA import stability limit of 4500 MW (value used for test/experimentation purposes).
Import limits declared by TSO are taken into account as "special" critical branches, in order to guarantee that the market outcome does not exceed the limits. This is detailed in section 5.3.

2.2.5 Generation Shift Keys

The D-2CF basecase defines the estimated working point of the grid. It is this working point, from where we investigate the impact of a change of net positions on the flows on the CBs. It is the Generation Shift Key (GSK) that defines how a change in net position is mapped to the generating units in a bidding area.

In the graph on the right an example is shown how a 100 MW change of net position in TSO A and C will be mapped to the generating units by the GSK

Note: this section is only a definition of the GSK; in section 5.8, each TSO describes how its GSK is determined.



2.2.6 Initial FB parameters calculation

The initial FB parameters computation is a centralized computation with the following outputs per critical branch:

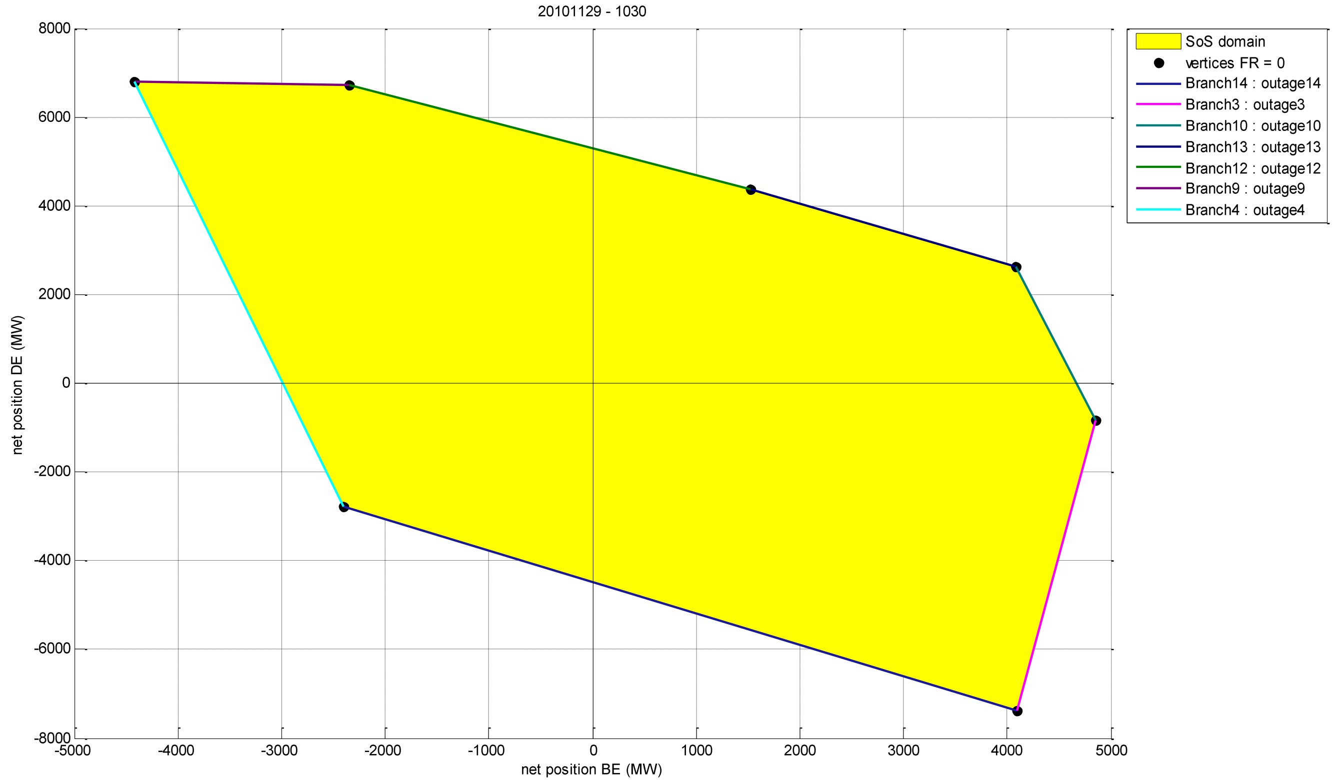
- the **Available Margin** on a critical branch:
  Margin = Fmax - Fref - FRM

  As the reference flow (Fref) is the physical flow computed from the common base case, it reflects the loading of the critical branches given the exchange programs of the chosen reference day.

- the **PTDF factors** (Power Transfer Distribution Factors) that represent the variation of the physical flow on a critical branch induced by the variation of the net position of each hub. PTDF factors are computed with a sensitivity calculation on the common base case by using the GSK.

As a real example from the 2010 experimentation, in the graph below a two-dimensional slice of the FB domain, as defined by the flow-based parameters of the critical branches listed in the table hereunder, is illustrated. The slice shows the FB boundaries that limit the feasible net positions of Germany and Belgium at a zero French net position (the Dutch net position is the dependent variable in this case, see also the footnote 9 on page 24).

Critical branch		*FB parameters*				
		Margin	*PTDF*			
Outage Id	Branch Id	Margin	BE-hub	DE-hub	FR-hub	NL-hub
outage3	Branch3	976.8	0.0719	-0.1480	-0.1823	-0.1252
outage4	Branch4	1277.4	0.0364	0.3740	0.2160	0.4641
outage9	Branch9	1125.3	0.0023	0.1655	0.0882	-0.0044
outage10	Branch10	1436.6	0.0509	-0.1880	-0.0755	-0.2568
outage12	Branch12	1113.7	0.0008	0.0840	0.0338	-0.1262
outage13	Branch13	1067.6	0.0005	0.0624	0.0230	-0.1345
outage14	Branch14	1026.5	-0.0005	-0.0672	-0.0223	0.1615



Note: for an introduction to the geometrical representation of the FB domain, please refer to section 5.1.

The following two processes, FB qualification and verification, have been incorporated and experimented in the 2010 FB experimentation and are the main improvement from the 2008 classical CWE FB capacity calculation method to the 2010 enhanced CWE FB capacity calculation method.

2.2.7 FB parameter qualification

Objective: application of the remedial actions in the FB parameters according to local capacity calculation procedures and risk policy leading to capacity optimization.

The operational FB qualification process is executed locally by each TSO on the merged D2CF, and covers the following:

1. For each non-redundant CB, the TSO applies the same remedial actions as currently applied in the daily operational capacity calculation process, such in coherence with their local capacity calculation procedures and risk policy. The way that the impact of the remedial actions is incorporated in the critical branches could differ between the TSOs (see detail in section 5.4).
2. Checks on the impact of remedial actions on the FB domain as a help for the operator by considering the following basic principles:
   - Is the FB domain comparable with the one of the previous day (i.e. max net positions comparison)? It should if the environment did not change significantly (i.e. consumption forecast, outages, …)
   - Especially, is FB domain bigger than LT ATC domain? Negative capacity offered to the DA capacity allocation (so called ‘precongestions’) resulting from a smaller FB domain is expected to occur rarely.

Remark: During the parallel run (ATC // FB), as TSO compute NTC values for a similar time frame and risk policy, the FB domain are at least equal or even bigger than the NTC one for realistic corners because they represent the same SoS domain.

Note 1: In the FB parameter qualification phase the FB domain might be increased.

Note 2: Sanity checks (e.g. PTDF factors in between -1 and 1, reasonable Fmax and FRM values, bad branches, ..) on the initial FB parameters computed by the RCA are also done by the local TSOs at this stage.

Note 3: each TSO executes locally the FB parameter qualification process.

2.2.8 FB parameter verification

Objective: verify that the FB domain is secure.

This FB process is the FB equivalent of the current ATCMC "Coordinated NTC verification step". TSOs verify on the D-2CF basecase the security of the FB domain by checking all the relevant vertices[5].

At this step of the process, TSOs have the possibility to ascertain the correctness of the FB parameters generated by the centralized computation:

- TSOs can check the grid security in the relevant vertices of the FB domain by customizing the generation pattern to the commonly observed one for the corresponding vertex **instead of** using **the linear GSK**
- TSOs can perform a full **AC loadflow analysis of the vertices,** thereby taking into account reactive power flows
- TSOs can check if the **voltage limits** of the equipment is respected
- TSOs can assess voltage stability (voltage collapse)

If security issues are discovered, TSOs can update their critical branch files (by adding new CBs, that were not perceived upfront as being limiting (for instance in the case of combined and/or unusual scheduled outages), or by decreasing Fmax values).

Note 1: each TSO executes locally the FB parameters verification process.

Note 2: In the FB parameter verification phase the FB domain is normally decreased.

Note 3: for operational feasibility it is very important that there is no need to compute intermediate FB parameters between the D-2 processes "FB qualification" and "FB verification". The way to allow this is described in section *5.5*.

2.2.9 "Emergency reduction button"

In case of critical conditions, TSOs need to be able to modify as quickly and simply as possible the FB domain offered to the market. This is for example the case when a major outage occurs in the night between D-2 and D-1. In such a situation, TSOs have the possibility to add maximum export limits and or minimum import limits based on expertise on critical operational cases. This function should be reserved for emergency situations only.

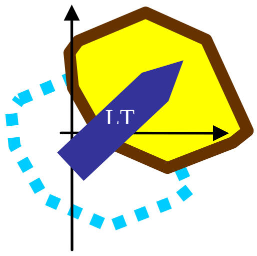
Note: this step of the process was out of the scope of the 2010 FB experimentation (as it is part of the fallback procedures that will be developed during the implementation phase).

[5] Vertices of FB domain are the equivalent of corners of the ATC domain. One vertex or one corner is characterized by a set of 4 net positions. One ATC corner is defined by 4 ATC usages, and one FB vertex is the intersection of 3 constraints.

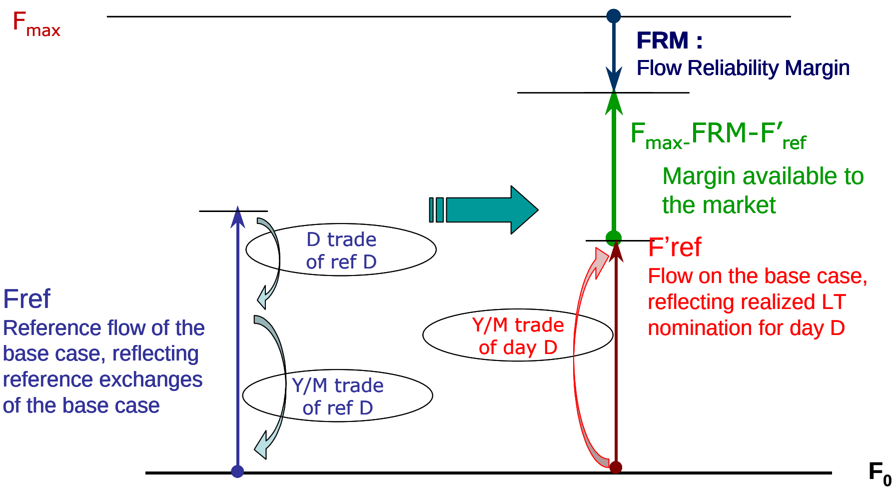
2.2.10 LT Adaptation + D-1 Validation + Presolve + Anonymization

The following four sub-processes are done in D-1 morning:

- **FB parameter adaptation to LT nominations**: as the reference flow (Fref) is the physical flow computed from the common base case, it reflects the loading of the critical branches given the exchange programs of the chosen reference day. Therefore, this reference flow has to be adjusted to take into account only the effect of the LT nominations of the execution day. The effect on the domain is schematically visualized in the figure on the right; a more in-depth explanation of this 'shift' of the domain is highlighted in section 5.2.



  The figure below represents this process for one specific timestamp.

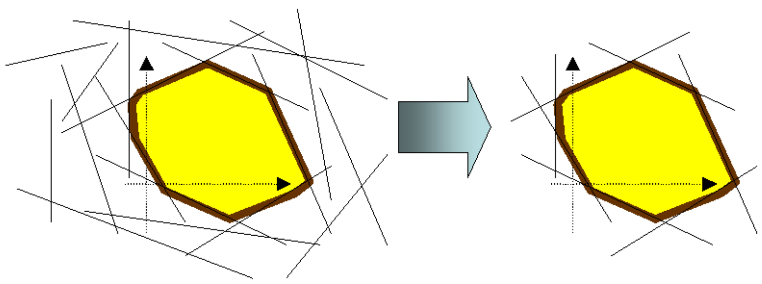


  Note: this process is equivalent to today's ATC computation for NTC and LT nominations (see also section 5.2):

$$\begin{cases} \text{ATC} = \text{NTC - LTnominations} \\ \text{NTC} = \text{TTC - TRM} \end{cases}$$

- **D-1 Validation of FB parameters:** this is a sanity check (e.g. files format compliance); there is no more possibility for capacity increase or reduction, regarding the short timing available

- **Presolve:** this action removes the redundant constraints from the set: only the binding constraints are kept as schematically shown in the figure below:



  Note 1: this action reduces the amount of input data offered to the market coupling algorithm without reducing their completeness or accuracy; furthermore, it enhances the transparency as the amount of information to be provided to the market participants reduces significantly.

  Note 2: the presolve is also applied in earlier stages of the operational process, like the FB qualification and verification, so that the TSO can check its binding constraints during these studies.

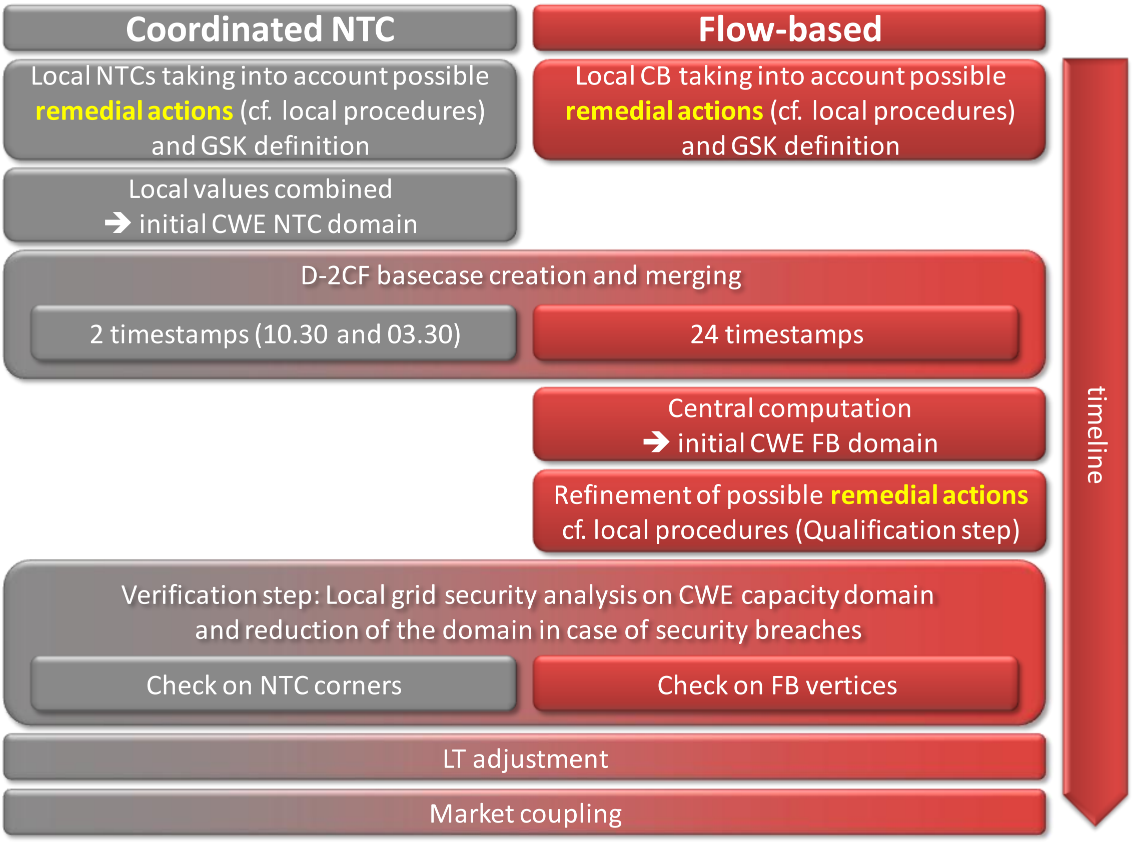
- **Anonymization of FB parameters:** before sending the input data to the MC system, the names of the critical branches are anonymized.

As a result, the FB constraints of the FBMC are described by the following set of equations:

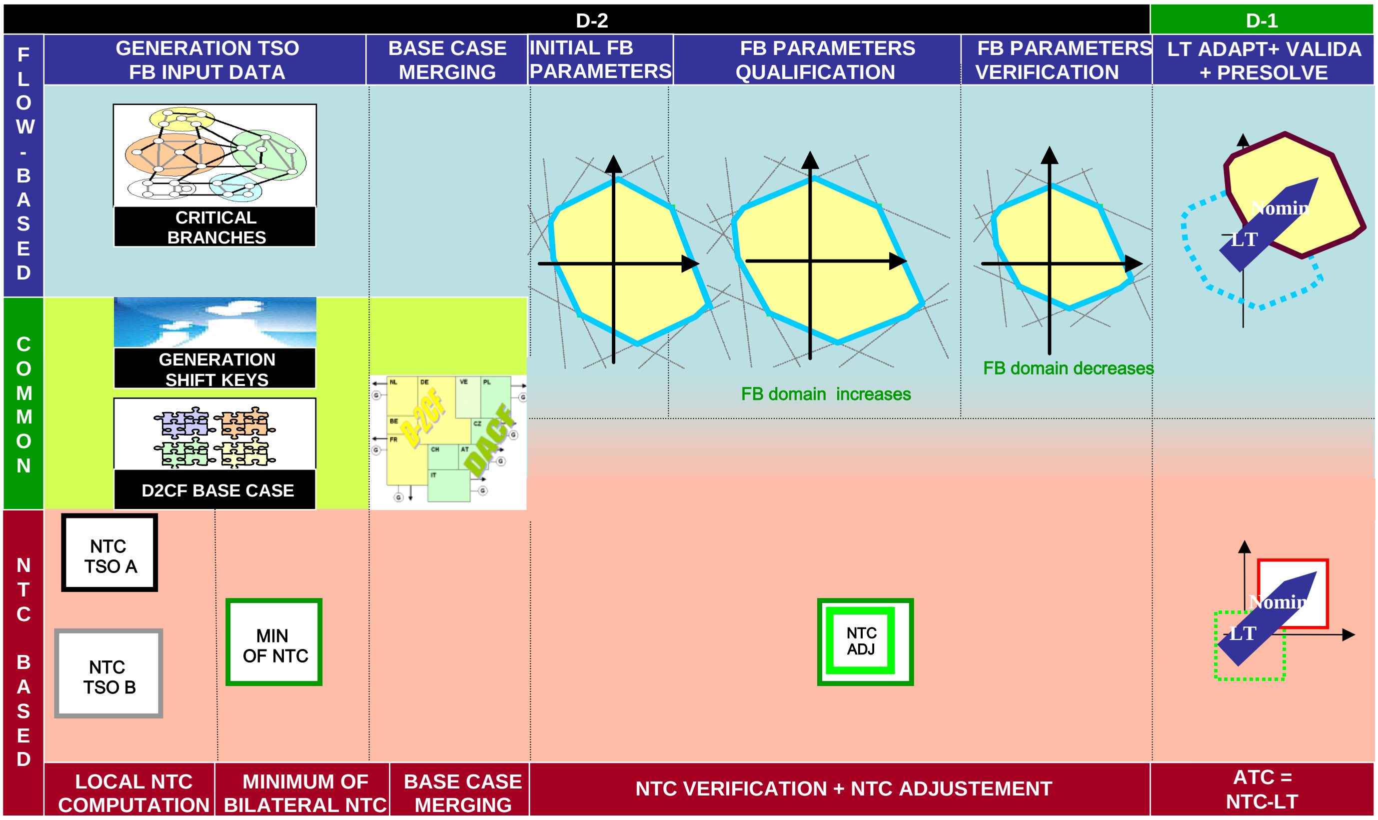
$$\begin{bmatrix} \\ PTDF \\ matrix \\ \\ \end{bmatrix} \cdot \begin{bmatrix} NE_{BE} \\ NE_{DE} \\ NE_{FR} \\ NE_{NL} \end{bmatrix} \leq \begin{bmatrix} F_{\max 1} \\ F_{\max 2} \\ \vdots \\ F_{\max p} \end{bmatrix} - \begin{bmatrix} F_{ref1}' \\ F_{ref2}' \\ \vdots \\ F_{refp}' \end{bmatrix} - \begin{bmatrix} FRM_1 \\ FRM_2 \\ \vdots \\ FRM_p \end{bmatrix} = \begin{bmatrix} RAM_1 \\ RAM_2 \\ \vdots \\ RAM_p \end{bmatrix}$$

2.2.11 Comparison with current coordinated CWE NTC/ATC capacity calculation process

The figure hereunder compares the operational process of the current coordinated NTC approach and the CWE enhanced FB process.



In the graphical overview hereunder, the evolution of both the ATC and FB domain are depicted:
- CWE coordinated NTC process (red zone)
- CWE enhanced FB process (blue zone)

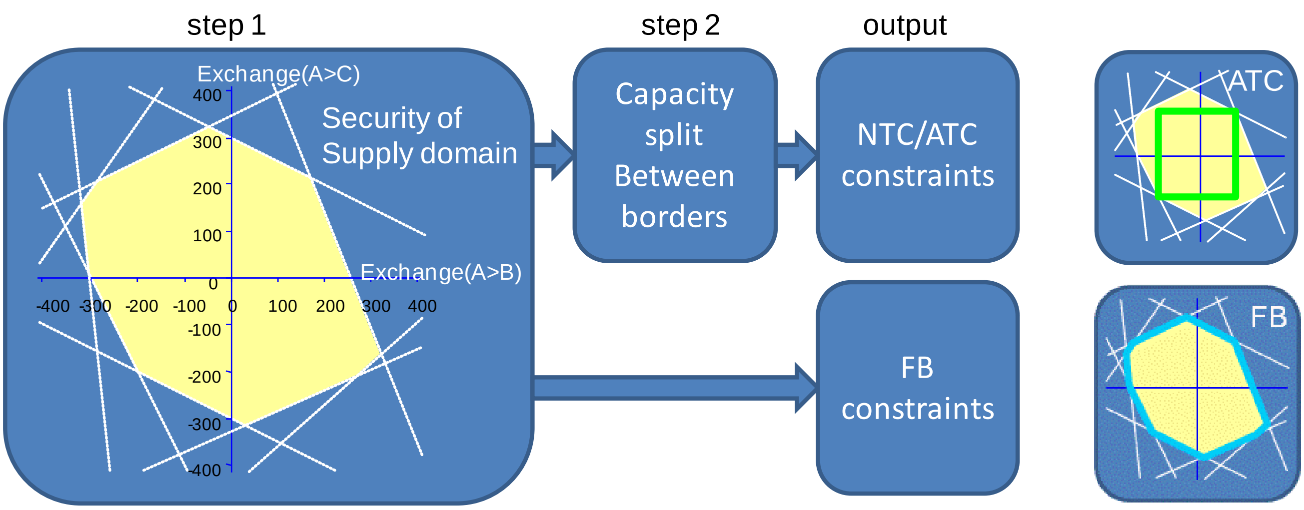


2.3 Increase of the capacity space offered to the market

In chapter 1.3, we have already seen that given the Security of Supply domain of the grid:

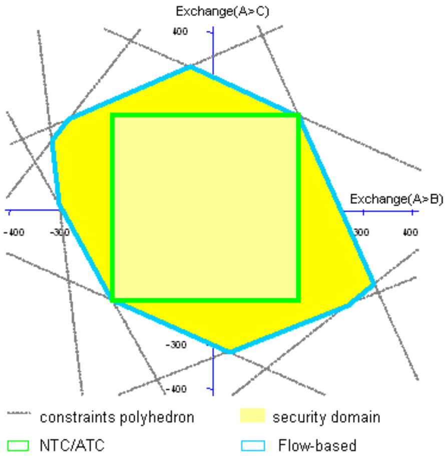
- The NTC/ATC constraints are a choice made by the TSO inside of this security domain: the TSO needs to make a choice on how to split the capacity among its borders
- The FB domain is the security domain itself; in FBMC the final capacity split between borders is not a choice of the TSO, but is market driven (at the time of market coupling allocation)

This is visualized in the figure hereunder.



Note 1: a pedagogical explanation about splitting the Security of Supply domain for ATC computation is done in section 5.1.

In theory, the FB domain includes the ATC domain by definition (thereby offering more trading opportunities) with the same level of security of supply as shown in the graph on the right (where the blue polygon is the FB domain and the green square the NTC domain).



As such, the FB mechanism will offer more trading opportunities to the market, which is indeed confirmed during the FB experimentation (see section 2.3.3).

Note 2: if the TSOs provide a FB domain that contains the ATC domain, flow-based market coupling leads automatically to a solution equal or better in terms of social welfare than the results of the ATC market coupling algorithm[6].

During the FB experimentation, TSO grid engineers used the same remedial actions in both the operational CWE coordinated NTC/ATC methodology and the CWE experimental FB methodology (the same local capacity calculation procedure and risk policy are considered and applied since this is the only way to ensure a 'fair' comparison between FB and ATC):

- Preventive and curative[7] topological measures,
- Preventive and curative phase-shifting transformer (PST) application,
- Curative redispatching
- No preventive redispatching
- No preventive countertrading

2.3.1 Indicators definition to compare FB vs. ATC domains

TSOs provide to the market coupling system the grid constraints, in which the market can take its positions, either as ATC or FB constraints. In mathematical terms, the TSOs provide a search space reflecting the grid's operational limits to the market coupling system.

The purpose of this section is to present indicators that allow to quantify a search space (also called domain in this document) and facilitate a comparison between the ATC search space and the FB search space, without the need for market data.

Each indicator has a specific purpose as indicated below:

Id	Designation	Purpose
Indicator 1	ATC corners within the FB search space?	To ensure that remedial actions applied in the NTC operational capacity calculation are also taken into account in the FB experimentation.
Indicator 2	Volume of both the ATC and FB search space	To quantify the "size" of the full FB and ATC domains
Indicator 3	Max. "Net Positions" & "Bilateral Exchanges between Hubs" within the search space	To give market players an alternative grip on the FB domain and to provide a measure per direction on the gain of using FB methodology in terms of capacity space given to the market when compared to ATC

2.3.1.1 Indicator 1: Are the ATC corners within the FB search space?

Reminder of ATC corners concept

---

[6] Market Coupling is a constrained optimization procedure:
- Objective function: Maximize social welfare
- Control variables: Net Positions
- Subject to:
  - Σ net positions = 0
  - Grid constraints: the market can establish exchanges between zones within the security constraints of the grid, either defined by:
    - ✓ ATC constraints
    - ✓ FB constraints

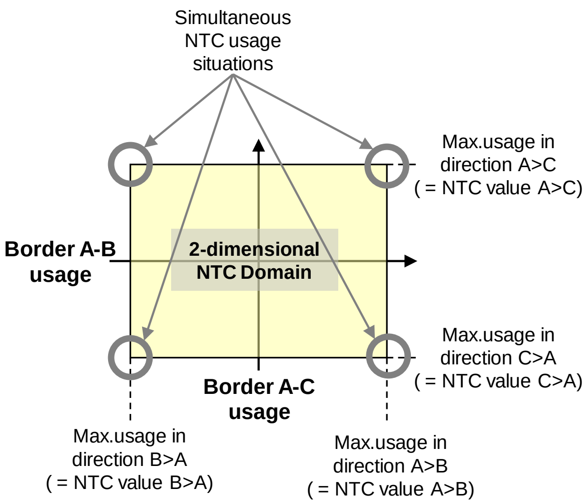
[7] A remedial action is said to be curative if it is applied after a fault. A remedial action is said to be preventive, if it is applied in anticipation of a fault or for N constraints. A TSO can consider curative remedial actions since lines can be overloaded for a short period of time. For a more precise definition, see ENTSO-e RGCE (former UCTE) handbook policy 3, chapter A4.

In case of 3 bidding areas having two electrical borders, the NTC domain is a 2-dimensional space, and there are four possible simultaneous NTC usage situations, as represented in the figure on the right.

The possible combinations of simultaneous NTC usage in both directions on the CWE borders will thus be represented by quadruplets (being {FR-DE usage, FR-BE usage, BE-NL usage, NL-DE usage}), each term of which has two possible values: an NTC value for direction A>B, and an NTC value for direction B>A. Therefore, there are 16 different quadruplets per hour, referred to as being the 16 corners. The 16 corners are illustrated later in this section.

Each corner is thus represented by 4 commercial exchanges, and thus 4 net positions[8].

The check whether the ATC corners are included within the FB search space can be performed as follows. The flow on each CB, for each corner of the ATC domain, can be computed by multiplying the corresponding net positions of the ATC corner with the PTDF matrix:



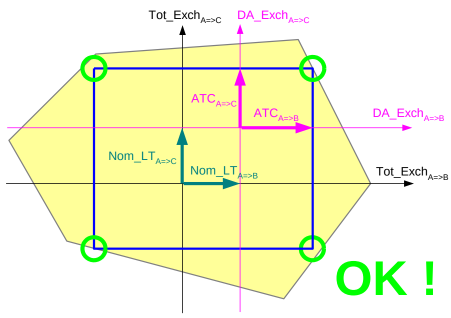
$$\text{PTDF} \quad \text{Net Position} = \text{Flow}$$

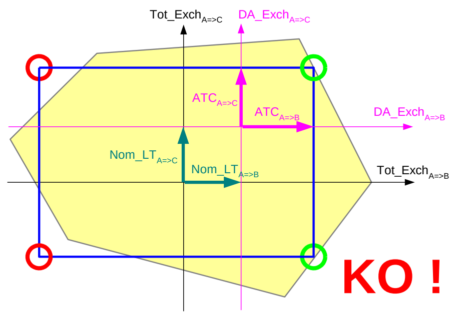
If for a corner, the calculated flows on each critical branch are smaller than or equal to the RAM (Remaining Available Margin), the corner is within the FB search space.

Note 1: this exercise should be repeated for all 16 corners.

Note 2: this check can be done either with ATC or with NTC values. The latter option enables one to perform the check in D-2, while the check with ATC values requires the LT Nominations to be available (i.e. on D-1).

In the graph on the left-hand side, the corners of the NTC domain (marked with the green circles) are included in the FB domain (yellow). In the graph on the right-hand side, the two of the corners of the NTC domain are outside the FB domain (marked with the red circles).





In addition to this check, for each corner, the distance (in terms of MW margin) between the ATC corner and the FB constraints is computed by subtracting the calculated flows (as they are computed by means of the PTDF factors) from the RAM (under FB). In case an ATC corner is not included in the FB search space, this distance quantifies the depth of the overload.

- If the Distance > 0, the ATC corner is included in the FB search space and distance = margin left
- If the Distance < 0, the ATC corner is not included in the FB search space and distance = overload depth

Example:

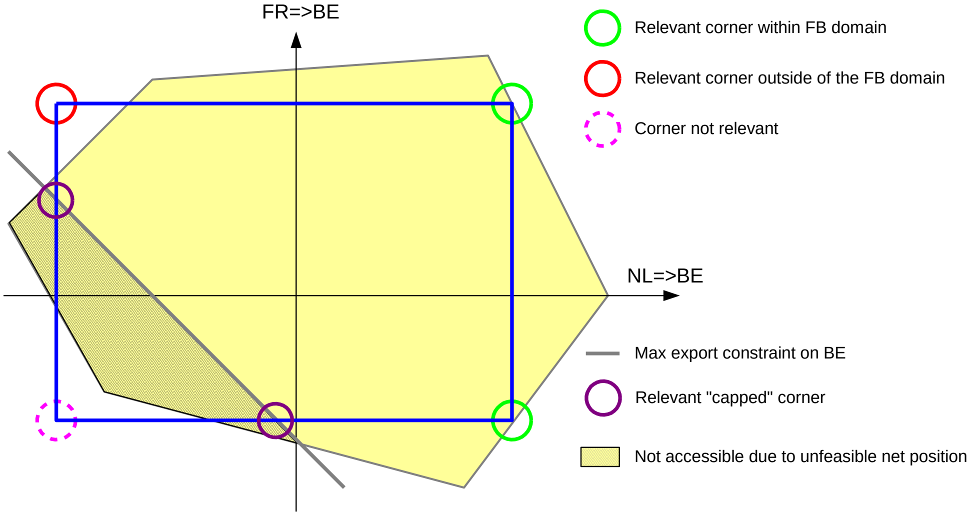
			Distance per critical branch and corner (in MW)															
Timestamp	**Outage Name**	**Branch Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
YYYY_MM_DD_HH	**Outage 1**	**Branch 1**	1955	2312	1323	1584	581	211	-50	938	1942	952	1680	-420	568	306	1310	-63

As a refinement to this indicator, this inclusion check is not applied for the corners that are not verified during the operational NTC verification, since they are judged by the TSO to be:

- **Impossible corners** because of maximum generation limits inside a bidding area. It is useless to compare areas of FB/ATC domains that are not feasible. Example: double NTC export in NL (NL>DE + NL>BE) or double NTC export in BE (BE>FR and BE>NL) are much bigger than the available generation capacity in those countries. The TSO can introduce this net position limit of a bidding area, which leads to a 'capping' of the ATC domain. The resulting "capped ATC domain" is more appropriate for a comparison

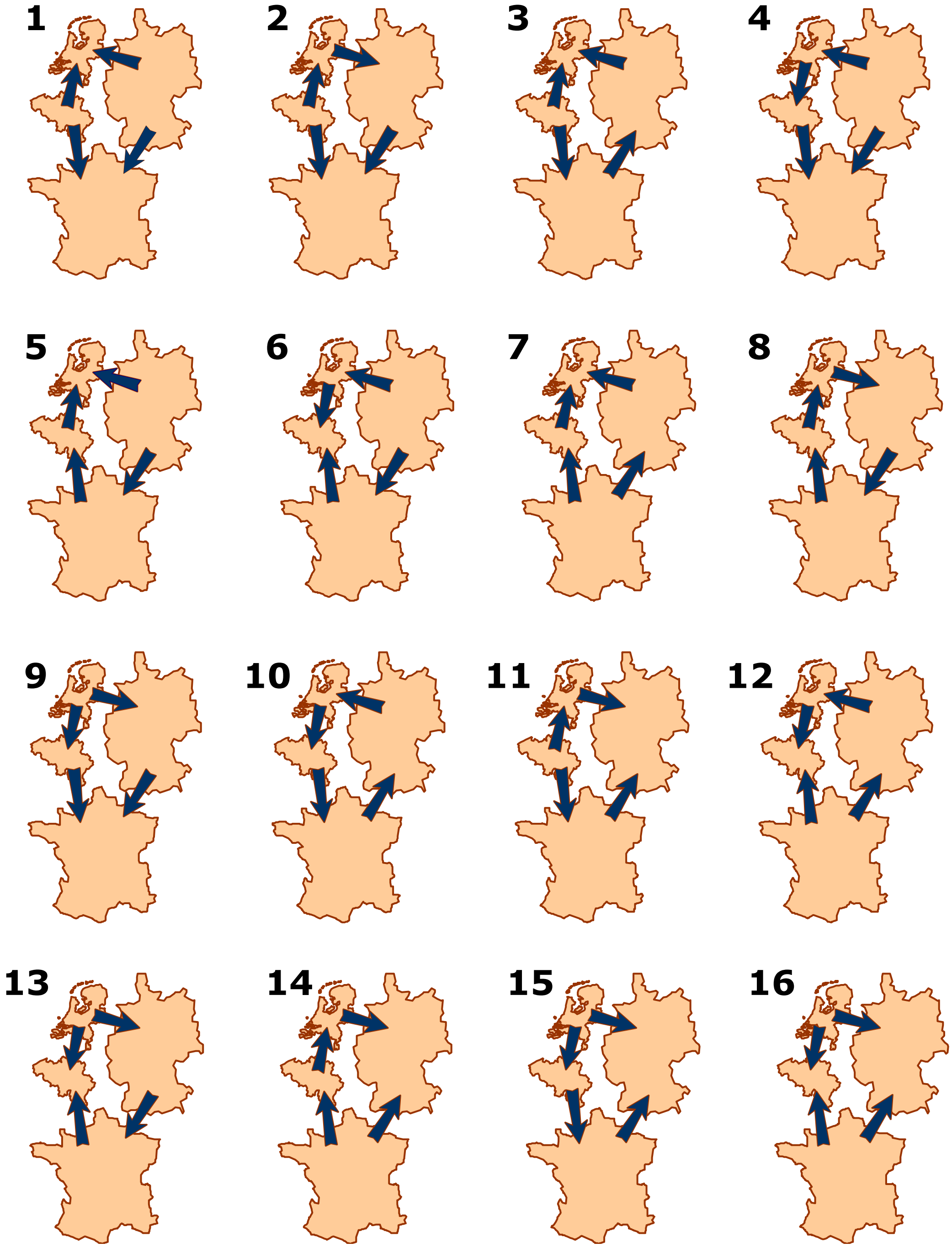
[8] For one bidding area, the net position is the sum of the commercial exchanges with this bidding area.

with the FB domain as illustrated in the figure hereunder (the ATC domain is the blue rectangle, the FB domain is the yellow polygon).



- **Unlikely corners** because of recent tendencies of CWE exchanges and/or historical data of corners appearance.
  In order to maximize today's NTC, TSOs deliberately assume that some market directions are unlikely to happen for the day ahead. TSOs are aware that the security may not be fulfilled in those unlikely directions. If TSOs would not apply this practice, today's NTCs would be much lower, since it would always be like a worst-case scenario. This is one of the main flaws of NTC; as such we can clearly state that FB improves the security of supply. This point is detailed in section 2.4.

In the graphs below an overview is given of the 16 corners that have been defined for CWE:

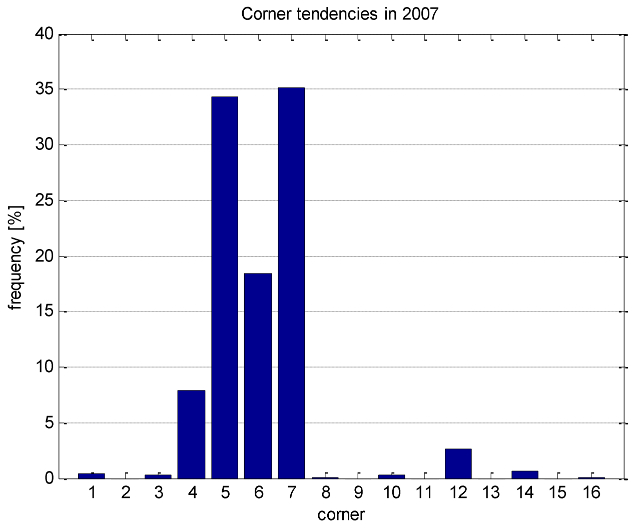


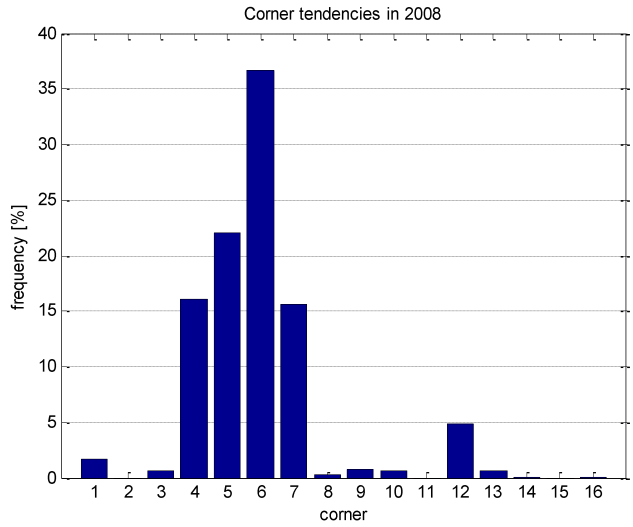
Based on the concept of the CWE corners, we can introduce the notion of corner tendency for a set of netted CWE bilateral exchanges: a set of CWE bilateral exchanges is considered as having a "corner #n tendency", if the bilateral exchanges have the same direction as the NTCs of corner #n.

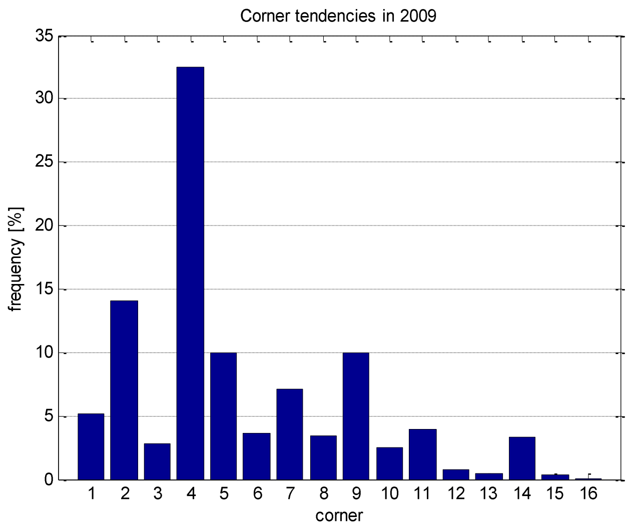
Example: corner 7 is [FR=>BE, FR=>DE, BE=>NL, DE=>NL], hence the following set has a "corner 7 tendency"

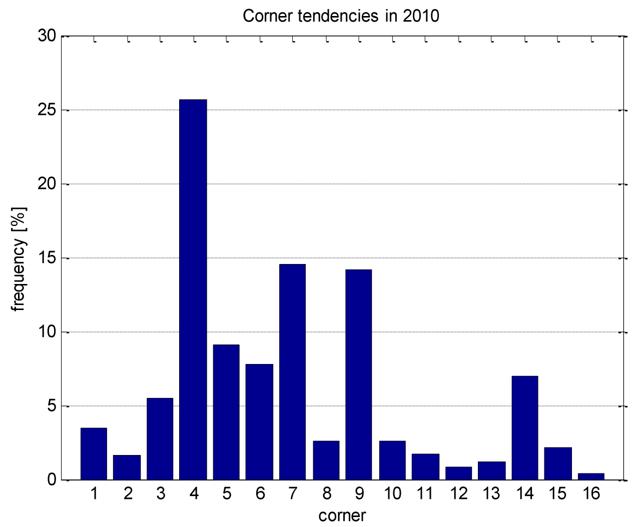
- FR=>BE = 500 MW
- FR=>DE = 1000 MW
- BE=>NL = 850 MW
- DE=>NL = 1150 MW

The following diagrams illustrate the corner tendencies (see also note 2, hereunder) as observed from the historical realized exchange programs in the last four years:









Note 1: the corner tendency will be monitored during the "parallel run" with respect to ATCMC market results, and the list of corners that are flagged to be unlikely by a TSO will be updated, if needed.

Note 2: A corner may be labelled unrealistic, while exchanges do happen in the same direction of the corner, as these exchanges do not necessarily reach the full exchange of the corner itself.

2.3.1.2 Indicator 2: Volume of both the ATC and FB search space

Both the FB constraints and the ATC constraints define a search space for the net positions to be determined within the market coupling. For the CWE MC this is a 3-dimensional search space[9] of which a volume can be computed (in MW^3).

Note: comparing two search spaces by their volumes implies that all parts of a given search space are equivalent in terms of market value, which is obviously not the case since market players favour some market directions over others.

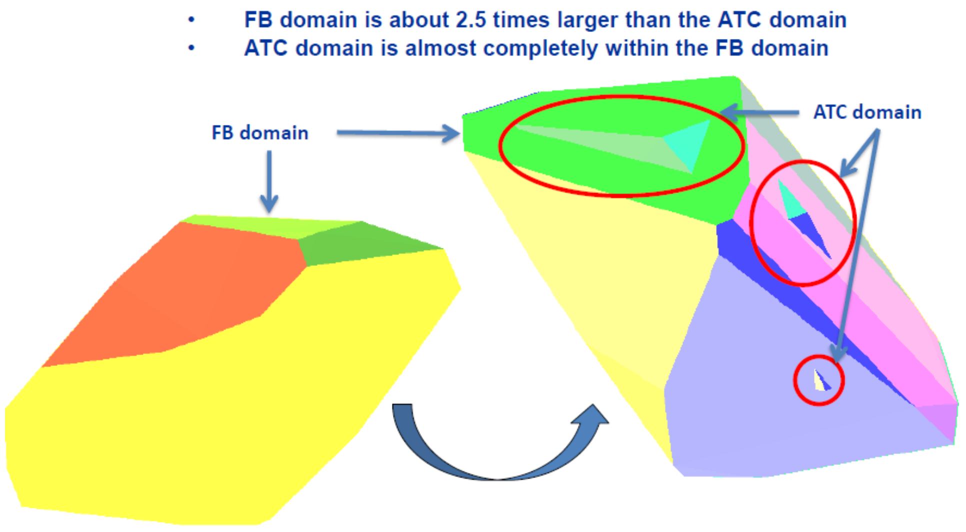
Example: *Timestamp 2/3/2010 10h30 of the FB experimentation. The three-dimensional bodies of both the ATC and FB search space for this timestamp are depicted in one graph. The volumes of both the ATC and FB search space are computed, as well as the volume of the intersection of the two; if the latter figure equals the volume of the ATC domain, this indicates that the ATC domain is fully included in the FB one.*

---

[9] Because the sum of the 4 CWE net positions equals zero, one net position can be written as a combination of the three remaining ones:

$$NE_{BE} + NE_{DE} + NE_{FR} + NE_{NL} = 0 \quad \rightarrow \quad NE_{FR} = -NE_{BE} - NE_{DE} - NE_{NL}$$

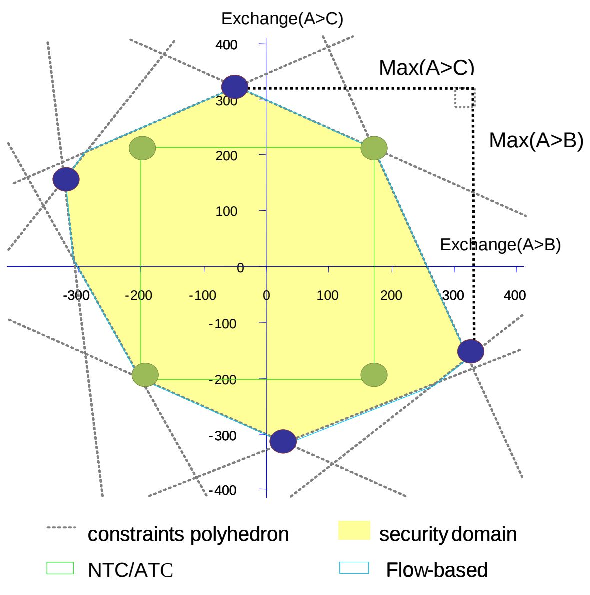
This property makes that the search space can be visualized as a three-dimensional body, of which the volume can be determined.



2.3.1.3 Indicator 3: Max. "Hub Net Positions" & "Bilateral Exchanges between hubs" within the search space

Other figures providing insight on the search space are the **maximum net positions** (import and export) and the **maximum bilateral exchanges between hubs**[10] that are feasible within the search space.

As can be seen from the figure hereunder, the NTC/ATC method (green dots) and the FB method (blue dots) will show different values for the maximum net positions / bilateral exchanges between hubs that are feasible:



Note 1: Maximum bilateral exchanges between hubs that are feasible in the FB domain are non-simultaneous values. This can be easily seen from the figure above: the maximum bilateral exchange from A to C (the value Max(A>C): the value on the y-axis indicated by the blue dot on top of the graph) cannot occur at the same time as a maximum bilateral exchange from A to B (the value Max(A>B): the value on the x-axis indicated by the blue dot on the right of the graph), as the combination of those values (the dashed square) is outside the security domain.

Note 2: NTCs/ATCs are by definition simultaneous values that limit the bilateral exchanges between bidding areas. This can also be seen from the figure above: the upper right corner of the ATC domain (marked by a green dot) is the

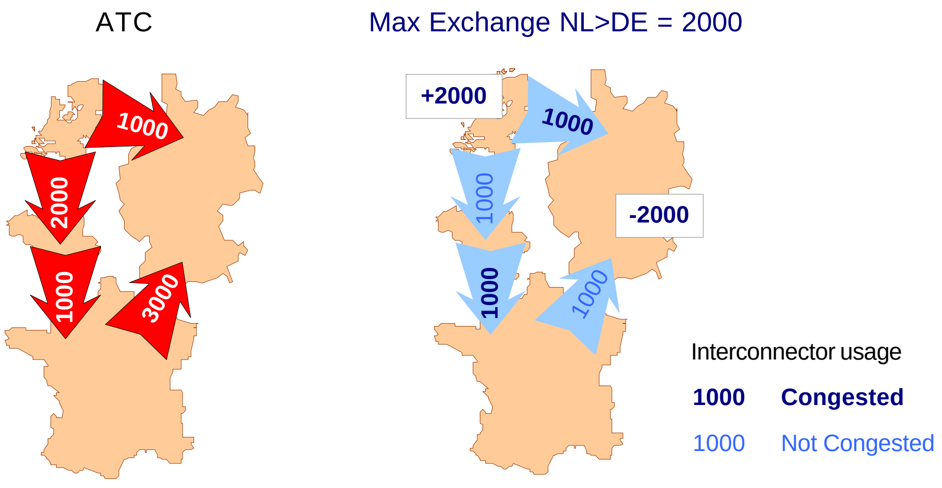
[10] The maximum bilateral exchange between hubs is determined between two hubs that do not need to share an electrical border; the net positions of the two remaining hubs are zero.

corner where simultaneously the maximum bilateral exchange from A to C and the maximum bilateral exchange from A to B are feasible (in the ATC domain).

Note 3: maximum bilateral exchanges under ATC do not equal the ATC values themselves, due to the fact that there exists generally more than one contract path between two market areas, and the ATCMC algorithm will naturally make use of all possible paths to maximise the market value.

***Example**: maximal bilateral exchange from the Netherlands to Germany*

- *Commercial* trade from NL to DE will use NL>DE, but also NL>BE + BE>FR + FR>DE
- Hence, the maximum bilateral exchange NL>DE is $ATC_{NL>DE}$ + min($ATC_{NL>BE}$, $ATC_{BE>FR}$, $ATC_{FR>DE}$)

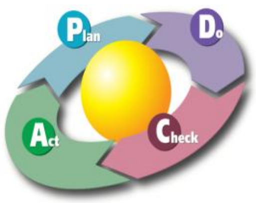


***Example indicator values**: Timestamp 22/11/2010 3h30 of FB experimentation*

		FB		ATC	
		max	min	max	min
Maximum Bilateral exchanges source to sink	BE>FR	3618	4626	2575	4527
	BE>NL	5043	4626	2575	3647
	DE>FR	9840	5713	3420	4555
	DE>NL	5931	6249	3696	3777
Maximum Net Positions	BE	5698	-4626	2575	-4527
	DE	11911	-10653	4541	-5757
	FR	9225	-10269	6280	-3420
	NL	8419	-7996	4004	-3696

2.3.2 2010 Enhanced FB experimentation cycles

The FB experimentation was performed during the year 2010, in the form of one year "PDCA" (Plan ➔ Do ➔ Check ➔ Act) cycles on a monthly basis.



P	Adapt method to take into account validated improvements from previous cycle
D	Run FB MC precoupling business process
C	Compare the FB vs ATC results of the same days
A	Analyze results and propose improvements for the next cycle to approach target

Cycle	Business Dates		Initial FB parameters	Qualified FB parameters	Remarks
	From	To			
CWE enhanced FB learning process (prior to ATC MC)					
1	16/11/09	20/11/09	3h30 & 10h30 TS		
2	4/1/10	8/1/10	3h30 & 10h30 TS	3h30 & 10h30 TS	Introduction of FB qualification process & impossible corners concept
3	1/2/10	5/2/10	3h30 & 10h30 TS	3h30 & 10h30 TS	Introduction of unlikely corners concept
4	1/3/10	7/3/10	3h30 & 10h30 TS	3h30 & 10h30 TS	First trial on FB verification process (for previous cycle timestamp). FB space verification on 1/2 at 10h30
5	29/3/10	4/4/10	3h30 & 10h30 TS	3h30 & 10h30 TS	Introduction of the possibilityof impacting remedial action on PTDF FB space verification on 3/3 at 10h30
6	28/4/10	2/5/10	24 TS /day	3h30 & 10h30 TS	Go-live of centralized FB prototype Introuction of 24 TS / day D2CF merge FB space verification on 29/3 at 10h30
7	23/5/10	29/5/10	24 TS /day	3h30 & 10h30 TS	FB space verification on 27/5 at 10h30
8	30/6/10	6/7/10	24 TS /day	3h30 & 10h30 TS	FB space verification on 1/7 at 10h30
9	16/9/10	16/9/10	24 TS /day		Only initial FB parameters computation (FB qualification not executed because of ressources problems)
10	20/10/10	26/10/10	24 TS /day	3h30 & 10h30 TS	Stabilization cycle
CWE enhanced FB data for FB MC impact analyse study (after ATC MC)					
11	22/11/10	5/12/10	24 TS /day	24 TS /day	
12	4/1/11	17/1/11	24 TS /day	24 TS /day	

These cycles have been executed in ex-post mode (delay of about 3 weeks regarding the business dates), by TSO key users (FB experts and grid experts aware of the current operational process and situation of the grid), and grant the feasibility of the operational process.

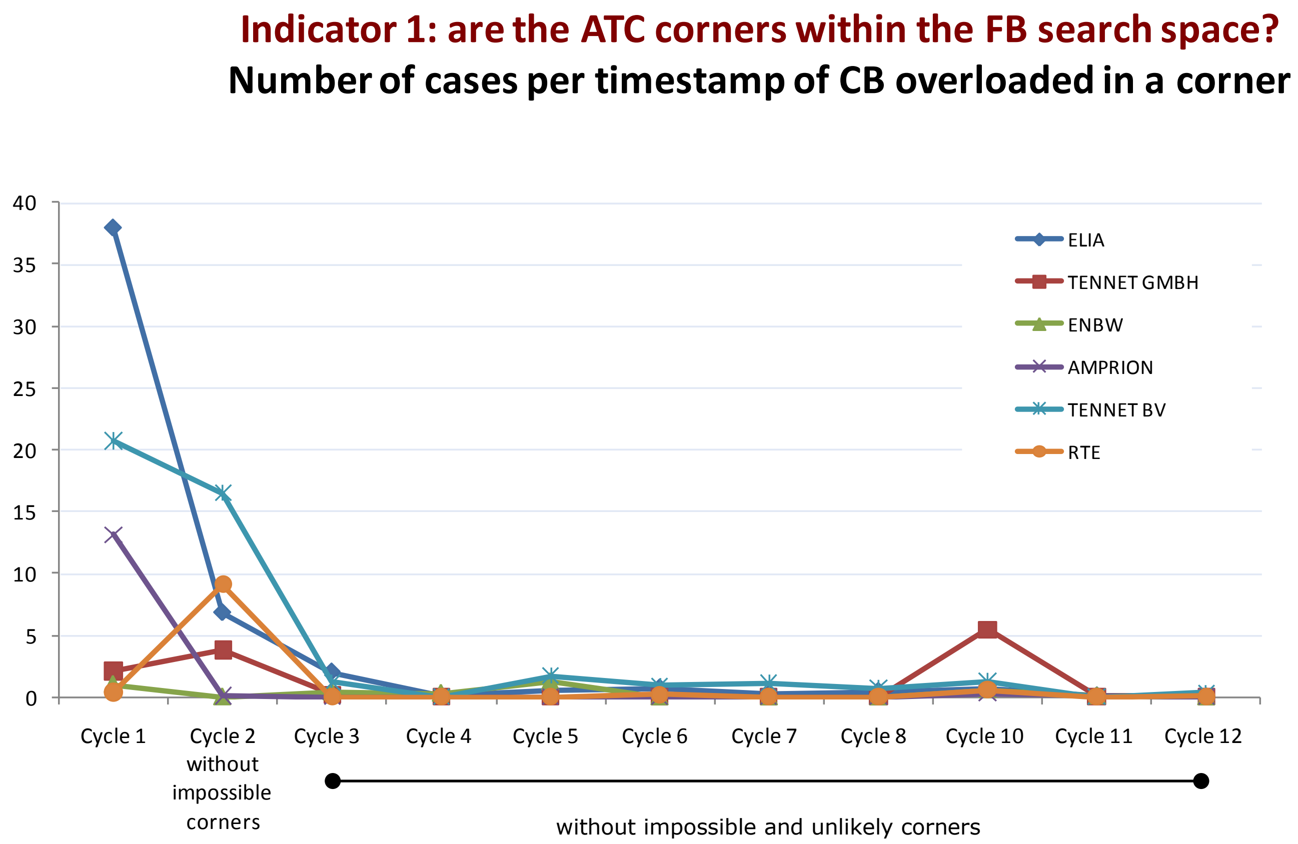
The methodological improvements leading to the proposed CWE enhanced FB were validated during the monthly meetings of the FB WG.

During the FB experimentation, CWE TSOs have been able to identify possible improvements concerning capacity calculation in general. One of those concerning the intraday capacity calculation as presented in section 2.6.2, the other improvements are not the real core of this report but are highlighted in section 5.6.

2.3.3 Experimentation results

From December 2009 to October 2010, 10 monthly cycles have been performed by the FB WG. Keep in mind that the TSO grid engineers, in order to produce these data, used the same local capacity calculation procedures and risk policy, and thus the same remedial actions, in both the operational ATC process and the experimental FB process. This is the only way to ensure a real comparison between FB and ATC.

The following figures show the results of the three indicators presented in the previous sections. It is worth noticing that a clear learning effect can be observed from the graphs; the hands-on experience and refinement as obtained by the application of the PDCA cycles.



The figure above shows that after the application of the 2010 CWE Enhanced FB methodology improvements in the first 2 cycles, the FB domain is not overloaded anymore for the relevant NTC corners; i.e. the relevant NTC corners are inside the FB domain.

Note 1: the timestamps considered for the graphics are 3h30 and 10h30, since these are the two D2CF timestamps available for the NTC process.

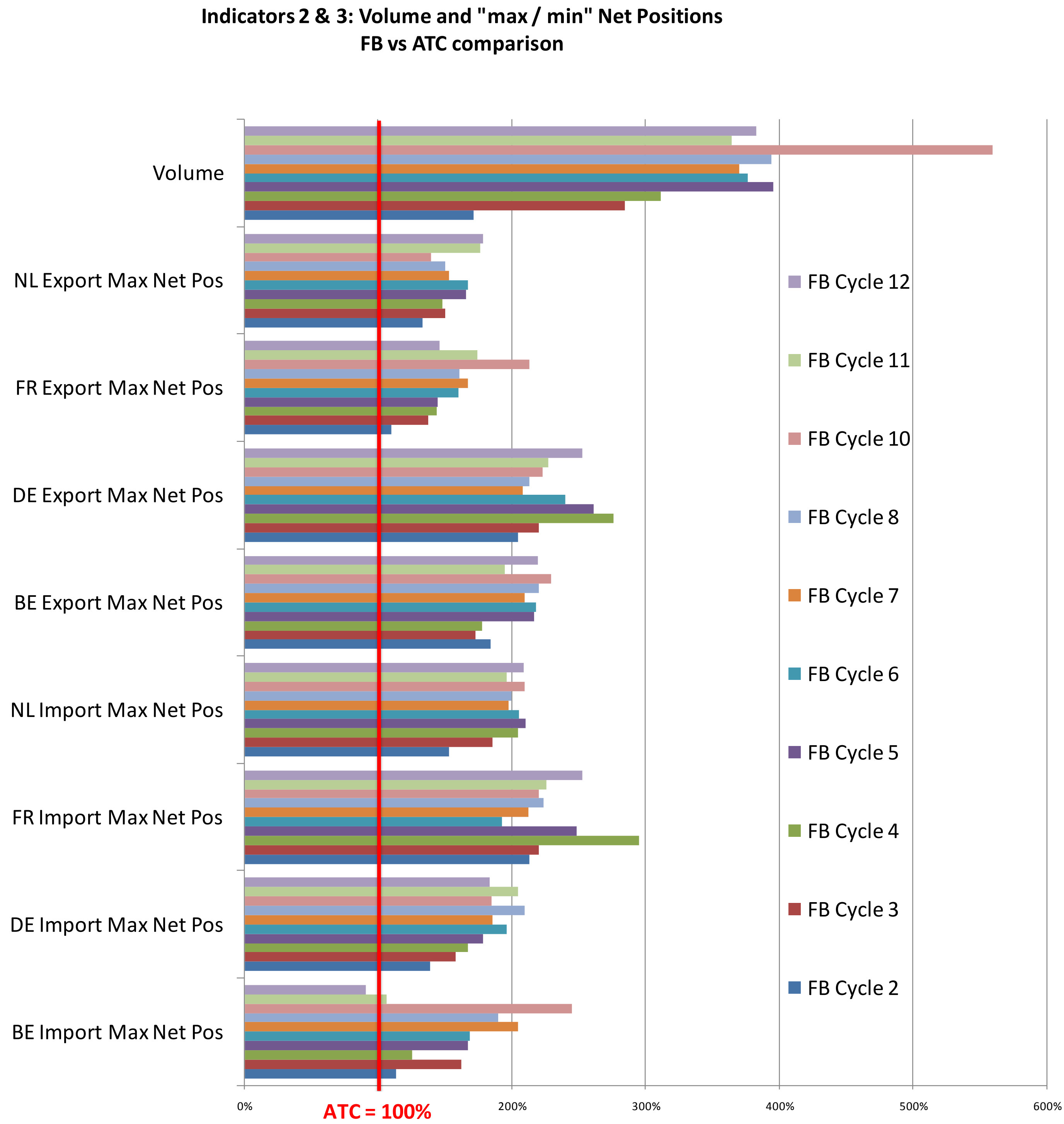
Note 2: Cycle 9 is not included in the graph as only the initial FB parameter calculation was performed (see also the overview table of the cycles in section 2.3.2)

Note 3: In cycle 10, TenneT GmbH had some ATC corners that were outside the FB search space. These overloads of CBs were observed during the NTC verification of these days as well, but the TenneT GmbH grid expert decided not to trigger an NTC curtailment because of non-realistic flows in the D2CF basecase, which caused these overloads. Since it was not possible to correct the D2CF basecase, it clearly underlined the need for fallback procedures that are to be developed during 2011 in order to handle with those kind of exceptions. Furthermore, this was the trigger for the FB WG to analyze the possibilities to monitor and improve the quality of the current CWE D2CF basecase in the future.

Note 4: for the indicators 2 & 3 the concepts of impossible and unlikely corners were not used. The volume and Net Position values compare the full NTC search space with the full FB one.

Note 5: from November 2010 up to and including January 2011, the produced FB parameters will be used for the "Price/Market impact analysis" performed jointly by PXs/TSOs that is presented in chapter 3.

The figure below confirms that FB offers more trading opportunities than the ATC for all market directions of the same days with at least the same level of security of supply.



Note 6: starting with cycle 11, an ELIA stability import limit of 4500 MW (see section 2.2.4) was taken into account in the FB method. This limit applies to the NTC computation as well.

2.4 Improvement of the security of supply and cooperation between TSO

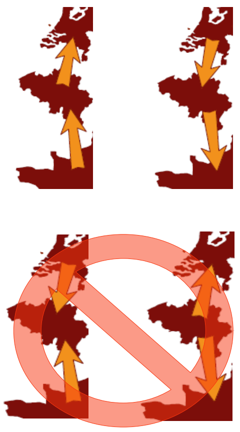
CWE enhanced FB improves the ATC methodology as FB improves the cooperation between TSOs, which allows an increase in coordination between TSOs

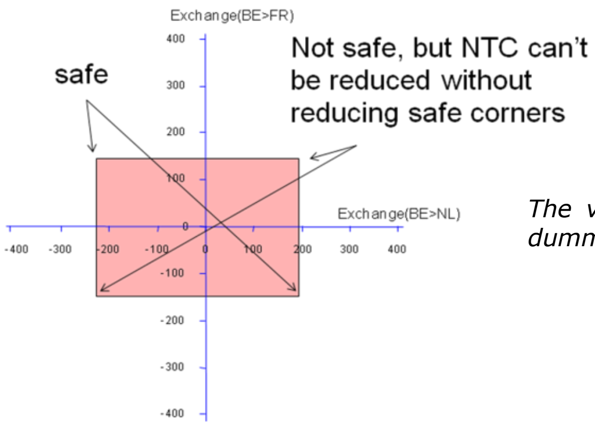
The FB description is closer to the reality of the grid, which induces a natural need for increased cooperation and information exchange between the CWE TSOs in the FB operational process. Furthermore an increase in the level of coordination between the TSOs is facilitated. This is in contrast to the opacity and lack of physical meaning of the NTC values.

Under FB, interdependency of the cross-border exchanges is reflected from the beginning of the process for all the directions of the capacity space. This is in contrast to the current coordinated NTC process where the first step (initial local TSO computation) is not coordinated.

Flow-based gives a more accurate description of the Security of Supply domain. In section 2.3 it is explained that for a given level of SoS the FB domain is larger than the ATC one from the theoretical point of view. However, in order to maximize today's NTCs, TSOs deliberately assume that some market directions are unlikely to happen for the day ahead. They are called unlikely corners and these NTC corners are sometimes outside of the Security of Supply domain and therefore also outside of the FB domain.
If TSOs would not apply this practice, today's capacities would be much lower as indicated in the example below, since the NTC value for a given direction is by definition the same for different NTC corners. This is one of the main flaws of NTC.

Belgium example: *The dominant market patterns for Belgium are South>North or North>South. Therefore Elia maximises its NTCs for these patterns. South>North yields NTC(FR>BE) and NTC(BE>NL), while North>South yields NTC(NL>BE) and NTC(BE>FR). But then the sum of import NTC [resp. export NTC] turns out to be higher than the maximum admissible import [resp. maximum admissible export] of Belgium. Elia cannot provide both maximum capacities to the market for being transited South>North or North>South, and safe import or export limits at the same time. This is an inherent limitation of the NTC methodology.*





The values on the axes are dummy figures only

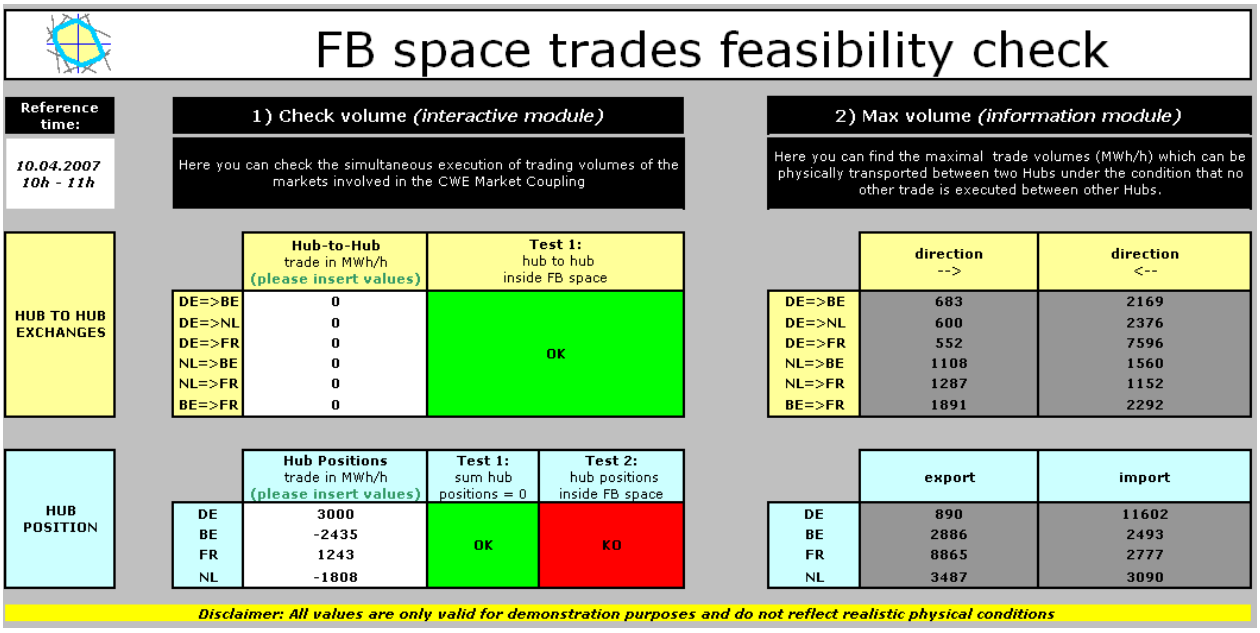
Elia chooses to provide maximum capacities to the market, but if one day the market behaves differently than foreseen, and reaches one of the unlikely corners, Elia will have to use exceptional D-1 and real-time measures to guarantee grid security. FB simply removes this issue.

2.5 FB addresses transparency requirements and concerns on market players understanding

The FB domain, i.e. the non-redundant (presolved) FB parameters consisting of PTDF factors and margins associated to the critical branches, will be communicated to the market before allocation. This could be presented as in the following example:

Critical branch		*FB parameters*				
		Margin	*PTDF*			
Outage Id	Branch Id	Margin	BE-hub	DE-hub	FR-hub	NL-hub
outage3	Branch3	976.8	0.0719	-0.1480	-0.1823	-0.1252
outage4	Branch4	1277.4	0.0364	0.3740	0.2160	0.4641
outage9	Branch9	1125.3	0.0023	0.1655	0.0882	-0.0044
outage10	Branch10	1436.6	0.0509	-0.1880	-0.0755	-0.2568
outage12	Branch12	1113.7	0.0008	0.0840	0.0338	-0.1262
outage13	Branch13	1067.6	0.0005	0.0624	0.0230	-0.1345
outage14	Branch14	1026.5	-0.0005	-0.0672	-0.0223	0.1615

Additional figures, that are/can be obtained from the FB domain, can be supplied to the market in order to provide more grip on the FB domain. The indicators mentioned in section 2.3.1.3, i.e. the maximum net positions (import and export) and the maximum bilateral exchanges between hubs that are feasible within the search space, are examples of additional figures that could provide valuable insight into the FB search space. As the maximum bilateral exchanges between hubs and/or the maximum net positions feasible in the FB domain are non-simultaneous values (see also section 2.3.1.3), a tool for checking on the simultaneous feasibility of certain values can also be supplied to market parties:



As the flow-based constraints are real existing elements in the grid, the hot spots in the grid are clearly identified, allowing enhanced use and development planning of grid infrastructure. Even better, the shadow price[11] of the FB constraint in case of congestion indicates the loss of welfare due to the active constraint. In a way, the grid elements get a 'price tag' when they turn out to be limiting for the CWE market coupling.

FB is close to the physical reality of the grid, which induces a natural need for increased coordination and information exchange between the CWE TSOs in the FB operational process. This means that the transparency among TSOs is even stronger than before. The transparency of FB as a capacity calculation mechanism, despite the fact that it is a complex methodology, is unmatched as it is a truly coordinated capacity calculation mechanism.

2.6 Compatibility of FB implementation for CWE MC with the adjacent capacity calculation processes

2.6.1 Computing NTCs on non-CWE borders

Introducing FB capacity calculation on the CWE borders could have an impact on the computation of NTCs on other borders of the CWE TSOs. This paragraph aims at describing the way CWE TSOs intend to calculate their D-2 NTCs on other borders when FB in CWE will be in place.

2.6.1.1 RTE

FR-ES NTC will not be affected by FB in CWE, since Spain is an electric peninsula for the French network.

FR-UK NTC will still be the nominal value of IFA cable.

FR-IT NTC will still be computed yearly in the Technical Task Force (TTF) procedure between Terna (IT), Swissgrid (CH), APG (AT), Eles (SI) and RTE (FR).

FR>CH NTC will remain unchanged.

[11] The shadow price represents the marginal increase of the objective function in an optimization problem if the constraint is marginally relaxed. In other words: the shadow price is a good indication of the increase in social welfare that would be induced by an increase of capacity on the active network constraint. As a consequence, non-binding network constraints in the market coupling solution have a shadow price of zero, since an increase of capacity on those network elements would not change the optimal market coupling solution nor the flow on the network element concerned

CH>FR NTC will be the minimum value of the value submitted by Swissgrid and the value computed weekly by RTE (applying its current methodology for capacity splitting between borders: giving 1/3 of the available margin on each critical branch to BE, DE and CH[12])

2.6.1.2 ELIA

Belgium has no electrical borders outside CWE.

2.6.1.3 TENNET BV

The TenneT grid is connected to the U.K. and Norway with two DC cables. The capacity calculation of the BritNed and NorNed cable will remain unchanged with the introduction of flow-based market coupling. For both cables the nominal value will be used.

2.6.1.4 TENNET GMBH

For TenneT GmbH currently the NTC calculation of non-CWE borders is independent of the calculation of CWE NTCs. There seems no need to change this under FB.

2.6.1.5 ENBW & AMPRION

DE>CH: the calculation method of the NTC-Value DE>CH for the daily auction has to be readjusted with the introduction of the FB. Actually, the capacity is calculated by coordinating the so called "German C" (limiting the export from Germany to NL-FR-CH) and the "Swiss-Roof" (limiting the Swiss-import from FR-DE-AT). With the FBMC, the exports from Germany to Netherlands and France are limited by the FB constraints, so the C-Function in the current form has to be adapted. Therefore, a coordination of the value Germany-Switzerland has to be done bilaterally, with estimations for the values DE>FR and DE>NL as an input for the C-Function. The resulting value DE>CH after coordination (based on the minimum-rule) can be introduced afterwards into the FB-model.

CH>DE NTC will remain unchanged.

2.6.2 Compatibility of FB in D-1 with an intraday process using ATC

2.6.2.1 Target situation: FB intraday process with D-1 FBMC

CWE TSOs express their belief that FB is the best capacity calculation and allocation method for the CWE intraday process and fully support FB as an operational target.

Intraday FB capacity calculation after D-2 FB capacity calculation would consist in the following steps:

- Each TSO updates its D-2 CBs and GSK (and available remedial actions)
- ID FB parameters are computed based on DACF (and then updated on IDCF)
- FB parameters are verified and CBs updated if needed

Note: As a consequence of this statement, CWE TSOs will require from future NWE intraday processes, a full compliancy with the FB modelling (this will affect in particular the so-called capacity management module).

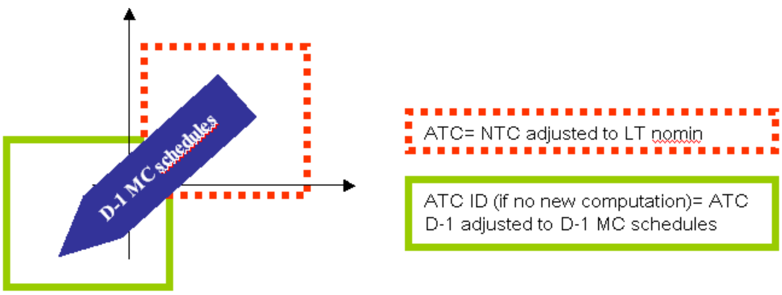
Anyhow, for pragmatic reasons, this ID FB implementation would be a second step, once FB has been implemented in D-1 together with ATC in intraday.

[12] http://clients.rte-france.com/htm/an/offre/telecharge/Capacity_Calculation_Methodology.pdf chapter 2.4

2.6.2.2 Current situation: ID ATC computation with ATCMC in D-1

Generally, ID ATC is currently computed as ID NTC – (LT Nomin + D-1 MC schedules). The current ID NTC/ATC computation leaves room to more coordination between the CWE TSOs, which is currently based on bilateral agreements:

- Most of the CWE TSOs have not implemented a local ID NTC computation, thus D-1 NTC/ATC is used.

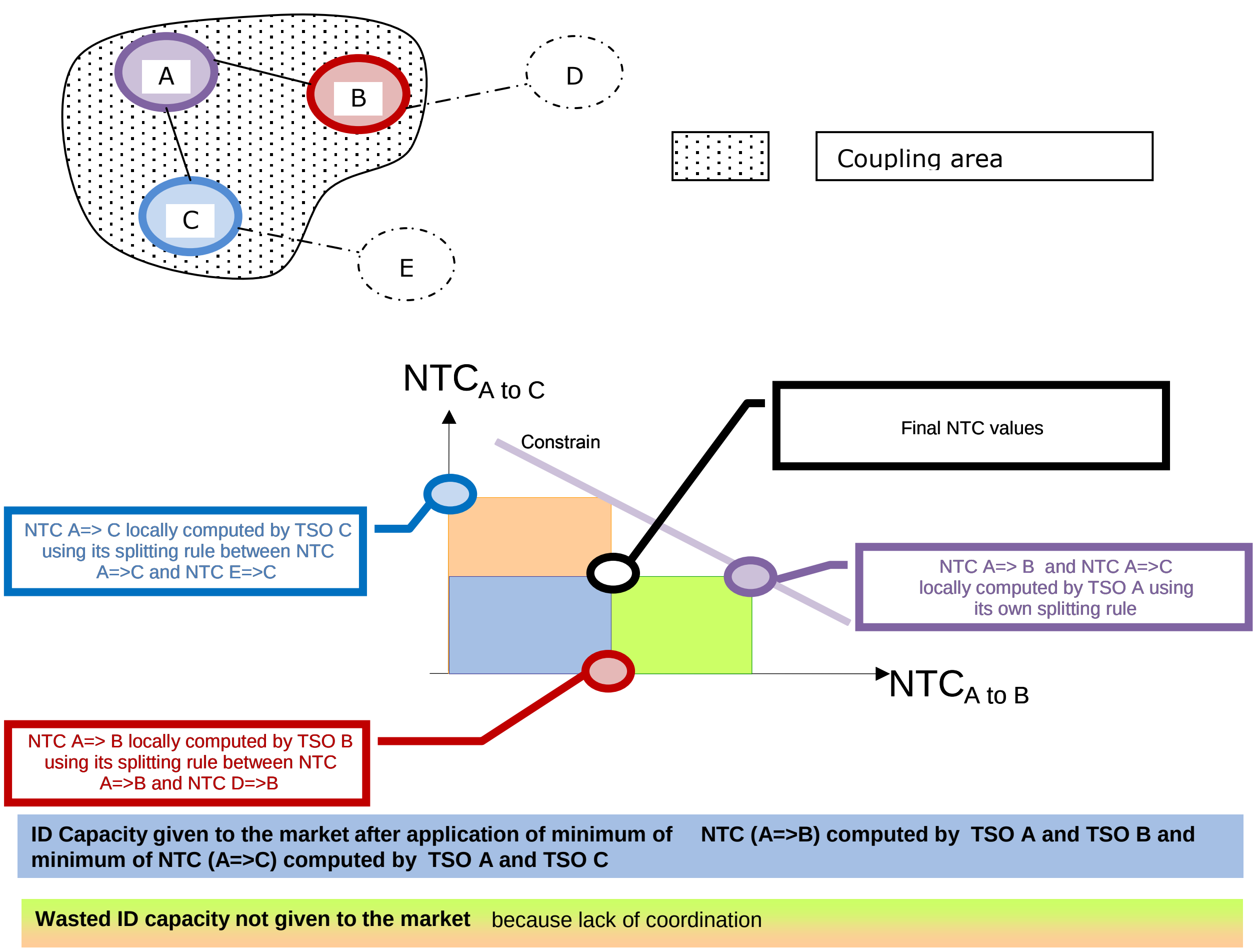


- The CWE TSOs that have implemented a local ID NTC computation have the opportunity to adjust bilaterally their D-1 NTC/ATC values.

This lack of coordination causes two main problems:

Problem 1: No optimisation of ID capacity values

Two neighbouring TSOs will apply different capacity splitting rules for their borders. Since the final ID NTC A>B is the minimum of the NTCs computed by TSO A and TSO B, some available capacity will probably be wasted. This is illustrated in the following figure



***Remark**: the coordinated NTC D-1 for the ATCMC is also not optimised: instead of coordinated splitting, the starting point of the process is the minimum value of locally-computed NTCs by two neighbouring*

TSOs (with their local splitting choice) which can only be decreased during the coordinated process (verification and adjustment). The unused D-1 capacity may be used in ID.

Problem 2: D-1 Security of Supply level decreases with ID capacity calculation

When two neighbouring CWE TSOs increase bilaterally the ID NTC of their common border, they use the last information available and may provide higher ID NTC to market. However this is not done in a coordinated way with the other CWE TSOs. Thus the SoS level granted in D-1, as a result of the coordinated NTC verification process, may be lost due to the ID NTC computation.

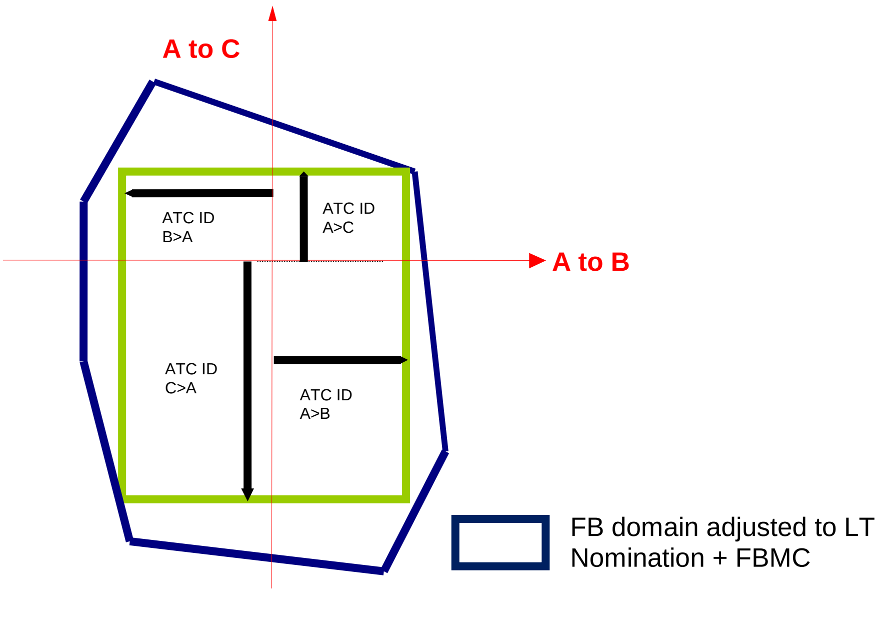
2.6.2.3 Interim situation: ID ATC computation with FBMC in D-1

Preliminary remarks:

- As long as FB is not implemented in intraday, FB for D-1 must be compatible with the current intraday ATC usage for allocation.
- TSOs must always have the possibility to reduce ID ATC in case of SoS issues.
- If two different ATC values on the same border are submitted by the two neighbouring TSOs, the minimum value will prevail.

2.6.2.3.1 Calculation of ID ATC after FBMC is feasible

Whatever the clearing point of the FBMC, CWE TSOs will always be able to find 8 non-negative ATCs respecting the security: this will be achieved by finding one ATC domain included inside the FB domain adjusted to the LT nominations and the FBMC clearing point.



Note: After switching to FB in D-1, ID ATCs are computed and not ID NTCs as explained in section 5.9.

2.6.2.3.2 How to improve ID capacity computation, when FBMC will be launched:

If no corrective actions are applied, the current two ID capacity problems described above with ATCMC, will still remain after switching to FBMC. Therefore, the FB implementation in D-1 is a good opportunity to improve the current ID capacity computation process.

Problem 1: No optimisation of ID capacity values

Solution: Coordinated splitting of ID ATC capacities

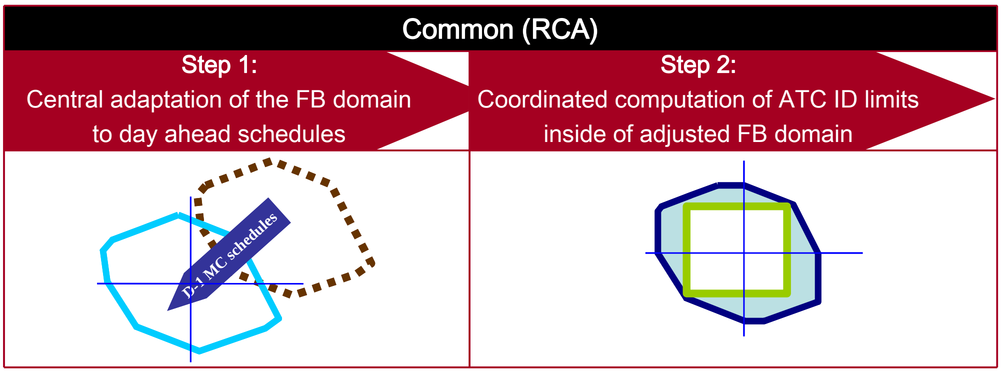
The coordinated ID ATC calculation process computes the 8 CWE ID ATCs directly from the adapted FB domain:

Step 1: Central adaptation of the FB domain to the day-ahead schedules

Input data: FBMC Net Positions + FB parameters adjusted to the LT nominations

Note: *an adjustment module exists already in the FB Common System for the FB LT adjustment process, and can easily be used for adaptation to the day-ahead schedules as well*

Step 2: Coordinated computation of ATC ID limits within the adjusted FB domain



Different ID capacity computation algorithms[13] have been proposed and developed during the FB experimentation to prove the feasibility of the coordinated splitting approach. Other/additional algorithms can be developed in the future.

Remark*: the final algorithm choice will be done during the FB implementation phase. TSOs acknowledge that, since there is no ID capacity pricing at the moment, the splitting principle will not be a very sensitive issue.*

Problem 2: D-1 Security of Supply level decreases with ID capacity calculation

When two neighbouring CWE TSOs increase bilaterally the ID NTC of their common border, this is not done in a coordinated way with the other CWE TSOs. Thus the SoS level granted in D-1, as a result of the coordinated day-ahead approach, may be lost due to the ID NTC computation.

Important remark: the solution proposed below can be also be applied today (under ATCMC) to ID capacity computation in order to improve the regional SoS.

Solution 1: *Forbid further bilateral capacity increase after a coordinated ID ATC splitting*

Solution 2: *Allow bilaterally ID ATC increase after a coordinated ID ATC splitting but granting SoS through:*

- ***local ID capacity computation with merged DACF/IDCF files***

[13] Algorithm 1: starting from 0, it increases the 8 CWE ATCs by 1 MW each, until it reaches a FB constraint. Then it keeps on increasing the ATCs that are not blocked by this constraint. Etc.
Algorithm 2: sharing physical margins between the (4) borders that are positively influenced with equal shares (i.e. ¼ in our case). Divide each share by the PTDF. The ATC is then the minimum value obtained over all CBs. Iterate until the ATC cannot be increased anymore.

and/or

⇨ ***ID ATC verification process with merged DACF files***

By combining the solutions described above, we identify 5 possibilities for the ID ATC calculation process after FBMC go-live.

Remark: the description covers only the first step of the ID capacity calculation in D-1; afterwards, as today, TSOs always have the possibility to reduce the ID ATC in case of security of supply issues. If two different ATC values on the same border are submitted, the minimum value prevails.

Option 0: local CC (Capacity calculation)

- Each TSO computes its ID ATC by itself
- Each TSO runs its local processes (e.g. security checks based on DACF, bilateral ATC increase...)

Option 1: local CC + coordinated verification

- As option 0 + ID ATC verification process with CWE-merged DACF files including:
  - ⇨ first ATC values of the CWE area are shared between the CWE TSOs
  - ⇨ local security verification on CWE-merged DACF files
  - ⇨ CWE common adjustment ATC process in case the grid security is violated
- Steps comparable with the CWE coordinated D-1 NTC mechanism

Option 2: Coordinated splitting + local decrease allowed

- Use of the FB domain adapted to FBMC results
- Coordinated splitting
- Each TSO can check the security of the ID ATCs on DACF and then IDCF (only coordinated ID capacity decrease is allowed)

Option 3: Coordinated splitting + bilateral increase/decrease allowed + coordinated verification

- Use of the FB domain adapted to FBMC results
- Coordinated splitting
- Each TSO can re-compute its ID ATC by itself (which is, however, to be aligned with the neighbouring TSO)
- Coordinated ID capacity verification process with merged DACF files (comparable with the CWE coordinated D-1 NTC mechanism)

Option 4: CWE fully-coordinated ID ATC calculation

- Each TSO updates its D-2 CBs and GSK (and remedial actions)
- ID FB parameters are computed based on DACF (and then IDCF)
- Coordinated ATC calculation within the FB domain (coordinated splitting)
- ATCs are verified and CBs are updated if needed

2.6.2.4 Evaluation and conclusion

In the table below, the different possibilities can be compared in terms of:

- Security of supply,
- Optimization of ID capacity proposed to the market and need for dedicated resources for ID CC

	Current process: D-1: ATC ID: ATC	Future intermediate situation proposals D-1: FB ID: ATC					Mid term target: D-1: FB ID: FB
		Option 0: local CC	Option 1: local CC + coord verif	Option 2: coordi split + only local decr	Option 3: coordi split + local incr/dicr + coord verif	Option 4: CWE coord ID CC, based on FBP	
CC based on DACF/IDCF or D-2 parameters	D-2 & DACF depending on TSO	D-2 & DACF depending on TSO	D-2 & DACF depending on TSO	D-2 & DACF depending on TSO	D-2 & DACF depending on TSO	DACF/IDCF	DACF/IDCF
Coordinated splitting on FB domain	Not applicable	No	No	Yes	Yes	Yes	Not required
Local verification with DACF/IDCF + Coord adjustement process	No	No	Yes	No	Yes	Yes	Not applicable
Bilateral capacity increase allowed	Not applicable	Not applicable	Not applicable	No	Yes	Not applicable	Not applicable
ID capacity decrease allowed if SoS issues	Yes						
Security of Supply	Medium	Low	High	Medium	High	High	Very high
Optimization of ID capacity proposed to market	Low	Very low	Low	Medium	Medium	High	Very high
Need of dedicated resources for ID CC	Low	Medium	High	Low	High	High	High

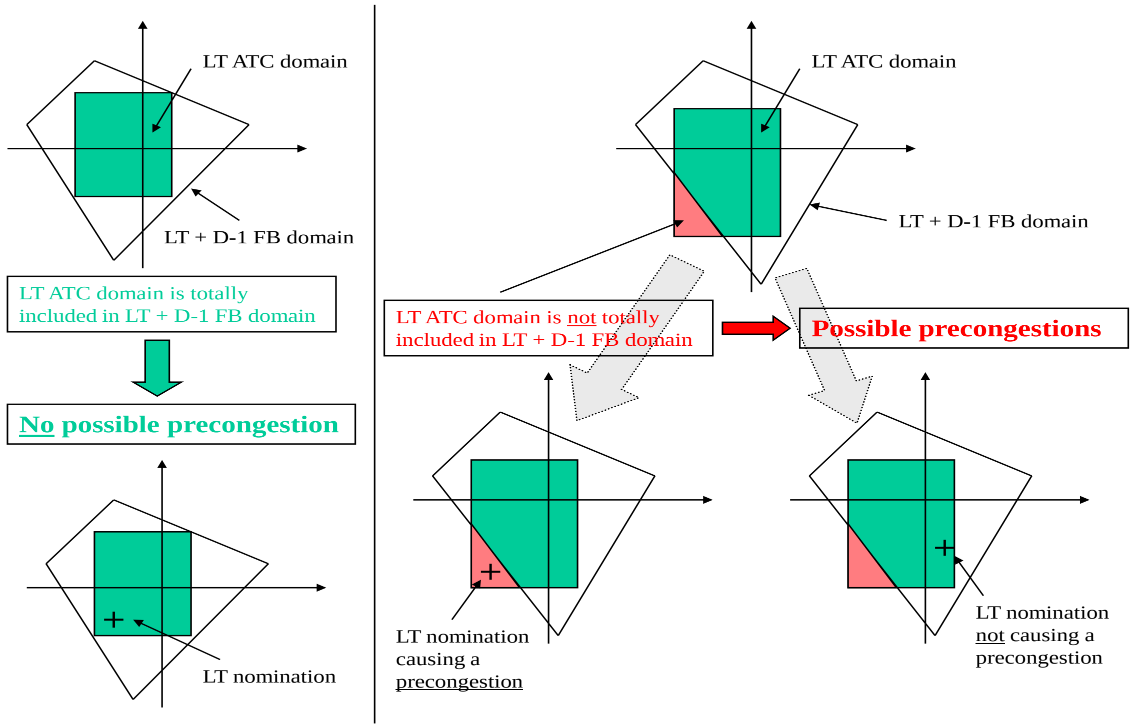
Conclusion:

- FB for D-1 is compatible with the current intraday ATC usage for allocation
- Whatever the clearing point of the FBMC, CWE TSOs will always be able to find 8 non-negative ID ATCs respecting the security
- CWE TSOs recommend an ID ATC calculation starting from a coordinated splitting of capacity out of the D-2 FB domain and a coordinated verification phase (Option 3)
- If no additional operational resources are available for some TSOs for the ID capacity calculation process, it could be acceptable as an interim solution to forbid capacity increase after the initial coordinated splitting (option 2)
- ATC calculation out of a FB domain calculated on DACF and then IDCF, instead of D2CF, could be an intermediate step before the implementation of FB in intraday (option 4)

2.6.3 Compatibility of FB in D-1 and Long Term (yearly and monthly) ATC and FTR

By definition, a precongestion is a situation where the long term nominations only, i.e. without having any additional nomination, cause congestion(s) in the FB model. In mathematical terms, a precongestion occurs when the RAM adapted with LT nominations is negative. In the NTC world, this would correspond to a negative ATC. In those cases, both under FB and ATC, the capacity is set to zero.

There is no possible precongestion if the LT ATC domain is fully included in the FB domain. If it is not totally included, there is a precongestion possibility. This is illustrated in the graph hereunder.



With regard to negative capacities, the following holds. In implicit auctions, TSOs could submit negative capacities (both under ATC or FB). But this option is not relevant since it would penalize day-ahead market coupling price formation (forcing market coupling to do implicit counter trading) and it would not give an incentive to the TSOs to compute relevant LT capacities.

Provided that Financial Transmission Right options (FTR options) are computed on network constraints and are not pure financial products without any connection to reality, they are equivalent to LT ATC with UIOSI (Use It Or Sell It) and no nominations. As the latter is fully compliant with implicit FB in day ahead, the same applies for FTRs.

2.7 Conclusion and recommendations of the CWE TSOs and next steps for implementation

During the 2010 CWE TSO FB experimentation it was proven that the Enhanced FB capacity calculation:

- is feasible from an operational point of view
- increases the proposed capacity offered to the market when compared to ATC
- improves the Security of Supply in unusual market directions and TSO cooperation compared to the CWE coordinated ATC method
- addresses transparency requirements and concerns on market players understanding
- is compatible with
    - the adjacent capacity calculation processes
        - D-1 NTC computation of the non-CWE borders,
        - LT NTC computation
        - CWE ATC Intraday computation

The theoretical improvements of Flow Based vs ATC have been confirmed during the 2010 CWE FB experimentation. From an SoS point of view, CWE TSOs recommend continuing describing the details of a FB implementation for CWE MC.

3. Price/Market impact analysis performed jointly by PXs/TSOs

3.1 Introduction

This chapter presents the **market impact analysis** performed in order to assess SoS domain modelling effects with FB constraints (FBMC) rather than ATCs (ATCMC) on market and prices (cf. general introduction in section 1.3). Besides theoretical considerations that were already studied[14], the market impact analysis relies on market simulations. Their main results are the market clearing prices and the bidding areas net positions obtained by "replaying" modified historical clearings in which ATCs are replaced by FB constraints.

Whereas the previous market impact analysis (2008) was hindered by data quality, the process described in Chapter 2 led to the generation of 2 times 2 weeks of FB constraints data allowing a better comparison of ATCMC and FBMC (cf. 3.2).

Results are analysed through a series of indicators ranging to day-ahead market welfare (DAMW) to price divergence (cf. 3.4).

3.2 Data

3.2.1 Data used

The data used will be the following:

For 2 months, 2 week each month, 24 hours each day, for FR, BE, NE, DE:

- PX's input data: Historical order books posterior to the coordinated ATC launch.
- TSO's input data:
  - FB constraints generated by key users;
  - Historical coordinated ATCs.

3.2.2 Limitations

In the 2008 Market Validation Analysis II report, some limitations of the data were mentioned:

- PX's input data:
  - Explicit auctions on some borders;
  - Orders based on the knowledge of the ATC system.
- TSO's input data:
  - Reconstruction from automated process;
  - Differences with the expected operational process.

Three of these four limitations are addressed in the planned simulation.

This means that there are no more explicit auctions on some borders, and that TSO's input data are not built in an automated process, and thus no differences with the expected operational process.

On the other side, some new limitations appear:

- 2 times 2 weeks of data, during 2 months (December and January), instead of 318 days equally distributed among the year. Therefore, it is not possible to extrapolate indicators to a yearly period.
- Potential discrepancies depending on the ITVC solution being based on ATC. Indeed, ITVC results in bidding orders corresponding to the volume exchanged with the Nordic area. This volume is computed with ATCs while it should be computed with FB constraints, but this is not supported by ITVC.

3.3 Intuitiveness Definition

The term "counter-intuitiveness" was introduced in Q4 2007 to describe some results of a FB market coupling test that did not match what market players generally think a coupling should yield.

However, turning this psychological discomfort into a positive definition of "intuitiveness" in order to adapt the algorithm design was not straightforward. Several approaches have been proposed for 3 years by the PXs or the TSOs. The current section is intended to fix clear definitions related to the "intuitiveness concepts". Let us first start with an example in order to illustrate how the problem was identified:

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[14] Market Validation Analysis II – External Report, CWE Market Coupling Project, 2008.

Example

Let consider the following 3-node example in which the flow from A to C is limited to 100 MW. An export from A to C uses twice as much of the "scarce" resource than an export from B to C. Therefore an export from A to C should provide the double of welfare than an export from B to C in order to use the resource.

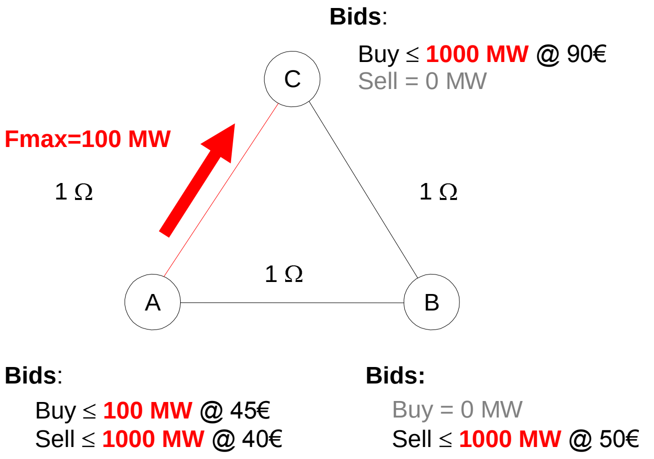


Figure 1: Three-node non-intuitive example (inputs)

The optimal situation is given below:

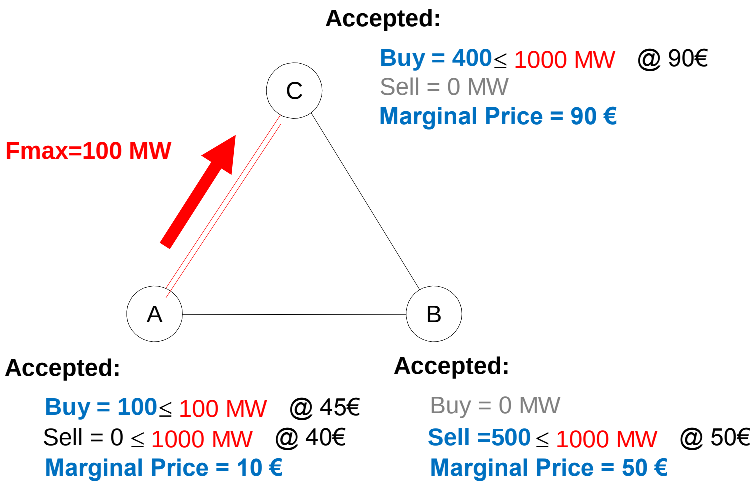


Figure 2: Three-node non-intuitive example (results)

The optimal solution gives a welfare of 15 500€:

- A imports 100 MW and has a marginal price of 10€
- B exports 500 MW and has a marginal price of 50€
- C imports 400 MW and has a marginal price of 90€

The situation is counter-intuitive, because the cheapest zone (zone A) imports.

On the contrary, the intuitive solution (definitions precised below) would be:

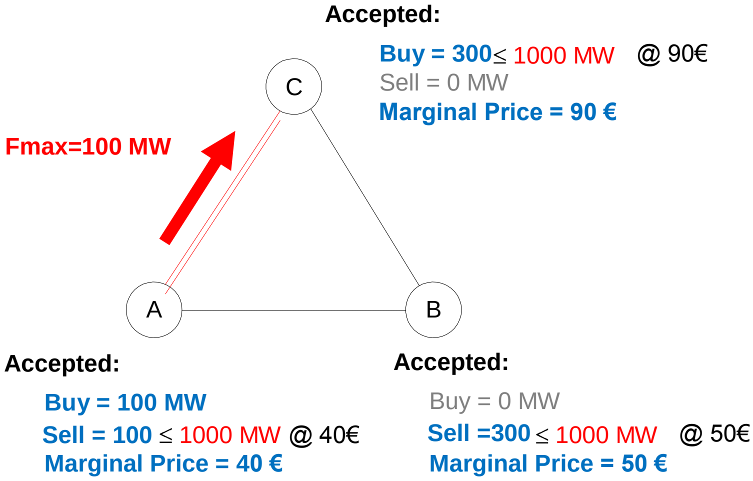


Figure 3: Three-node intuitive example (results)

The optimal solution gives a welfare of 12 500€:

- A imports 0 MW and has a marginal price of 40€
- B exports 300 MW and has a marginal price of 50€
- C imports 300 MW and has a marginal price of 90€

The situation is intuitive, to the detriment of the welfare.

3.3.1 Intuitiveness considering "source to sink" exchanges

Definition 1: For each k, the k cheapest markets are exporting (except if the k^{th} and the $k+1^{th}$ markets have the same prices)

Corollary 1: There exist at least one set of positive ATCs linking each pair of market for which this solution is optimal.

This intuitivity definition can be enforced in COSMOS through an heuristic. This algorithm is used to compute the FBIMC results presented in this report.

3.3.2 "Bilateral Intuitiveness" considering existence of interconnections

We define bilateral (commercial) exchange as an exchange between two physically directly connected bidding areas (For example, no bilateral exchange is possible between France and Netherlands or between Belgium and Germany as today with ATC).

Definition 2: We define a situation as being "bilateral intuitive" if it exists at least one set of intuitive (from the cheapest bidding area to the most expensive) bilateral exchanges, respecting net positions where:

Corollary 2: There exist at least one set of positive ATCs on each existing interconnector for which this solution is optimal.

Remark: This definition is more constraining than the previous one. Solutions not compliant with definition 1 and definition 2 will be called "non-intuitive" solutions.

3.3.3 Differences between both intuitiveness definitions

With the source to sink definition, the following situation is intuitive:

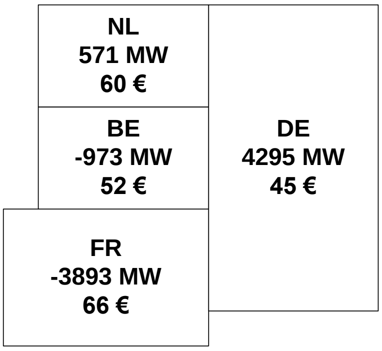


Figure 4: source to sink intuitive and bilateral counterintuitive situation

NL is exporting while its two adjacent bidding areas (BE & DE) are cheaper therefore it is non intuitive from the bilateral point of view.

For k=2, the 2 most expensive markets are NL & FR, they are globally importing (so that it is source-to-sink intuitive), but there is no interconnection between FR and NL which is the cause non bilateral intuive situation.

In addition to this example, FBMC may be extended to even more distant non adjacent bidding areas.

3.4 Analysis

3.4.1 Simulation

The simulation will consist in running COSMOS over the period of study with the following configurations:

- Isolated (no capacity) *(ISO)*
- ATC mode
- FB with intuitive market coupling *(FBIMC)* mode
- FB with market coupling *(FBMC)* mode
- Infinite capacity

The implementation of FBIMC is a heuristic which finds intuitive solutions but does not guarantee their optimality.

No ramping constraint on the net position (limitation of the net position change from one hour to the next) has been activated.

The comparison of ATC, FBIMC and FBMC will be based on a set of indicators which is described in this section.

3.4.2 Pre-coupling indicators

These indicators are useful to assess the quality of network constraints. They are not market indicators and are thus described in the feasibility report presented previously in section 2.3.1.

3.4.3 Security of Supply

The Security of Supply (SoS) is an important indicator. It is difficult to measure; therefore one should be sure that the SoS is identical before making comparisons. The section 2.4 is dedicated to this point.

3.4.4 Day ahead market welfare (DAMW)

The day ahead market welfare is the welfare computed by COSMOS. It is the sum of the buyer surplus, the supplier surplus and the congestion rent. It does not take into account the welfare linked to futures and to grid management and SoS costs. This indicator is usually called social welfare and is identical to the welfare computed in the previous market impact analysis[15].

Figure 5 illustrates the overall DAMW change in FBMC and FBIMC compared to ATC (column "Total") and the split of the change between buyers, suppliers and congestion rent (first three columns). Consistently with the expectations linked with the fact that the ATC domain is included in the FB domain, the welfare increases and the congestion rent decreases. As expected, welfare is reduced in FBIMC compared to FBMC but the decrease is small compared to the difference with ATCMC. Globally, the welfare increase covers 90% of the maximum possible increase reached by using infinite capacities.

[15] Market Validation Analysis II – External Report, CWE Market Coupling Project, 2008.

Figure 6 illustrate the DAMW change by country. It is noticeable that all countries see a welfare increase because it is not a theoretical expectation.

Figure 7 details the DAMW change by country and by actors. Globally, as expected from a theoretical point of view due to the capacity increase, supplier surplus increase in countries that are exporting more and buyer surplus increased in countries importing more and vice-versa. This is not specific to FBMC or FBIMC.

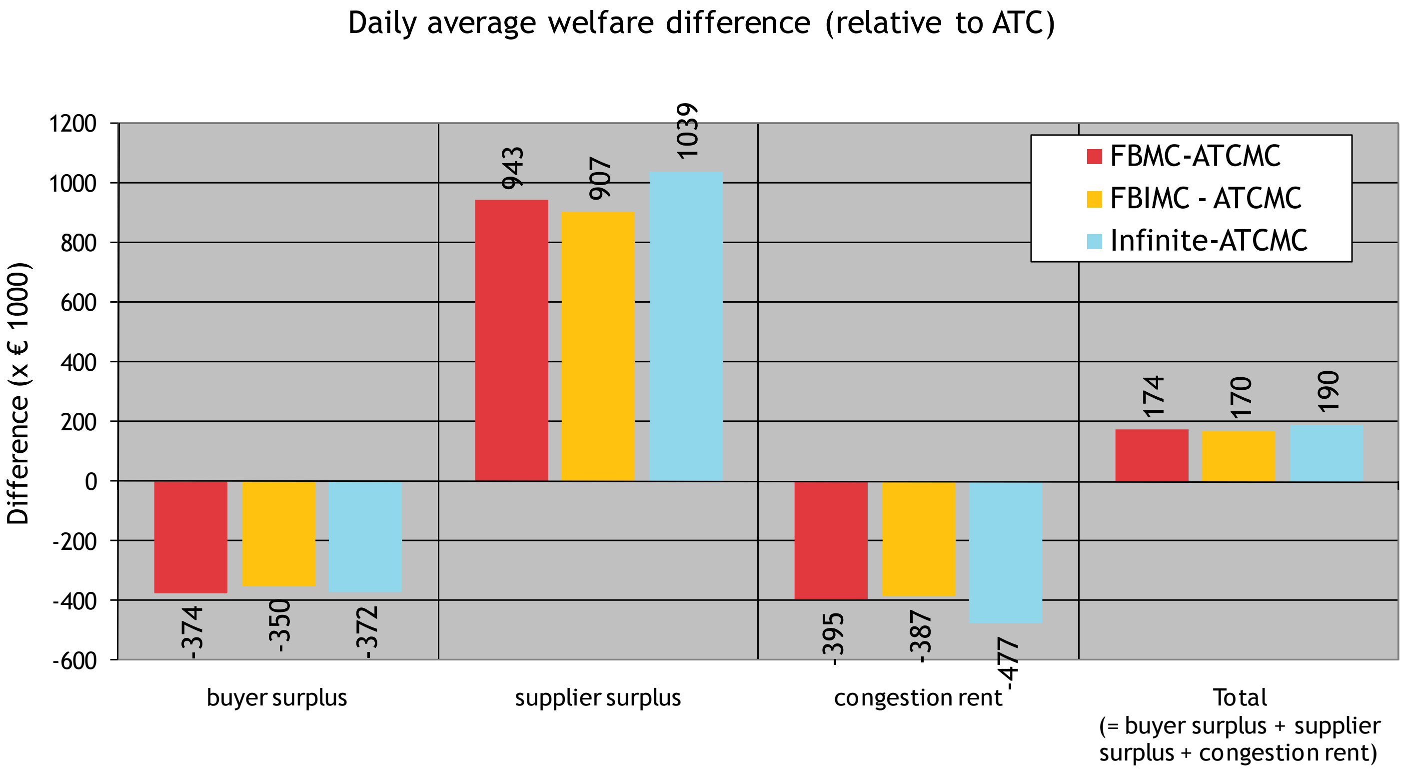


Figure 5: Daily average welfare difference relative to ATCMC split by actor

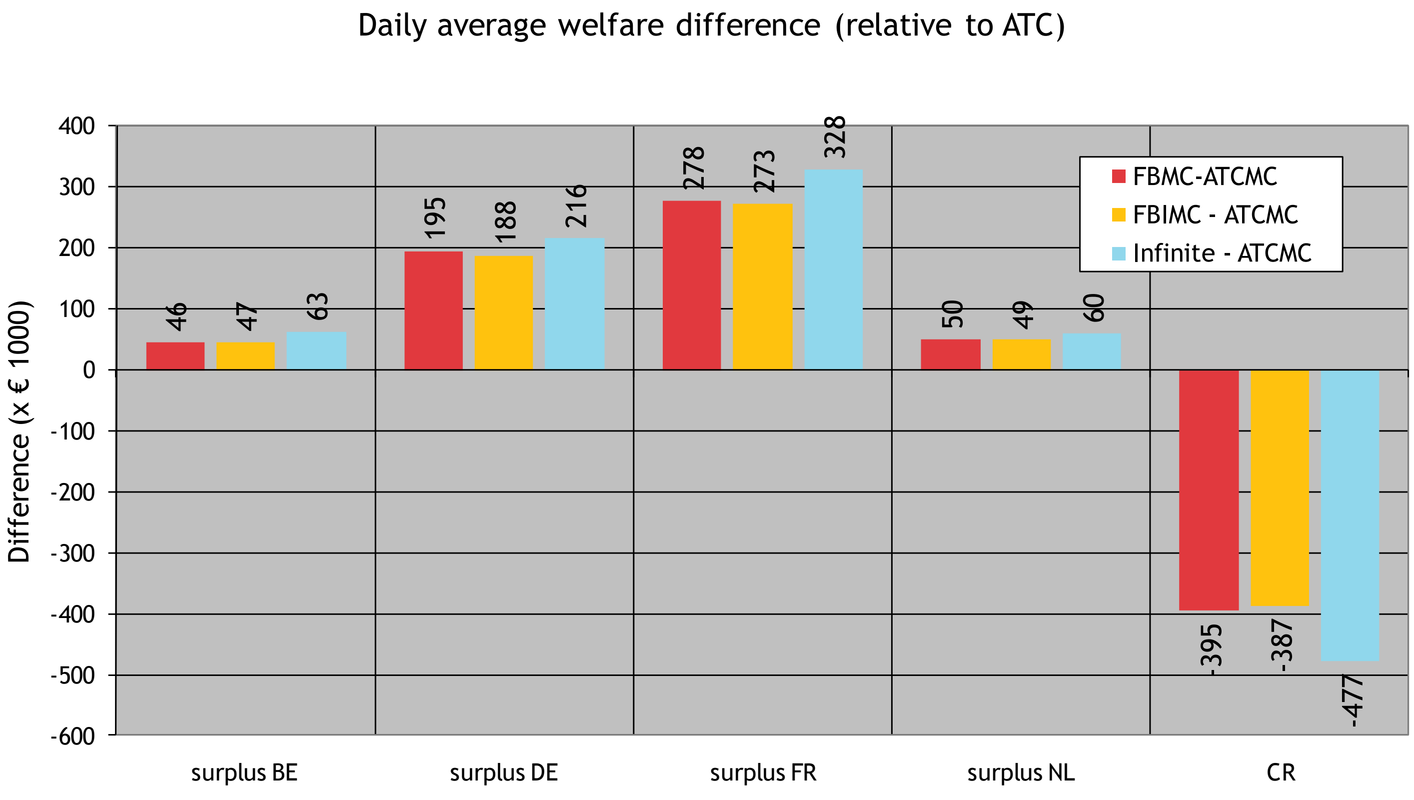


Figure 6: Daily average welfare difference relative to ATCMC split by country in €

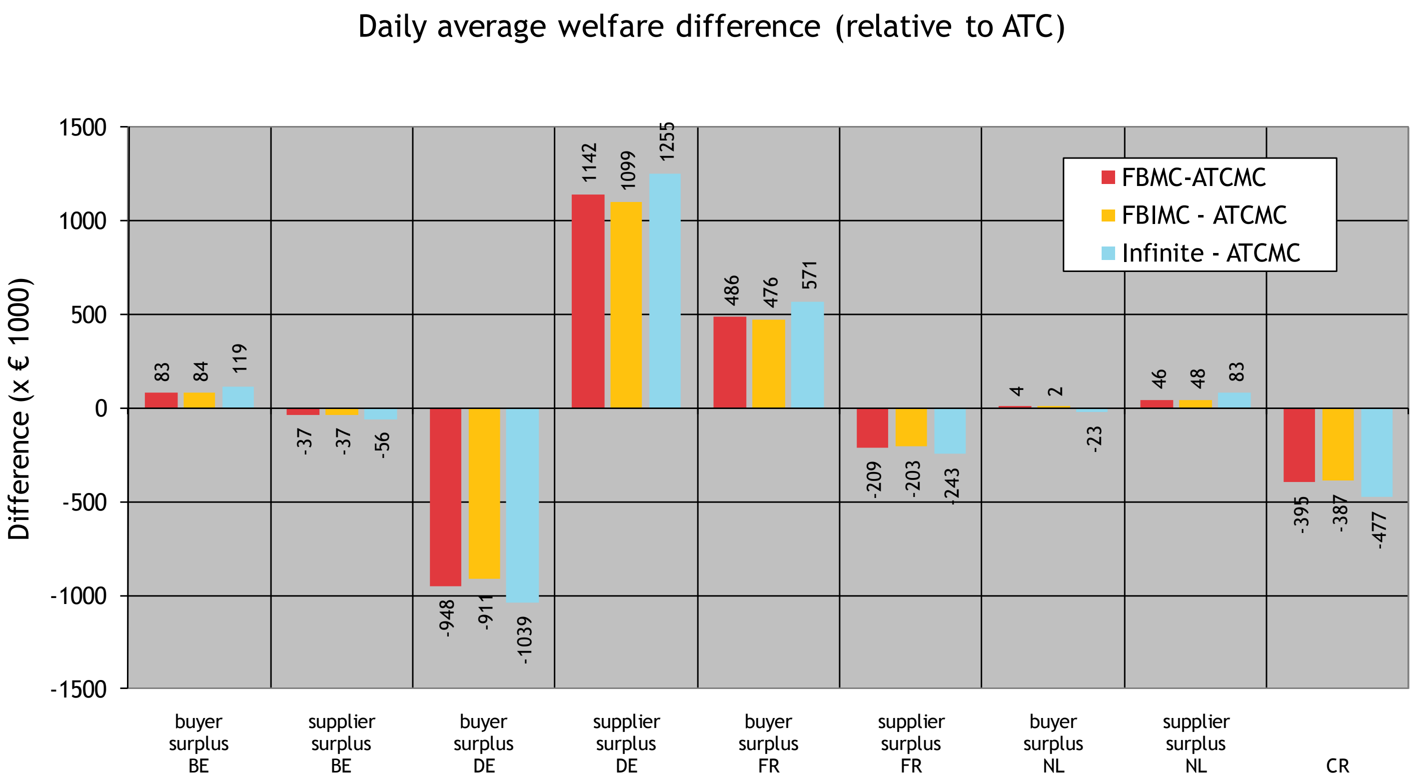


Figure 7: Daily average welfare difference relative to ATCMC split by country and by actor

3.4.5 Market clearing volumes

Market Clearing Volume (MCV) in a bidding area is defined as the sum over the whole period of the maximum per hour of the demand and supply clearing volume.

Figure 8 and Figure 9 show the change in total (summed over all the simulation period) clearing volumes (demand, supply, sum of demand and supply on Figure 8 and maximum of sum of demand and supply –i.e. MCV– on Figure 9) per country in FBMC relative to ATCMC. FBIMC results are similar. All countries see an increase of the MCV. The total clearing volume is almost stable: Overall, from ATC to FB, exchanges increase but the total volume of demand remains unchanged. The high increase of total MCV is linked to the fact that exchange increases are counted twice: once in the exporting country, once in the importing country. The main change is the increased export from Germany to France.

Figure 10 shows the detail per day and per country. It illustrates that FBMC and FBIMC most of the time lead to the same market clearing volume.

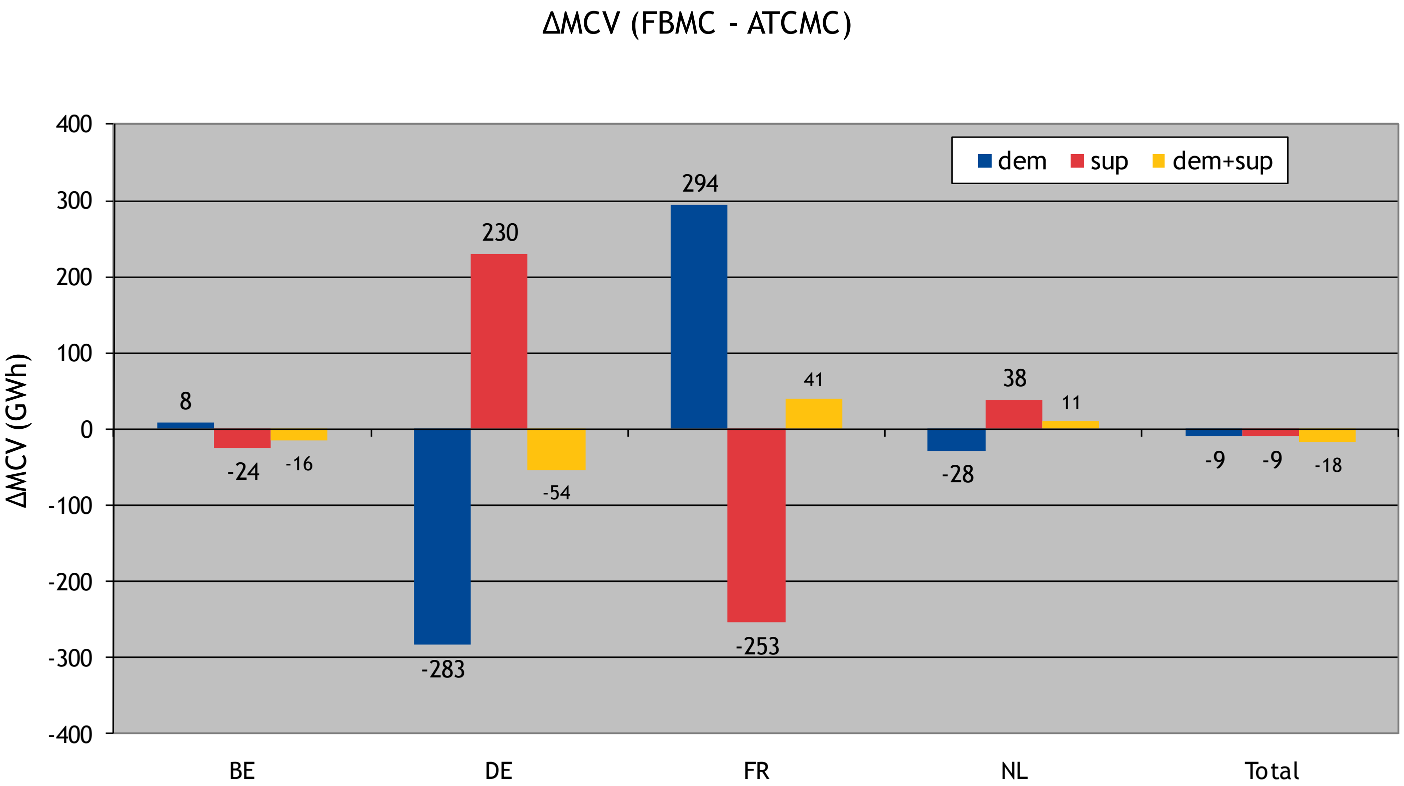


Figure 8: Sum of demand, supply and MC volume by country over all the simulation period

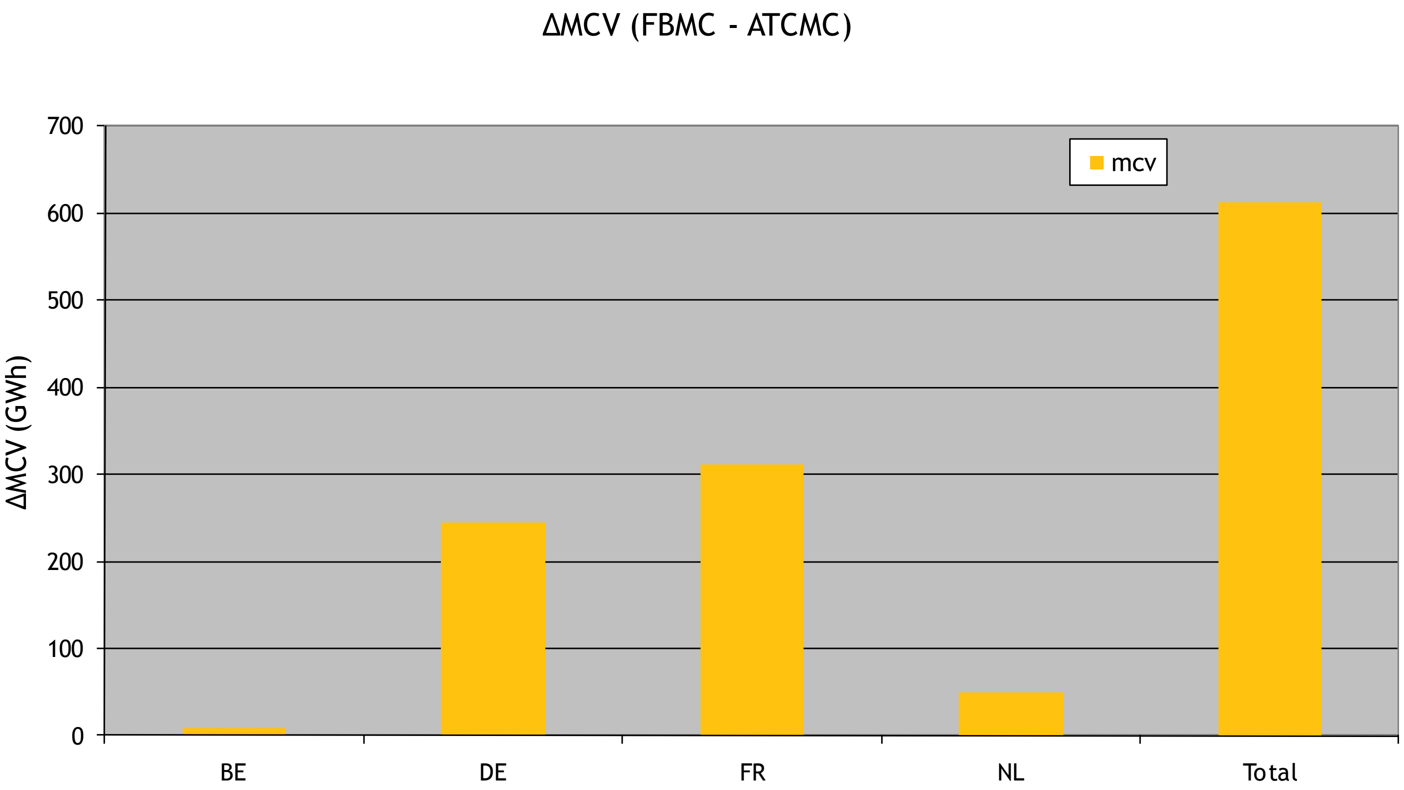
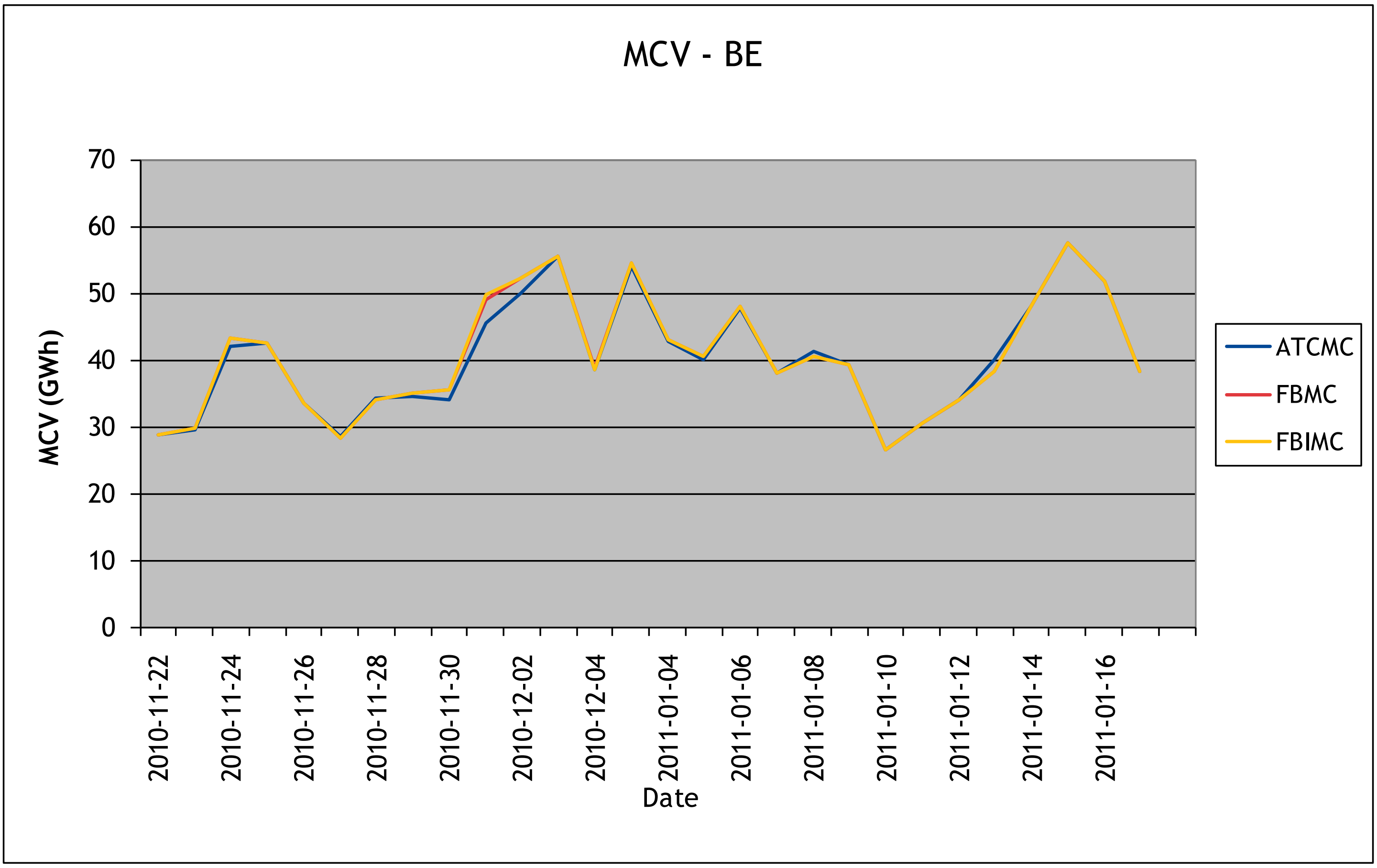
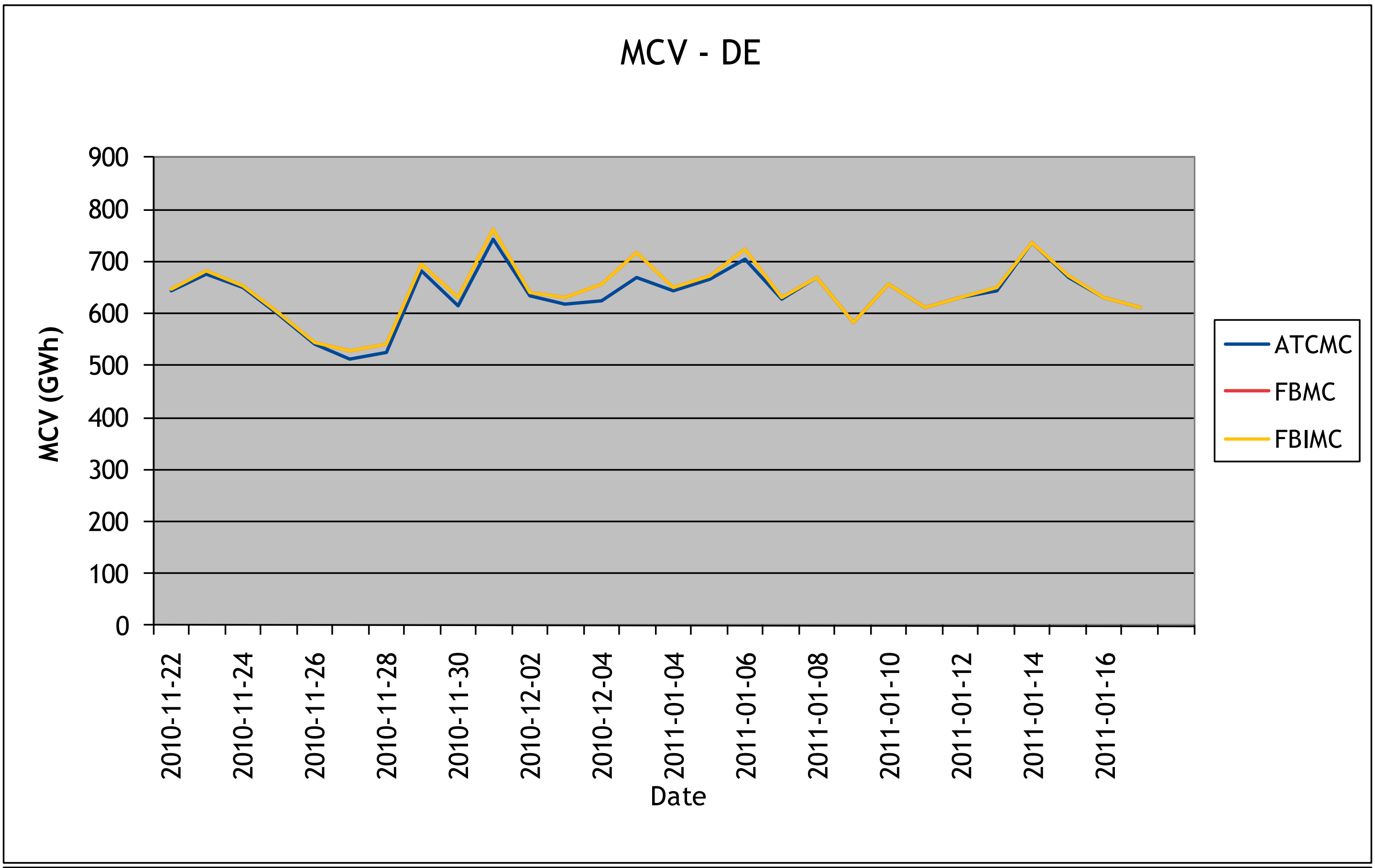
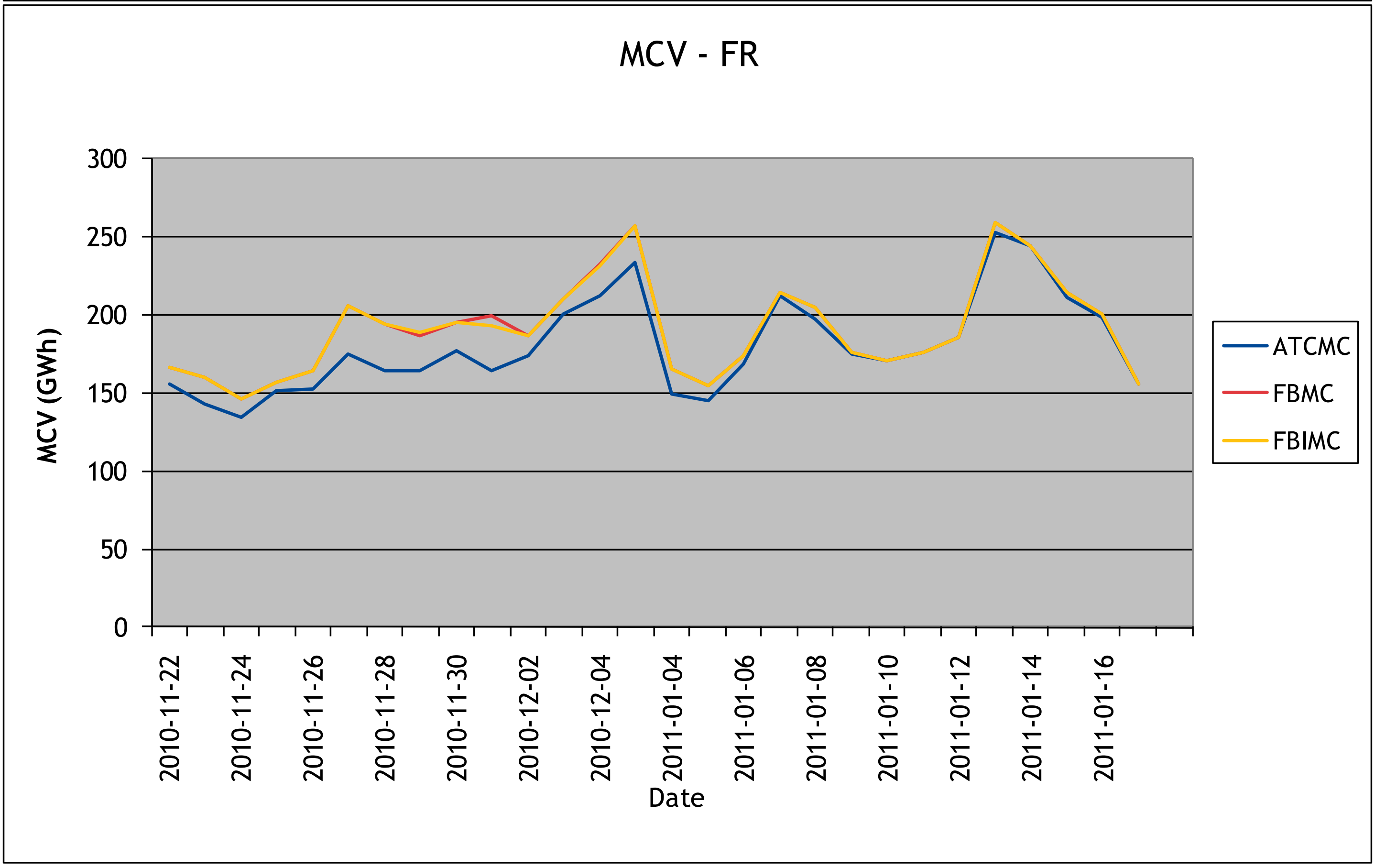


Figure 9: Sum of market clearing volume by country over all the simulation period




MCV - DE
MCV (GWh)
900
800
700
600
500
400
300
200
100
0
2010-11-22
2010-11-24
2010-11-26
2010-11-28
2010-11-30
2010-12-02
2010-12-04
2011-01-04
2011-01-06
2011-01-08
2011-01-10
2011-01-12
2011-01-14
2011-01-16
Date
ATCMC
FBMC
FBIMC


MCV - FR
MCV (GWh)
300
250
200
150
100
50
0
2010-11-22
2010-11-24
2010-11-26
2010-11-28
2010-11-30
2010-12-02
2010-12-04
2011-01-04
2011-01-06
2011-01-08
2011-01-10
2011-01-12
2011-01-14
2011-01-16
Date
ATCMC
FBMC
FBIMC

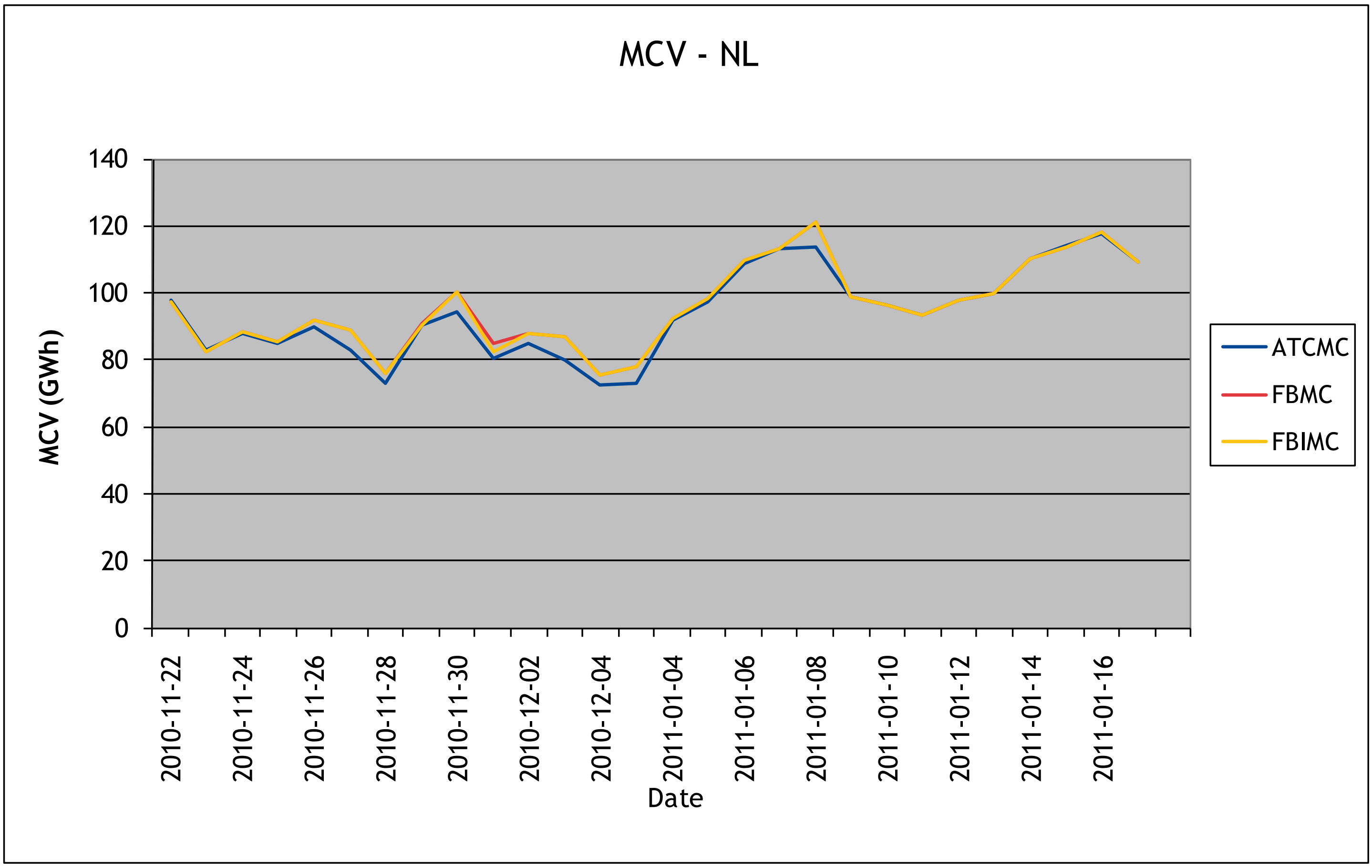


Figure 10: Daily MCV per country

3.4.6 Price convergence

Full price convergence ("Copper plate") is achieved when the price in all country is approximately equal (tolerance: 0.002 €/MWh). Partial convergence is reached when at least 2 countries have approximately the same price. Full divergence means that all countries have prices that differ more than the tolerance.

Figure 11 illustrates the convergence reached with each method. The first column "numHours" gives the number of hours on which the simulation was reached (24x14x2=672h). The next ones ("fullConv", "partialConv", "fullDivergence") are respectively the number of hours of full convergence, partial convergence and full divergence. Due to the inclusion of the ATC domain in the FB domain, increase of convergence was expected and is observed.

Due to the nature of FB constraints, less partial convergence (measured as the number of hours with at least partial convergence) was expected and is also observed. The small increase of partial convergence in FBIMC compared to FBMC is directly linked with the intuitiveness constraints on prices[16]. Note that a *full divergence is not necessarily worse than a partial convergence. For example,* let's consider a partial convergence of 2 zones with 40€/MWh and 2 zones with 80€/M*W*h, and a full divergence in FB with prices equal to 40.1 €/MWh - 40.2 €/MWh – 40.3 €/MWh – 40.3 €/MWh. Therefore, the analysis of other indicators like the price divergence (cf paragraph 3.4.7) is needed to assess the importance of the observed decreased partial convergence.

Overall, on the simulation period, which presented more congested situations than on average, FB allowed full convergence on 92% of hours instead of 52% in ATC.

Figure 12 represents the same results but in proportion rather than in number of hours.

[16] Indeed, when intuitivity is enforced, it results in limiting exchanges between countries up to the point where these countries have the same clearing price. Then, the flow between these countries becomes compatible with the price (and vice-versa) so that the situation is intuitive. In other words, the usual active constraint when enforcing intuitiveness after observing non-intuitive results is that the price difference between 2 bidding areas should be positive in the direction of the flow, so that the optimal solution is usually that the price difference is nul (the other situation implying the reversal of the flow has not been observed).

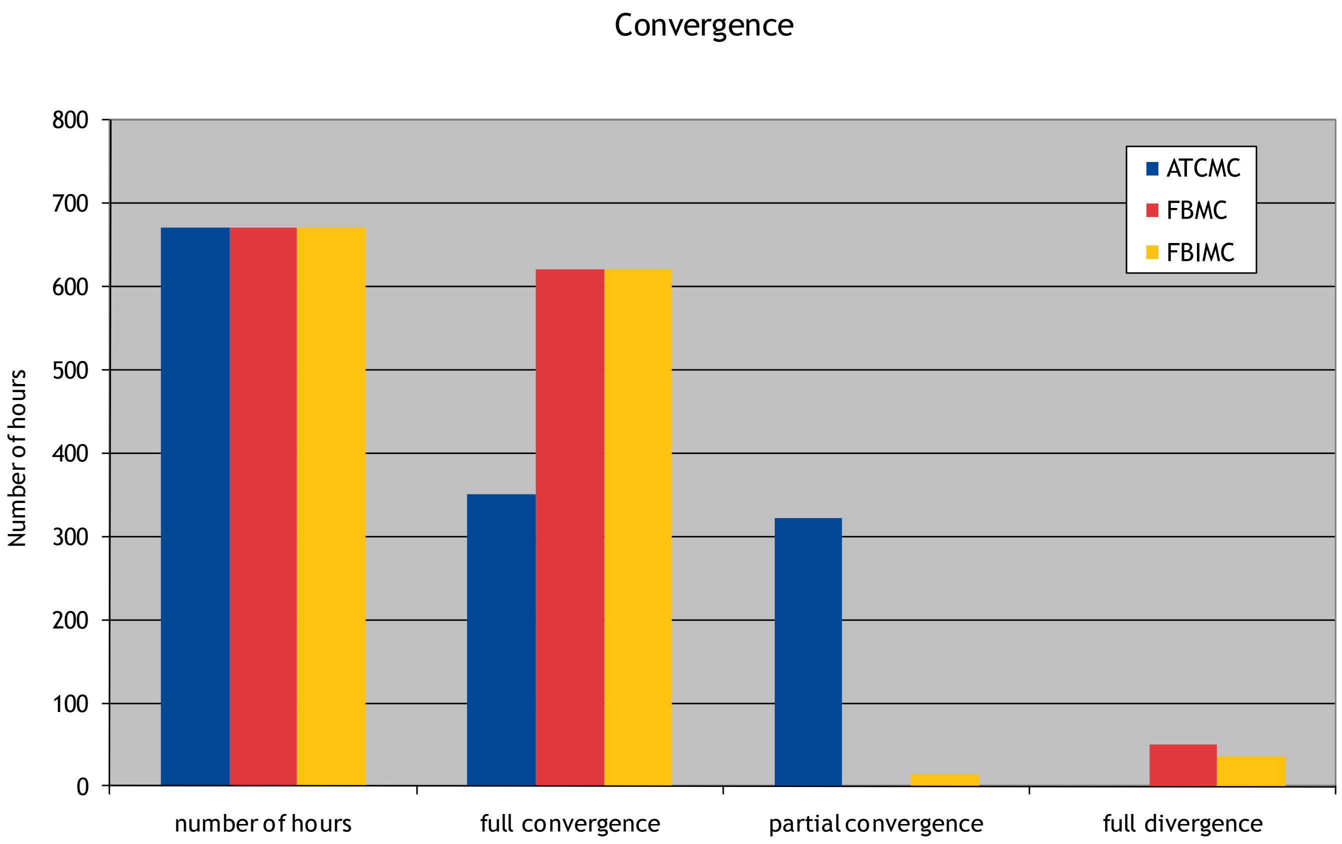


Figure 11: Convergence of prices over countries in hours (tolerance: 0.002€/MWh)

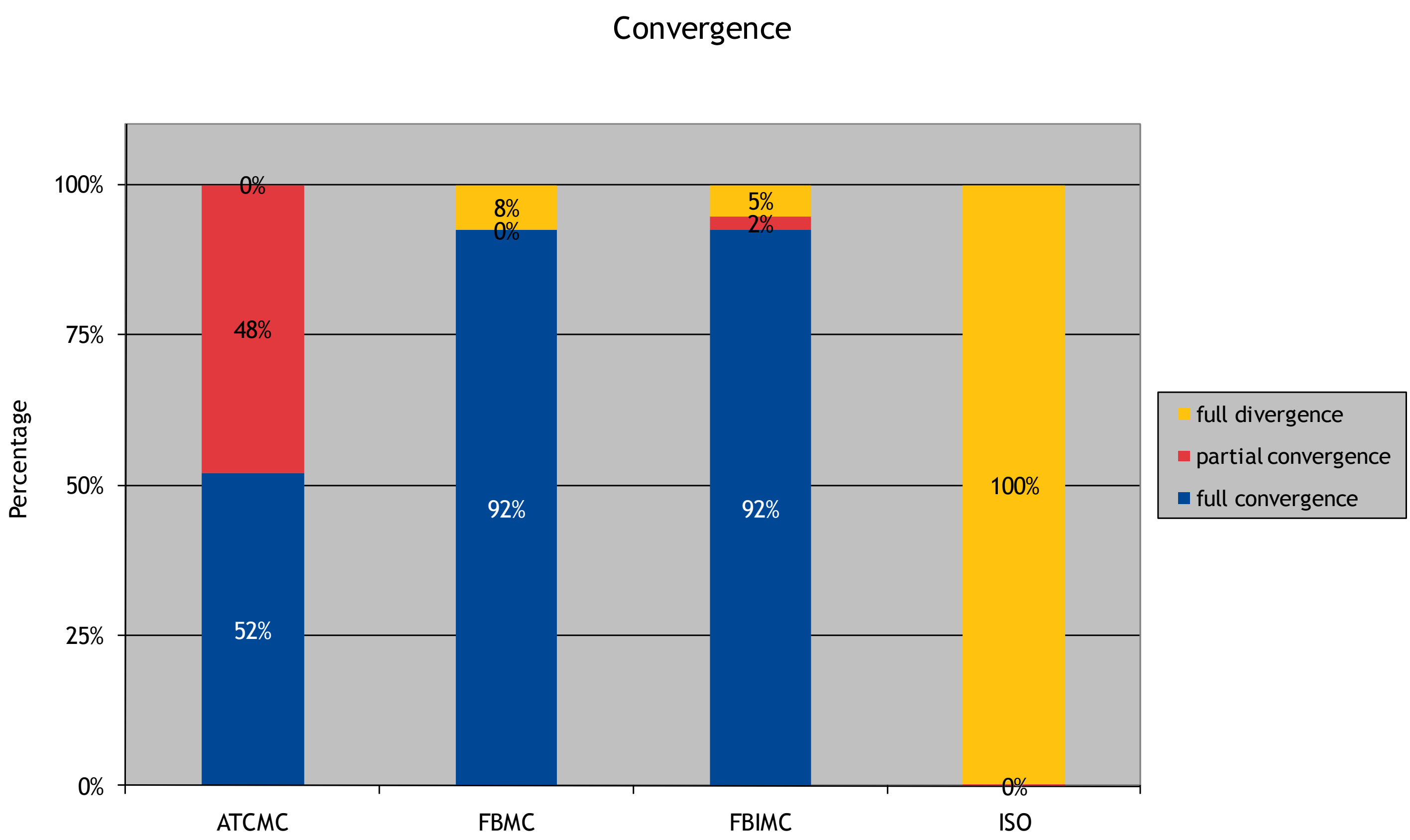


Figure 12: Convergence of price difference between countries in proportion (tolerance: 0.002 €/MWh)

3.4.7 Price divergence

The graphs below (Figure 13 and Figure 14) show the hourly difference between the highest and the lowest price among all countries, i.e. the maximum price difference, ranked in decreasing order for the different methods. As observed for the convergence, the divergence is lower with FBMC than with ATCMC for most hours. The FBIMC is very close to FBMC. However, the zoom on the first hours (Figure 14) shows that there is one situation for which the maximum price difference is larger in FBMC (and FBIMC, as the situation is intuitive) than in ATCMC. This situation is December 2nd, 19:00 and is analysed thoroughly in the frame below.

<u>December 2nd, 2010. 19:00</u>

The clearing situations in isolated mode, ATCMC and FBMC on December 2nd, 2010, 19:00 are depicted below (FBIMC is not because it is identical to FBMC):

<u>Isolated mode</u> **<u>ATCMC</u>** **<u>FBMC</u>**

The situation is analysed thorougly because, on the contrary to all other 771 situations, the price spread between the most expensive bidding area and the least one is higher in FBMC than in ATCMC (244.162 €/MWh vs 163.935 €/MWh). This is linked to a higher price in Belgium and a lower price in the Netherlands in FBMC compared to ATCMC.

Here are some observations and analysis:

- The ATCMC situation is within the FB domain.
- As expected, DAMW is increased between ATCMC and FBMC. Indeed, the objective of COSMOS is to maximize DAMW and not minimize price divergence.
- Price convergence between France and Germany is better while price convergence between Belgium and Netherlands deteriorated.
- The net position of Belgium is the same in ATCMC and in FBMC, while the Belgium price changes. Indeed, the analysis of supply and demand curves show that there is a "price vertical" in Belgium resulting in a price indetermination: for this net position, the Belgium price can be chosen in the range between 199.11 €/MWh and 350 €/MWh without changing the DAMW. This situation does not occur in other countries. The price in Belgium changes between ATCMC and FBMC because of the market coupling rules implemented in COSMOS: in ATCMC, as there is no congestion between France and Belgium, the Belgium price is equal to the French price. In FBMC, the price is determined by the PTDFs of the unique congested line of the situation: On this situation, the price in Belgium is higher than the price in France.

- The FBMC situation is source to sink intuitive (and thus the same as the FBIMC situation) and bilateral intuitive[17]. As a result, it is possible to find a set of ATCs that would have allowed obtaining the FBMC clearing situation in ATCMC (at least the same NEXs[18]) :

  ATC(DE⇒FR) = 3399 MW, ATC(FR⇒BE) = 910 MW, ATC(NL⇒BE) = 313 MW, ATC(NL⇒DE) = 312 MW

- The isolated price of Belgium is 3000 €/MWh, which indicates a low market resilience. The isolated price in France is 600 €/MW.h which indicates a tensed market linked to low temperatures in France.

From this analysis, various conclusions can be drawn:

- The FBMC situation could have been obtained in ATCMC if TSOs had provided a set of ATCs different from the historical one. For example, if their anticipation of the market direction had been different, they could have done an ex-ante market splitting giving the set of ATCs resulting in the same clearing situation as in FBMC given above. Therefore, the situation is not only linked to FBMC properties (contrary to non-intuitive situations).

- On this specific situation, due to the indeterminacy of the Belgium price, it would be possible to change the market coupling used by COSMOS to reduce the price divergence observed in this situation.

Overall, it is not possible to draw conclusions from only one exceptional situation. In following simulations, the number of hours with an increase of price divergence will be closely monitored. According to the conclusions of this monitoring, appropriate actions will then be taken.

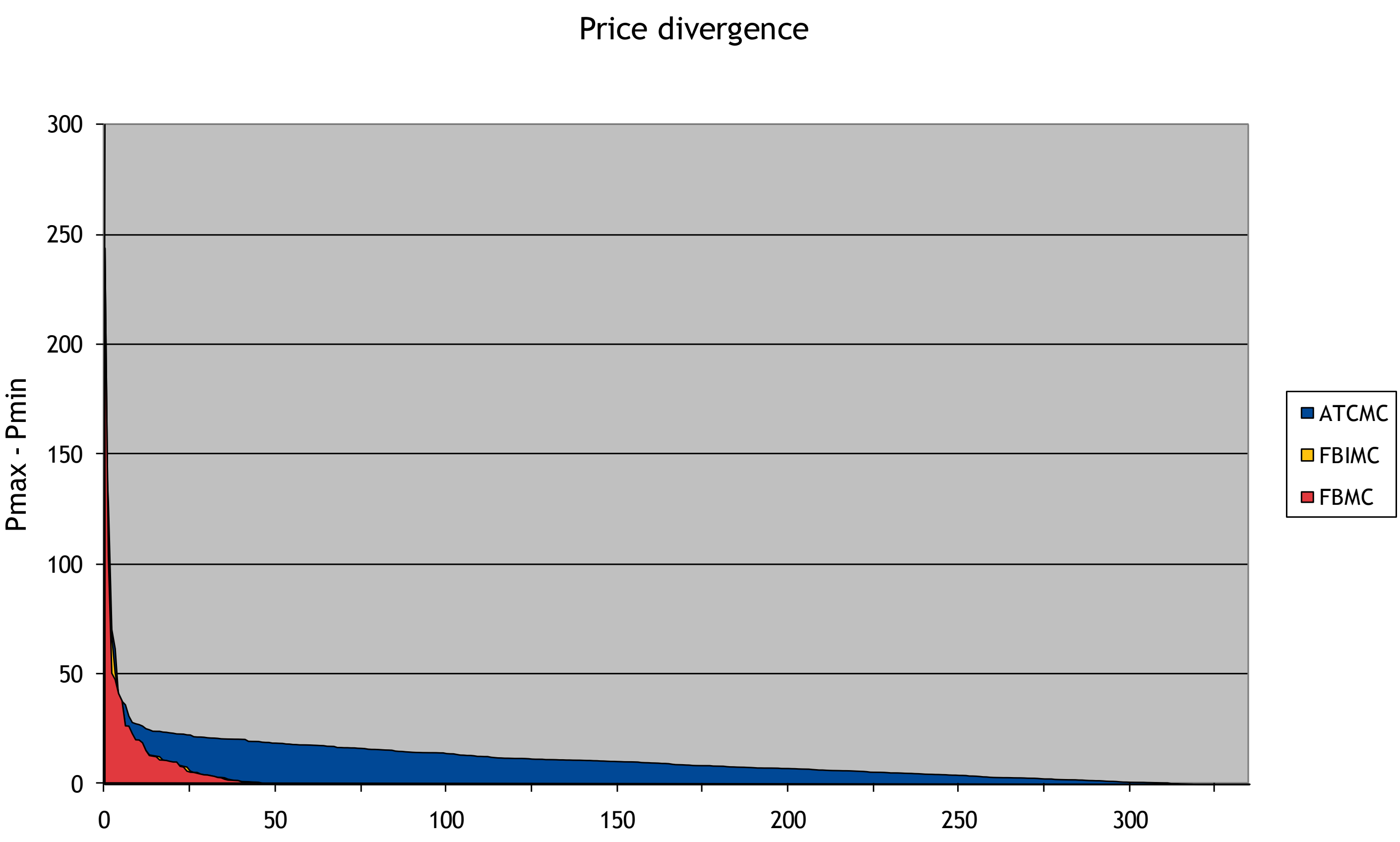


Figure 13: Maximum price difference distributions

[17] Possible BECs: BEC(DE⇒FR) = 3399 MW, BEC(FR⇒BE) = 910 MW, BEC(NL⇒BE) = 313 MW, BEC(NL⇒DE) = 312 MW

[18] Indeed, due to the price indeterminacy in Belgium, the given set of ATCs does not allow to determine the Belgium price as it creates a congestion on each Belgium border. In this case, the rule implemented in COSMOS results in choosing the middle of the price indeterminacy interval as the coupling price, i.e. 275 €/MWh. Note that this results in divergence (215 €/MWh) closer to the one obtained in FBMC (244 €/MWh) than to the one obtained with historical ATCs (164 €/MWh).

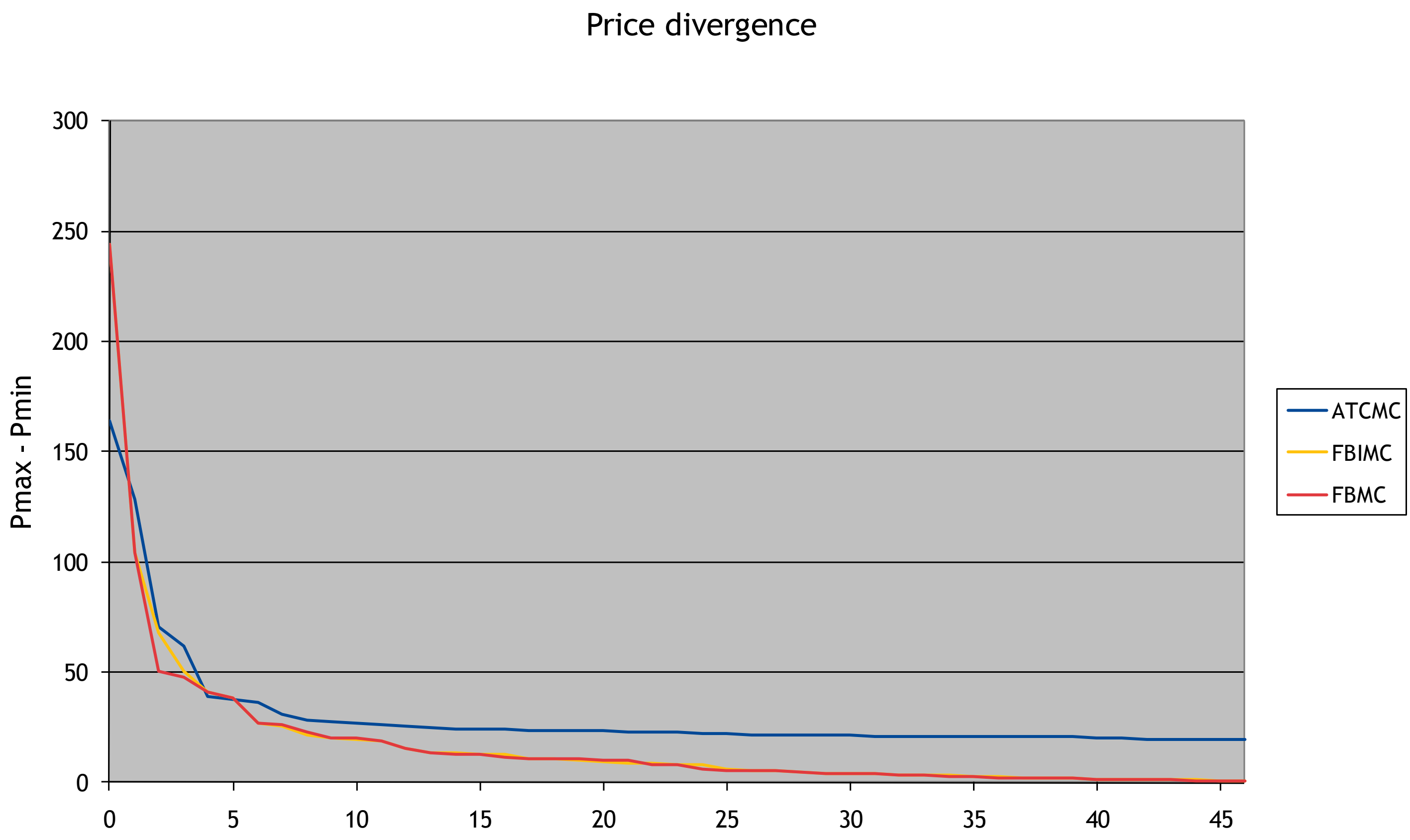


Figure 14: Maximum price difference distributions (zoom)

3.4.8 Base load price

The base load price is the price of selling/buying 1 MW during each hour of all the period. It is the average of the clearing price. Figure 15 shows this daily average and its standard deviation (the standard deviation of daily averages, not the standard deviation of hourly prices). The standard deviation illustrates the range of the daily price average. Assuming a normal distribution of the daily price average, the probability that the base load price of a given day is in of the plotted interval is 68%.

Globally, the price increases in countries exporting more and decreases in countries importing more. For Belgium and for France, the standard deviation is lower in FB than in ATC, meaning that the volatility on the base load price is reduced.

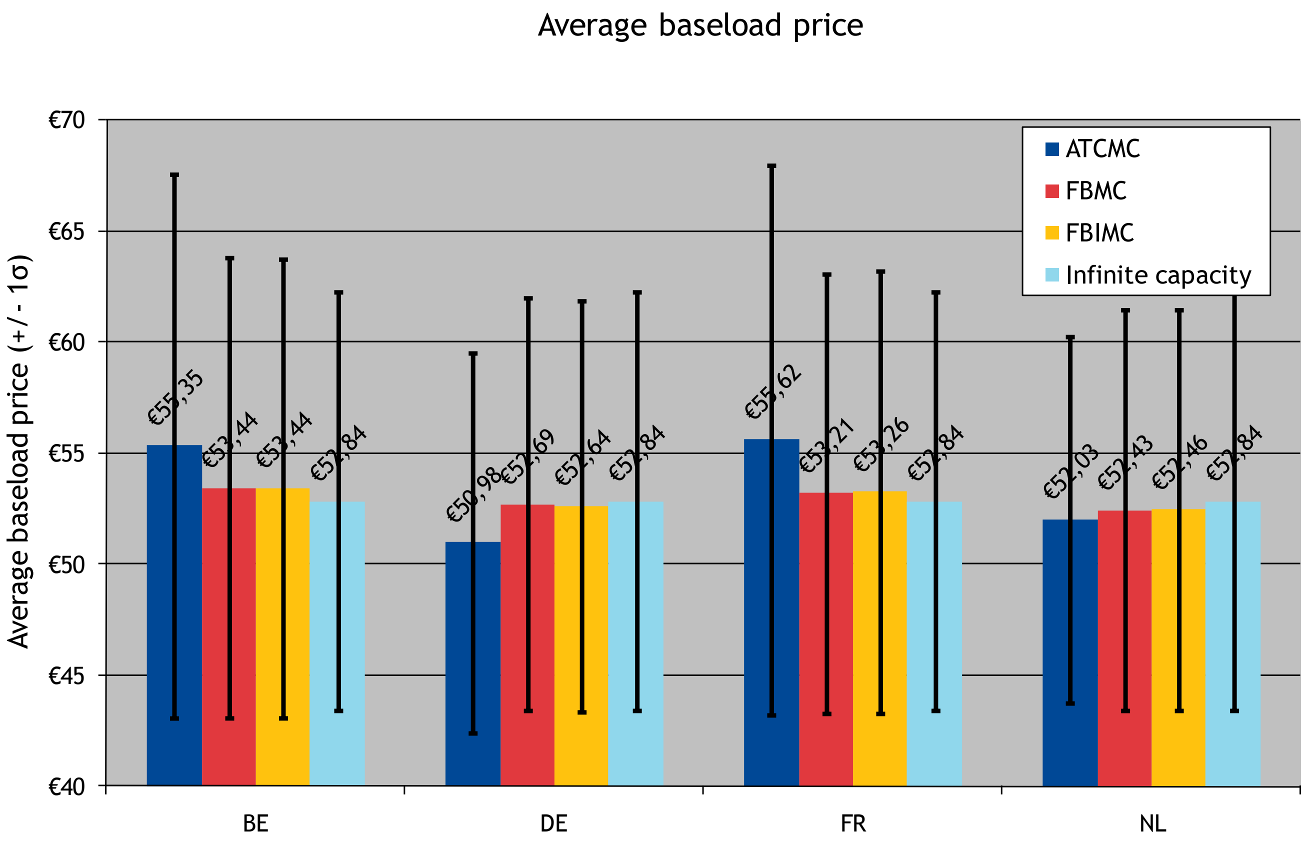
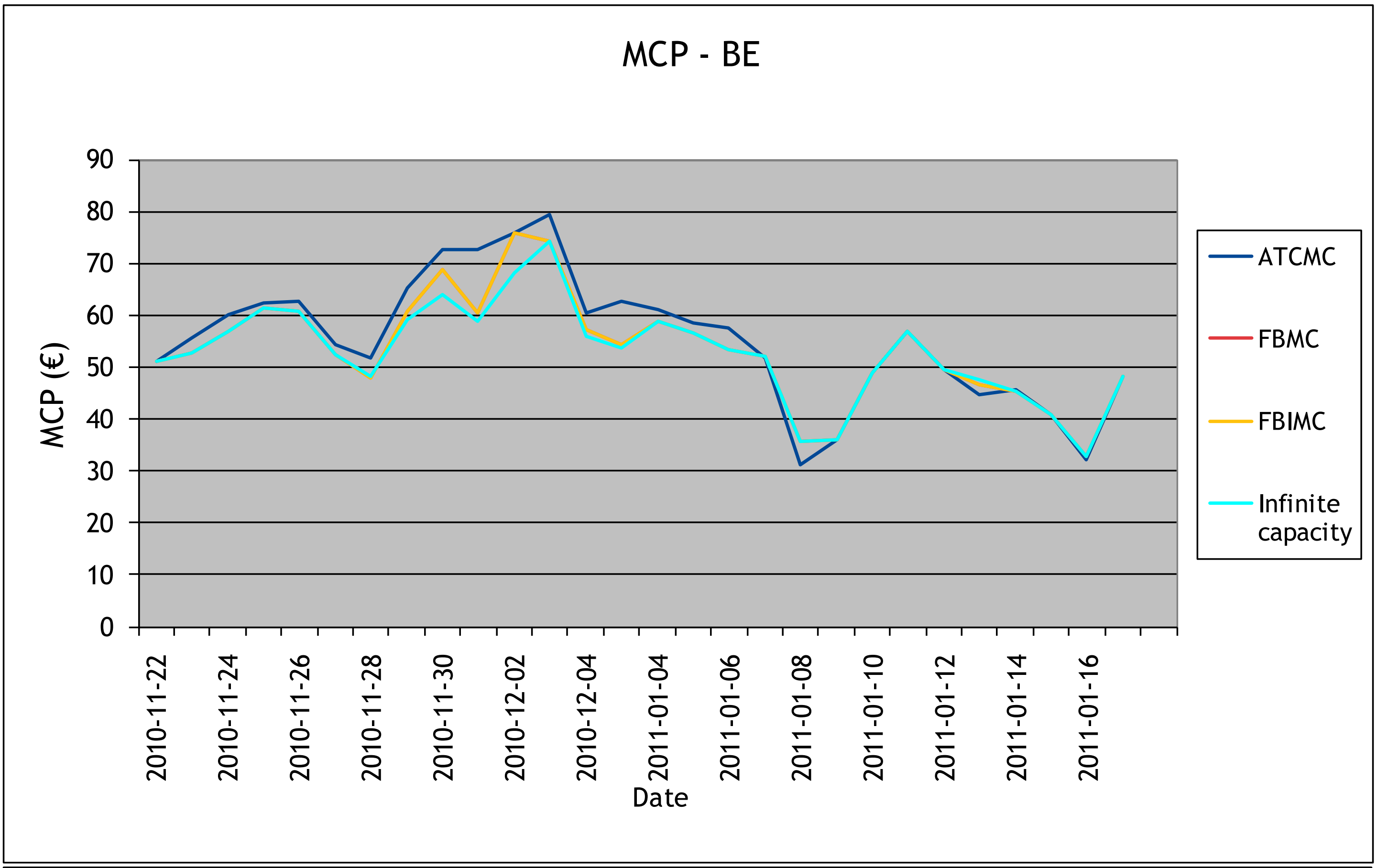
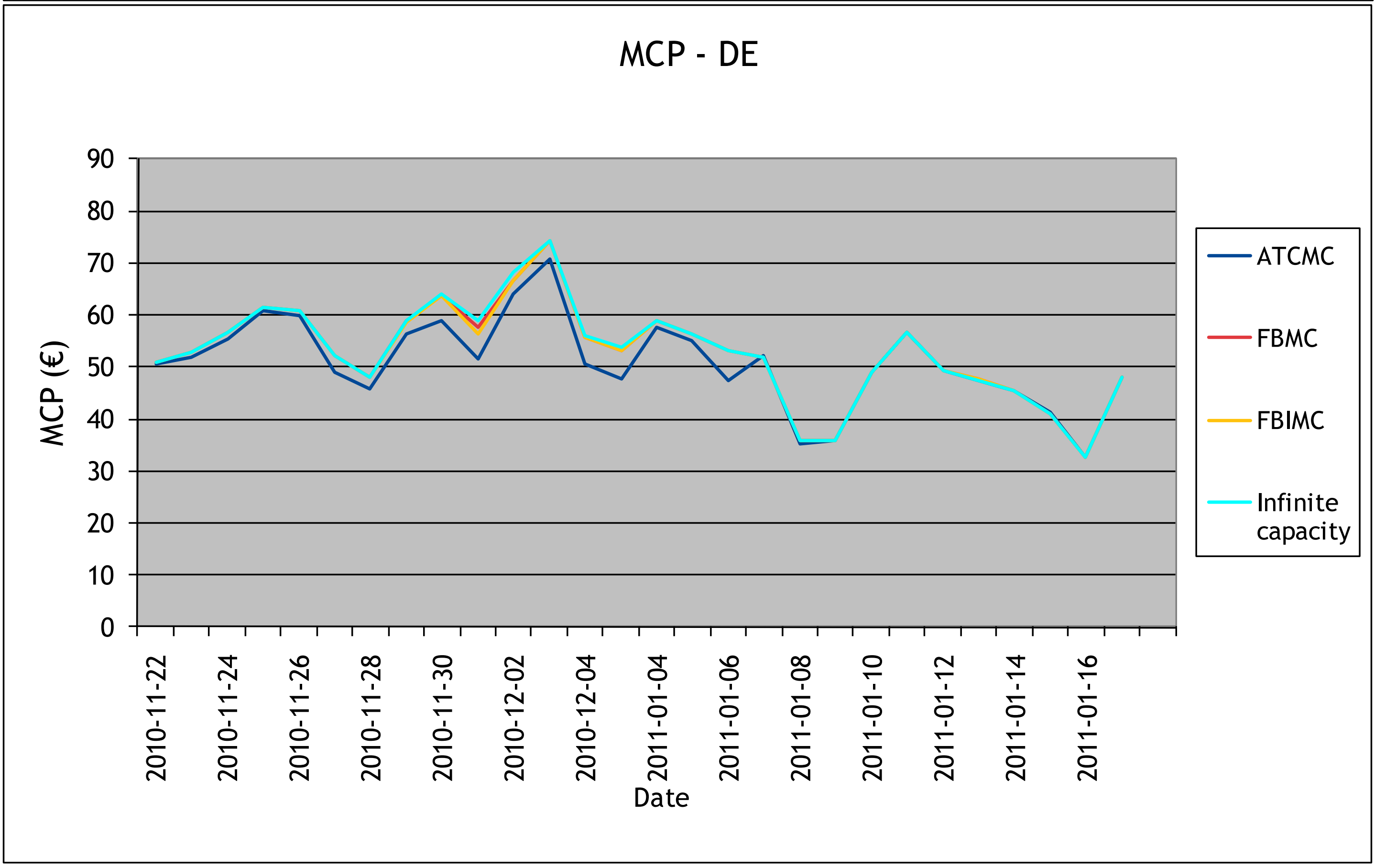


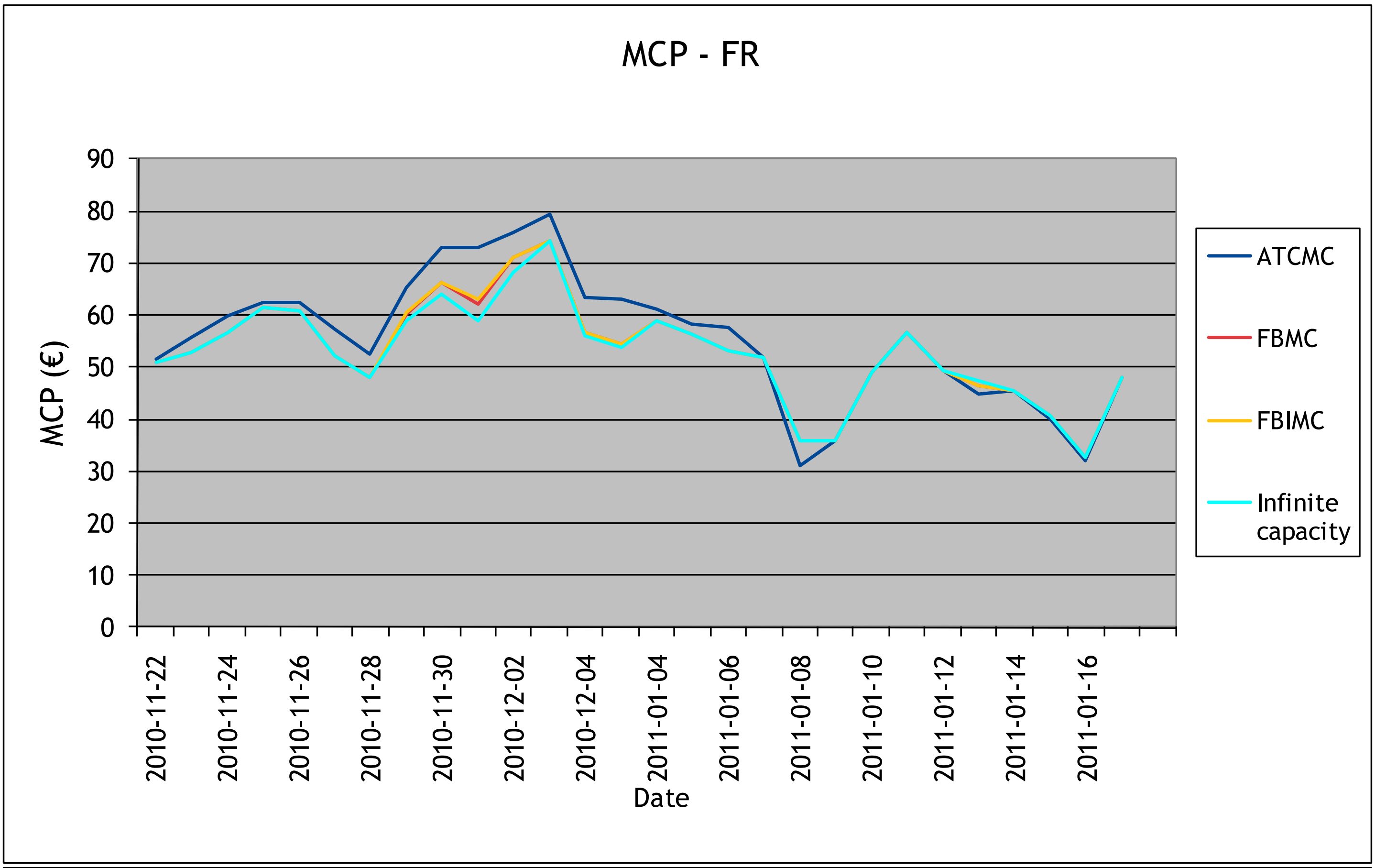
Figure 15: Average and standard deviation of baseload price per country

Given that the simulation period is rather short, it is possible to plot the daily baseload price per country in Figure 16. Figure 17 represents the hourly clearing price per countries. Both figures show that the difference between FBMC and FBIMC is small even on an hourly basis. The daily baseload price clearly shows that the 2 periods of 2 weeks were significantly different: the first one was rather tensed with many congestions, while the second one was rather flat with full convergence during most hours.

On December 2nd 19:00, the clearing price in Belgium is higher in FBMC (and FBIMC) than in ATCMC, up to the point that the difference between the maximum and the minimum price in the zone is increased compared to ATC (see paragraph 3.4.7).


MCP - BE
MCP (€)
90
80
70
60
50
40
30
20
10
0
2010-11-22
2010-11-24
2010-11-26
2010-11-28
2010-11-30
2010-12-02
2010-12-04
2011-01-04
2011-01-06
2011-01-08
2011-01-10
2011-01-12
2011-01-14
2011-01-16
Date
ATCMC
FBMC
FBIMC
Infinite capacity


MCP - DE
MCP (€)
90
80
70
60
50
40
30
20
10
0
2010-11-22
2010-11-24
2010-11-26
2010-11-28
2010-11-30
2010-12-02
2010-12-04
2011-01-04
2011-01-06
2011-01-08
2011-01-10
2011-01-12
2011-01-14
2011-01-16
Date
ATCMC
FBMC
FBIMC
Infinite capacity



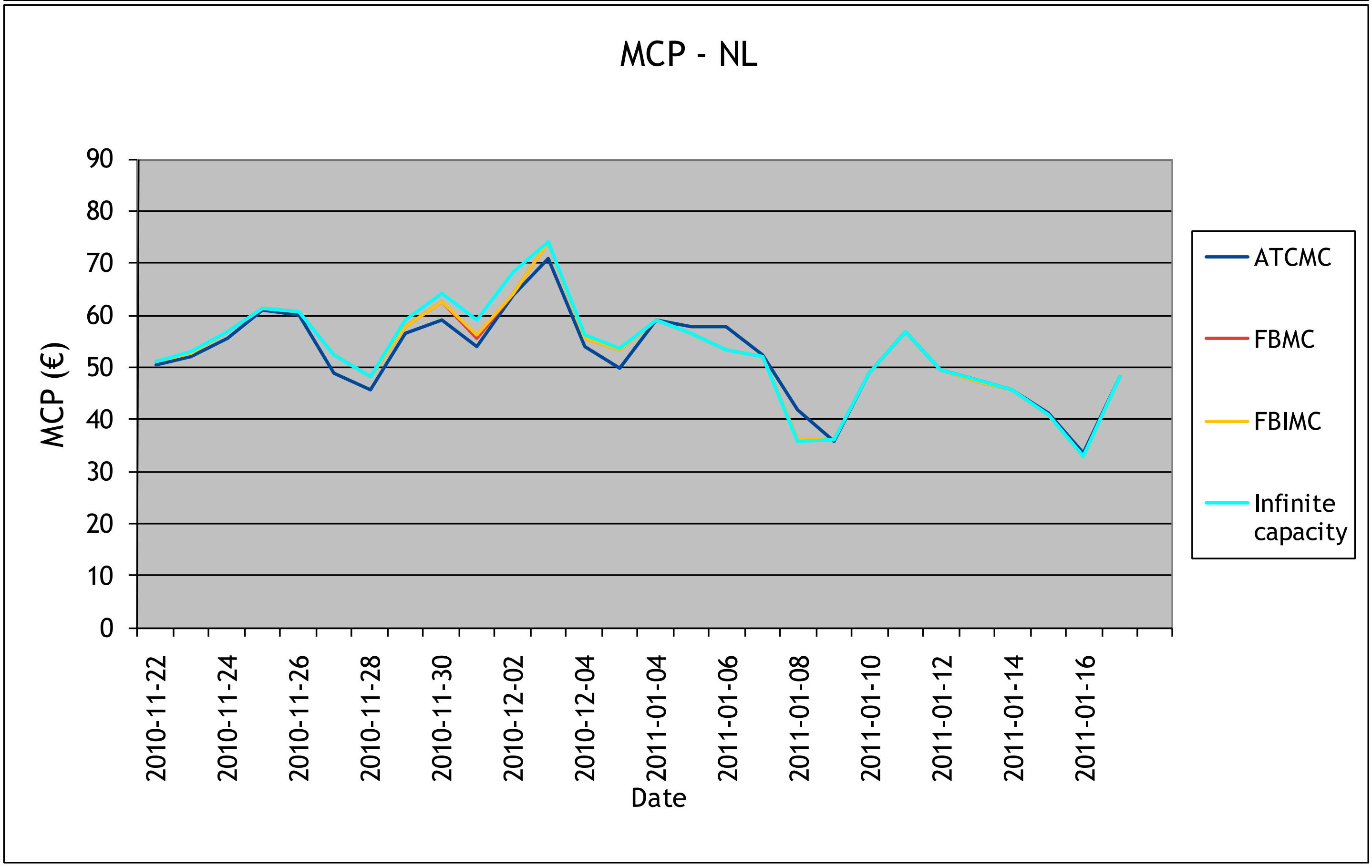
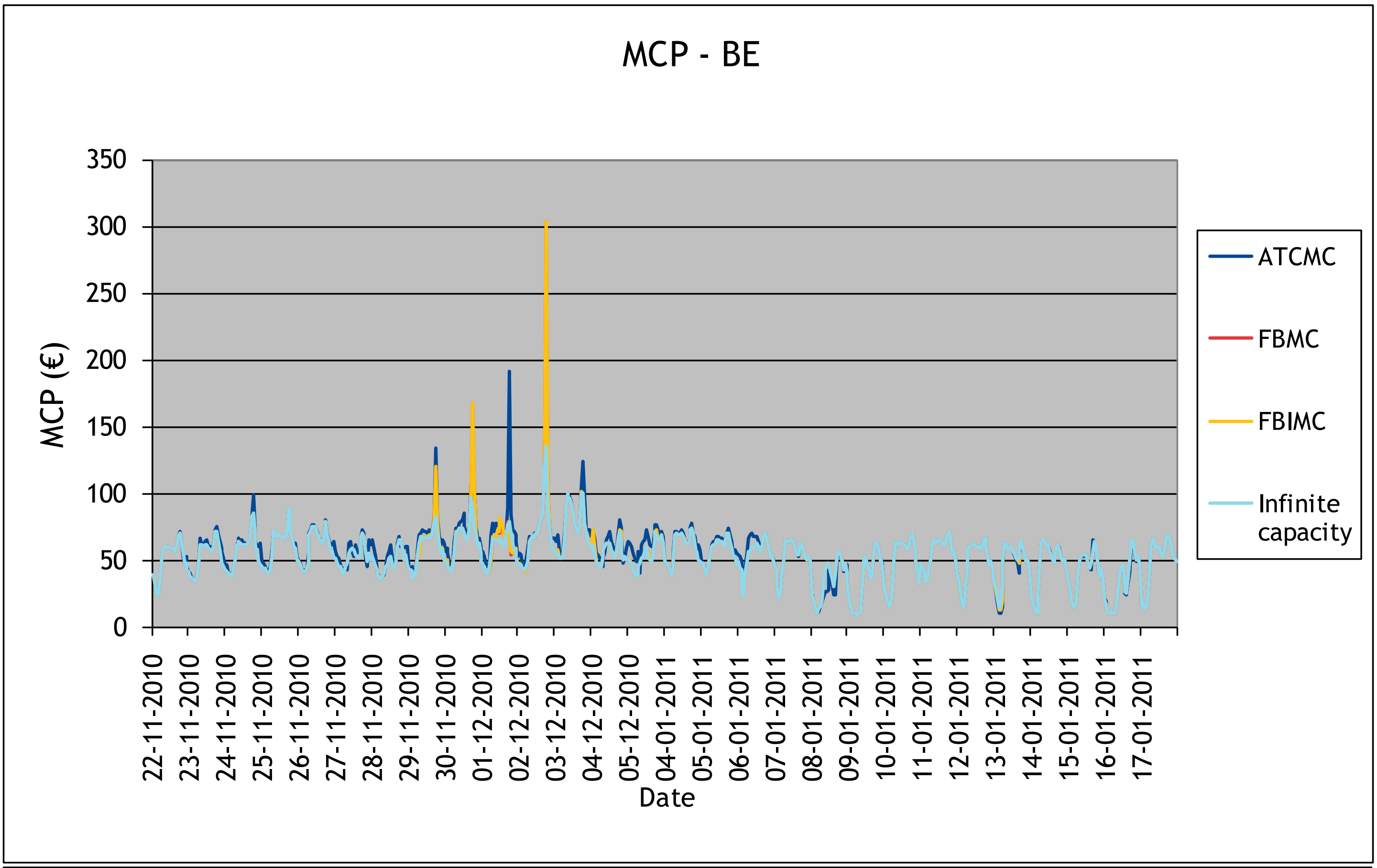
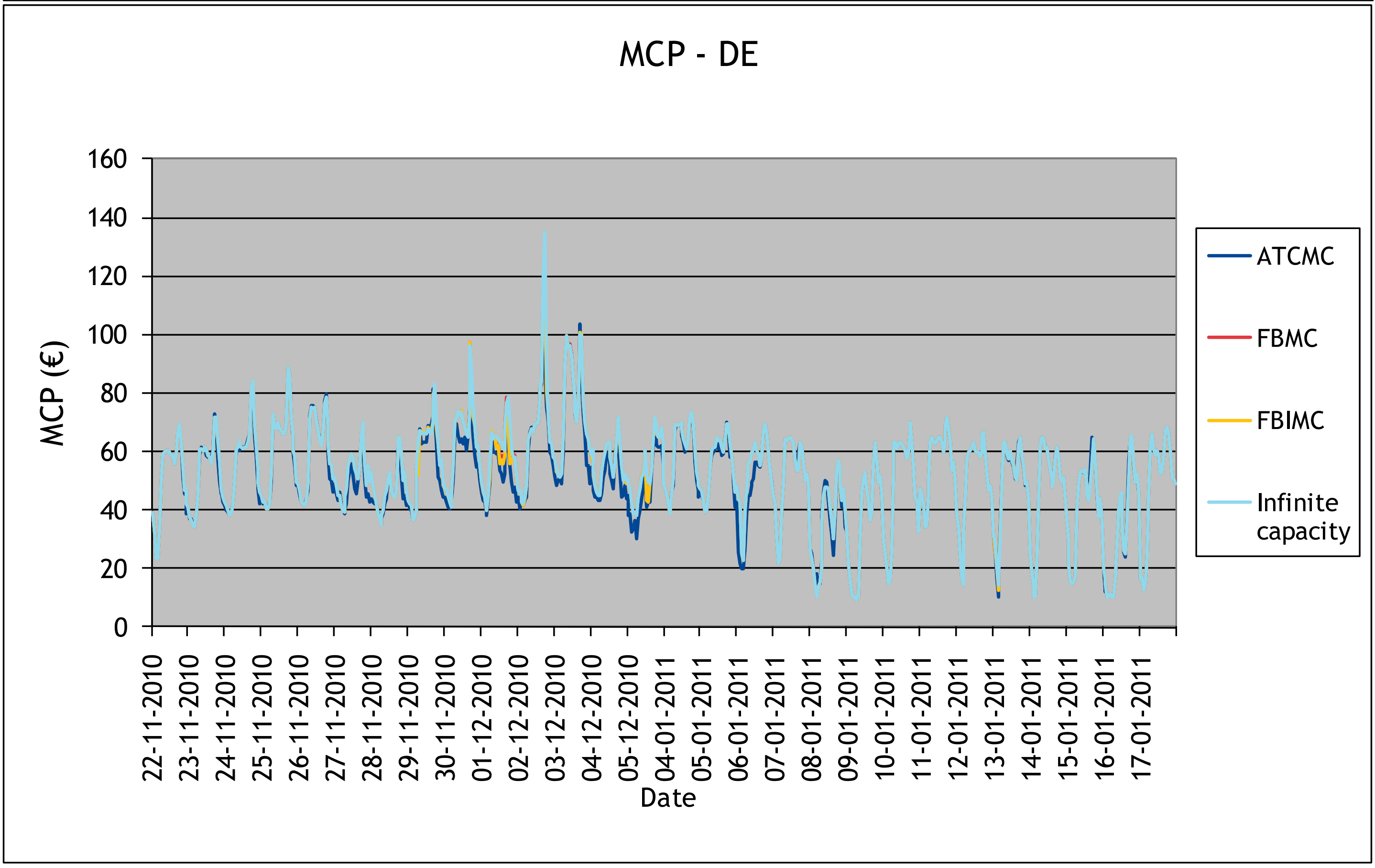


Figure 16: Daily baseload price per country


MCP - BE
350
300
250
200
150
100
50
0
MCP (€)
22-11-2010
23-11-2010
24-11-2010
25-11-2010
26-11-2010
27-11-2010
28-11-2010
29-11-2010
30-11-2010
01-12-2010
02-12-2010
03-12-2010
04-12-2010
05-12-2010
04-01-2011
05-01-2011
06-01-2011
07-01-2011
08-01-2011
09-01-2011
10-01-2011
11-01-2011
12-01-2011
13-01-2011
14-01-2011
15-01-2011
16-01-2011
17-01-2011
Date
ATCMC
FBMC
FBIMC
Infinite capacity


MCP - DE
160
140
120
100
80
60
40
20
0
MCP (€)
22-11-2010
23-11-2010
24-11-2010
25-11-2010
26-11-2010
27-11-2010
28-11-2010
29-11-2010
30-11-2010
01-12-2010
02-12-2010
03-12-2010
04-12-2010
05-12-2010
04-01-2011
05-01-2011
06-01-2011
07-01-2011
08-01-2011
09-01-2011
10-01-2011
11-01-2011
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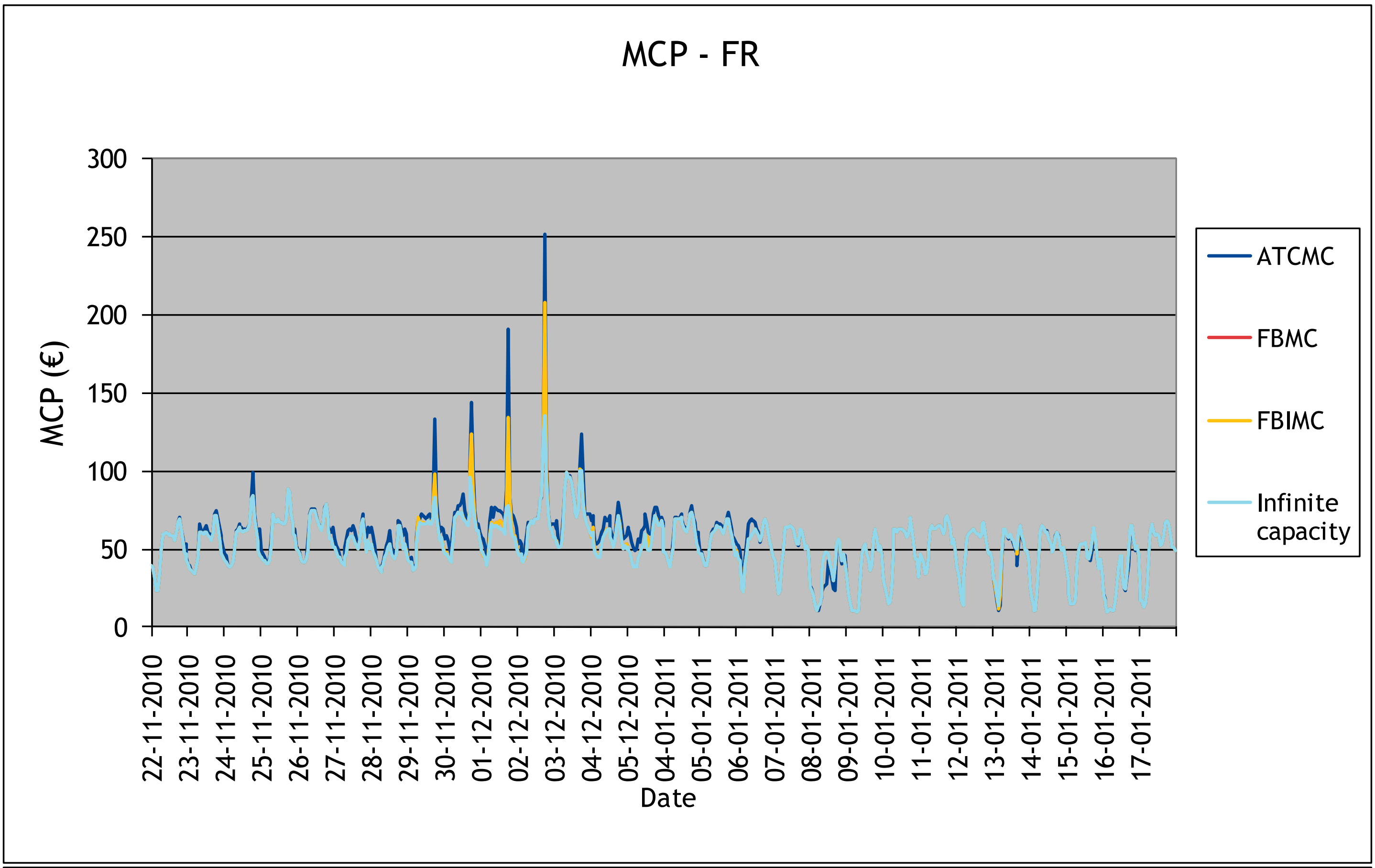
14-01-2011
15-01-2011
16-01-2011
17-01-2011
Date
ATCMC
FBMC
FBIMC
Infinite capacity



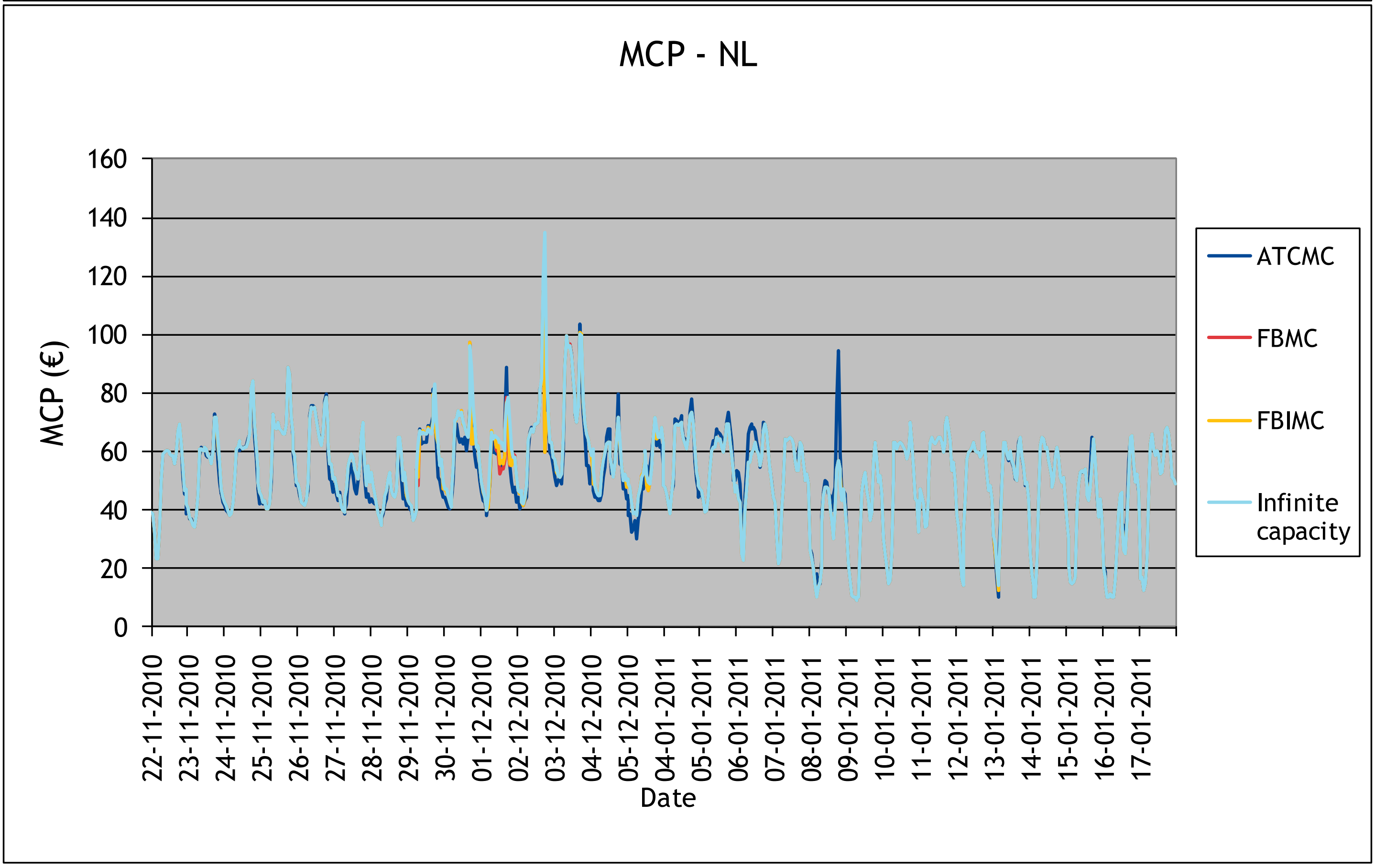


Figure 17: Hourly clearing price per country

3.4.9 Frequency of non-intuitive situations

- According to the "source-to-sink intuitivity"

Intuitiveness is defined in section 3.3. A non-intuitive situation can be characterized by the fact that the N countries with the lowest clearing price are exporting. The table below shows the number of hours in which such situations occurs.

Only 16 hourly situations out of 672 are non intuitive in FBMC. As expected, none are observed in FBIMC and ATCMC.

	Number of hours where situations are non "source-to-sink intuitive"	Proportion of hours where situations are non "source-to-sink intuitive"	Proportion of hours where situations are non "source-to-sink intuitive" among congested hours
ATCMC	0	0 %	0 %
FBMC	16	2.4 %	31.4 %
FBIMC	0	0 %	0 %
ISO	0	0 %	0 %

- according to the "bilateral intuitivity"

We define a situation as being "bilateral intuitive" if it exists at least one set of intuitive bilateral exchanges (from the cheapest bidding area to the most expensive).

	Number of hours where situations are non "bilateral intuitive"	Proportion of hours where situations are non "bilateral intuitive"	Proportion of hours where situations are non "bilateral intuitive" among congested hours
ATCMC	0	0 %	0 %
FBMC	16	2.4 %	31.4 %
FBIMC	0	0 %	0 %
ISO	0	0 %	0 %

Since bilateral intuitivity is more constraining than the source to sink intuivity we should always have the following inequality:

$$\textit{Number of source to sink non intuitive situation} \leq \textit{number of bilateral non intuitive situation}$$

Here it is verified: the situations identified as non intuitive are the same in both definitions of non-intuitivity.
In FBIMC, all situations are bilateral intuitive[19].

3.4.10 Comparison of isolated prices vs coupled prices

As coupling markets usually increases price convergence, situations in which one of the market clearing prices is higher than the highest price of all markets in isolated mode or in which one of the market clearing prices is lower than the lowest price of all markets in isolated mode are monitored.

It happens for one situation (November 29th, 8:00) with FBMC that a market clearing price is lower than the lowest price of all markets in isolated mode; no such occurrences in FBIMC and ATCMC were observed. The fact that it happens more often with FBMC is expected: indeed, there are 2 causes to such situations: either the effect of block orders -but it is expected that the price difference is relatively low- and non-intuitiveness, which happens only under FBMC. On November 29th, 8:00, the lowest market clearing price is 49.98 €/MWh in Germany in isolated mode whereas it is 48.26 €/MWh in Netherlands in FBMC, i.e. a difference of 1.72 €/MWh.

3.4.11 Hour-to-hour net position volatility

For a given country, the rapid change of the net position can be a problem because it happens very quickly at clock change. This is why the monitoring of the distribution of the hour-to-hour net position difference has been decided.

[19] This observation is meaningful as FBIMC enforces only source-to-sink intuitivity, and not bilateral intuitivity.

Figure 18 presents this results through histograms of hour-to-hour net position difference for ATCMC, FBIMC, FBMC and also infinite capacity market coupling. The volatility of net positions increases in FBMC and increases even more with infinite capacity: this feature comes from the increase of cross-border capacities (and therefore cross-border exchanges), and is not a feature linked to FB itself.

This volatility is questionnable from a TSO point of view, because it might endanger the security if too high differences of net positions from one hour to the other are observed: the generation might not be able to follow these high changes.

If this volatility is a problem for a TSO, as already studied before the launch of ATC market coupling, the ramping constraint could be activated in COSMOS to the level requested. A day-ahead market welfare decrease would be expected in these specific hours where the net position change is limited. Simulations would allow the computation of the welfare loss.

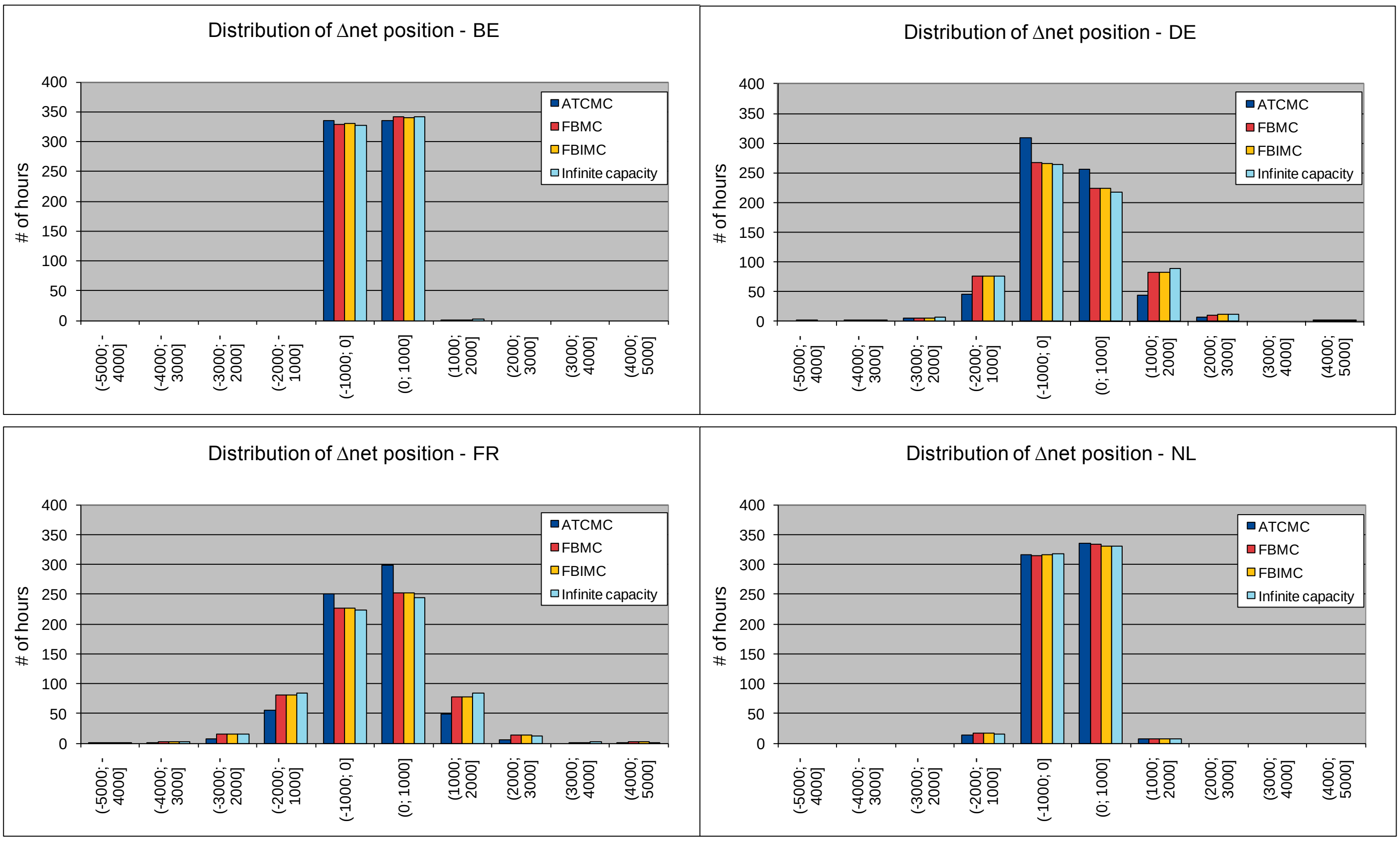


Figure 18: Net position volatility per country

3.4.12 Standard market resilience study

A resilience study consists in adding buy (resp. sell) base load bids at the maximum (resp. minimum) price allowed and to study the impact on prices. In a given situation, the more resilient method is the one for which the price change is lower.

To summarize the findings, the X^{th} centile of the price difference is computed[20]. For example, if the 90^{th} percentile of the price difference after the addition of a 1000 MW buy order is 6 €/MW.h, it means that, in 90% of situations, the price difference is lower than 6€/MW.h and in 10% of situations, the price difference is larger than 6 €/MWh. For sell orders, the definition is reversed: if the 90^{th} percentile is -6 €/MW.h, it means that, in 90% of situations, the price difference is larger than -6 €/MW.h (i.e. lower in absolute value).

Figure 19 and Figure 20 present the 90^{th} centile and the 97.5^{th} centile for each bidding area for ATCMC and FBMC. Overall, the resilience is better in FBMC than in ATCMC, which is consistent with the fact that the FB domain is larger than the ATC one. However, the 90^{th} and the 97.5^{th} centile for the 1000 MW buy order in Belgium is lower in ATC than in FB[21]. This is consistent with the situation of December 2^{nd}, 19:00 (cf. paragraph 3.4.7) in which the price in

[20] A centile (or percentile) is the value of a variable below which a certain percent of observations fall. For example, the 20th percentile is the value (or score) below which 20 percent of the observations may be found. See http://en.wikipedia.org/wiki/Percentile for more explanations.

[21] ATC MC clearing points are outside of FB domain when the FB MC resilience is worse than the ATC MC one, which normally appears only on unlikely and impossible ATC corners described in section 2.3.1.1.

Belgium is higher in FBMC than in ATCMC. Unfortunately, results for FBIMC were unavailable at the time of the report and may have shown an improvement the Belgium resilience. Finally, it is important to note that resilience is computed from price difference, therefore a decreased resilience does not mean that the Belgium price with an additionnal buy order would have been higher in FBMC than in ATCMC: indeed, one should take into account the overall decrease of prices on the Belgium market in FBMC.

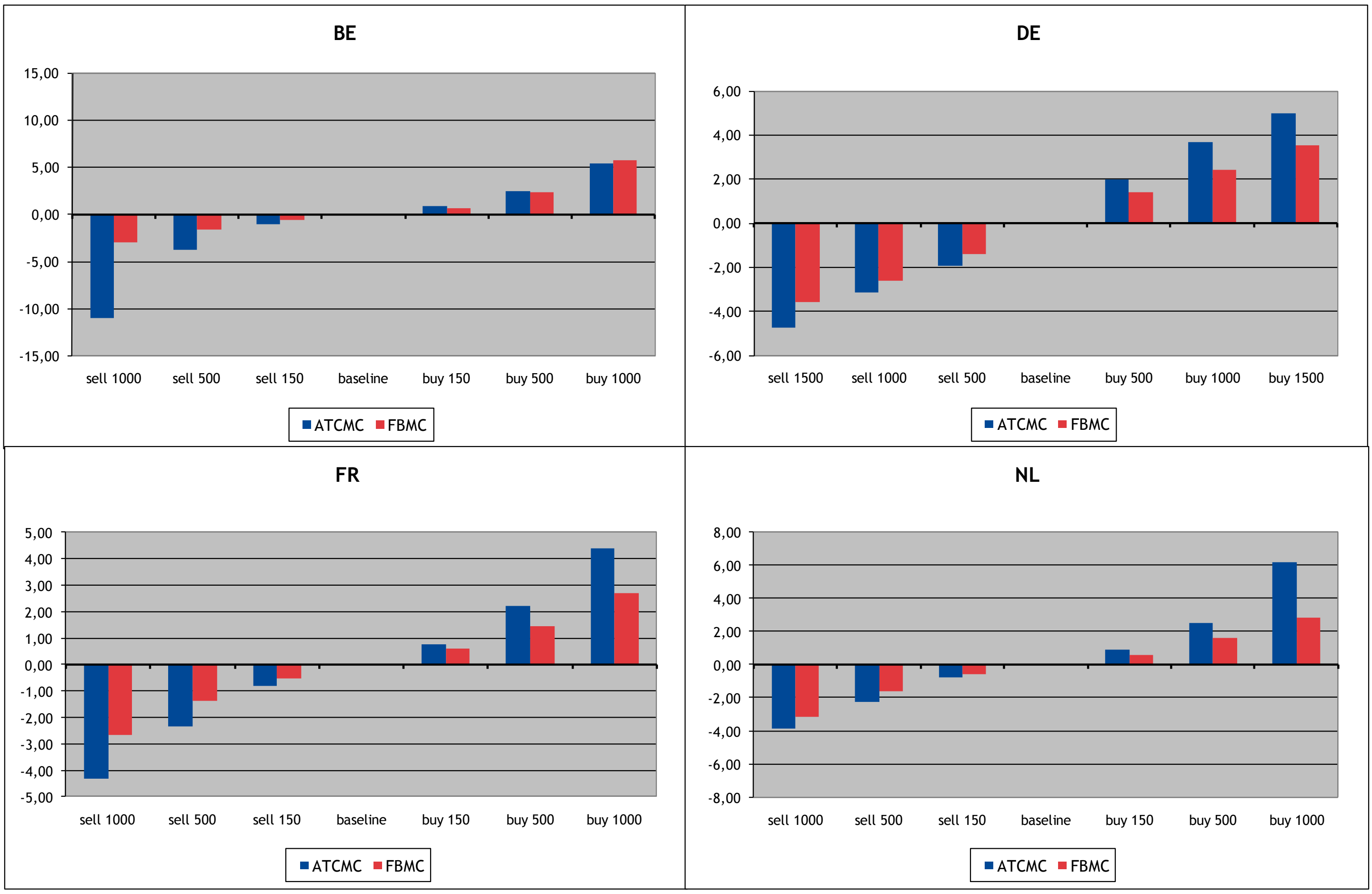


Figure 19: Resilience per bidding area at 90% in €/MWh

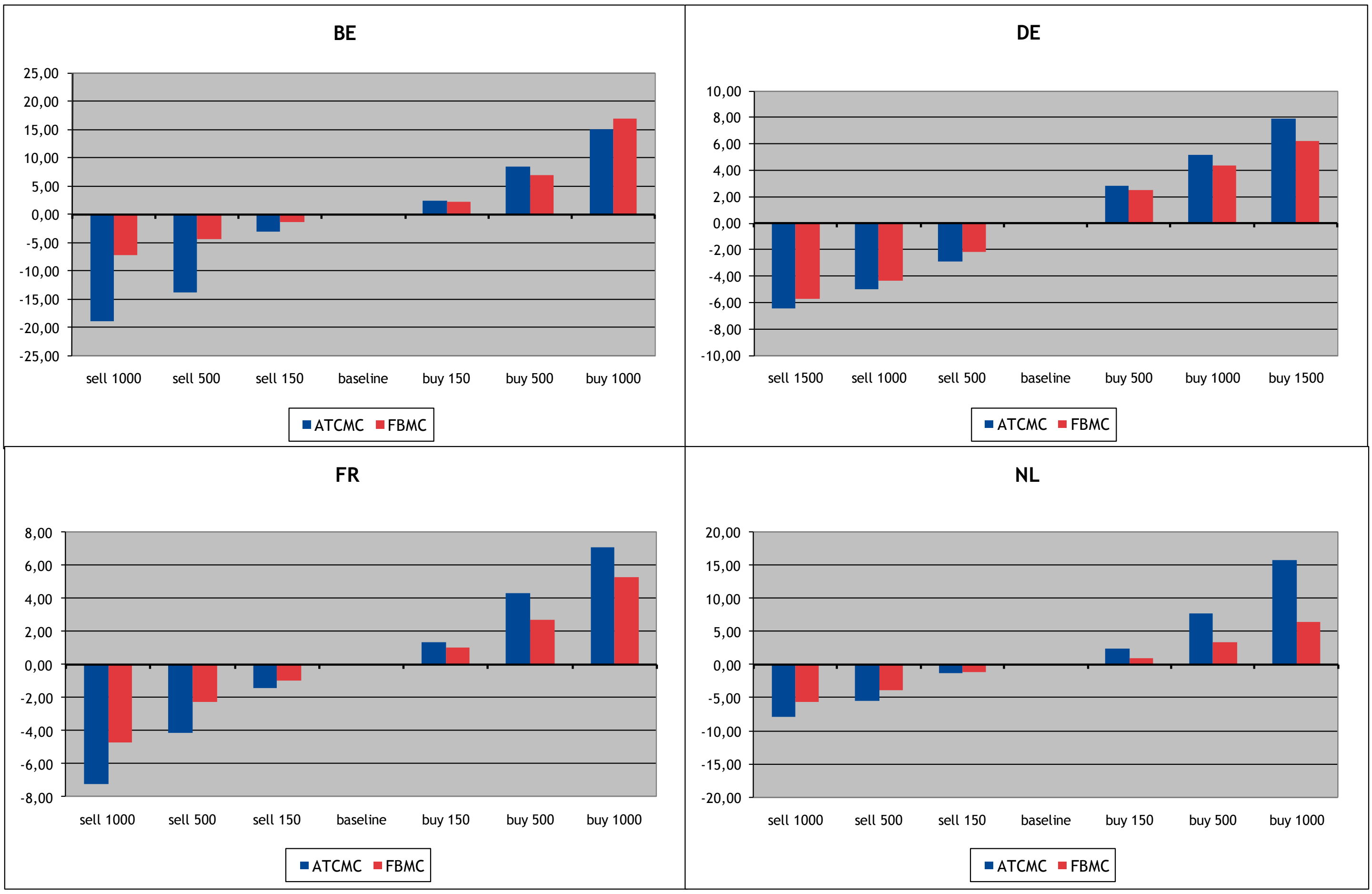


Figure 20: Resilience per bidding area at 97.5% in €/MW.h

3.5 Conclusions

Simulations comparing ATC, FBMC and FBIMC on a short period of time (2 times 2 weeks in winter) gave the following results:

- Day-Ahead Market Welfare and Convergence indicators are significantly better with FBMC or FBIMC than with ATCMC.
- Net position volatility increases, as there is more capacity with FB and thus more cross-border exchanges. This is an issue for TSOs from the operational point of view that is also monitored in the current ATCMC, but the problem can be solved by the activation of the so-called ramping constraint in COSMOS.
- Non-intuitive situations were found. Enforcing intuitiveness through FBIMC deteriorates only very slightly the indicators.
- Overall, resilience is improved in FBMC for all hubs (including Belgium), but a poorer resilience of the Belgium market in heavily congested situations was observed and should be monitored.

Notwithstanding the limitations mentioned in section 3.2.2, the market impact analysis concludes that FBMC and FBIMC have a positive impact on the market compared to ATCMC.

The FBV TF recommends continuing to monitor the indicators studied in this report while the project is ongoing in order to confirm the observations on representative simulation periods. It will also allow configuring the coupling algorithm through deciding between FBMC and FBIMC and helping to determine whether the bidding area ramping constraints should be activated or not.

4. Analysis of the interactions with coupling to other initiatives

4.1 Objective

The objective of this chapter is to evaluate qualitatively the scenario of CWE MC coupling to other initiatives especially under the FB methodology, and how CWE FB MC could be enlarged to other regions or project (FB-FB, FB-ATC, FB-Explicit…).
This document does not address governance issues at all.

Context:
Nowadays, different regional initiatives are ongoing, striving for more harmonization.
The different ongoing regional projects are the following:

- NWE (North West Europe): Northern market splitting / Interim Tight Volume Coupling (ITVC) between Germany and Denmark
- SWE (South West Europe): Market splitting between Spain and Portugal / Projects for creating a price coupling between France and Mibel, lead by Power Exchanges.
- CSE (Central South Europe): Italian market splitting and Slovenian price coupling
- CEE (Central Eastern Europe): Project to set up Flow-Based explicit auctions and Czech Republic-Slovaquia coupling
- FUI (France-UK-Ireland): Project of price coupling of GB and Ireland to CWE.
- PCR (Price Coupling of Regions): Cooperation of 6 Power Exchanges for an European Price Coupling Solution (APX-Endex, Belpex, EPEX Spot, GME, Nord Pool Spot, and OMEL)

In 2009, the EU target has been set to be a single price coupling, achievable by 2015.
Hereunder, the associated foreseen roadmap is depicted:

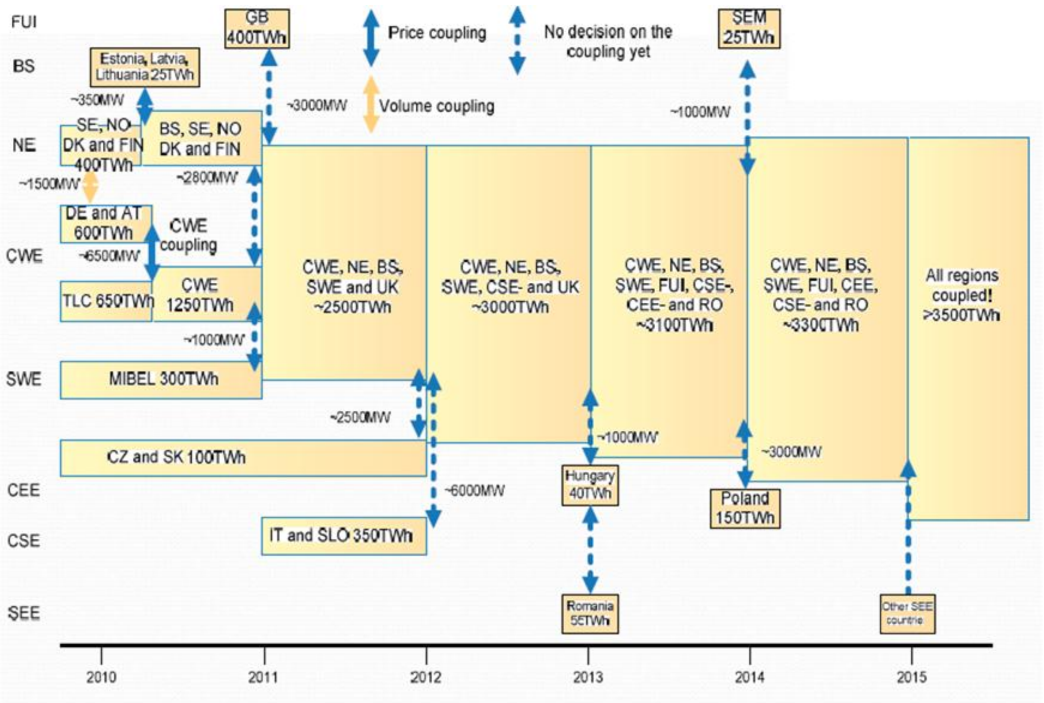


Figure 21 Florence forum roadmap[22]

4.2 Scenarios of coupling to other initiatives:

4.2.1 Price coupling

Any implementation path to European single price coupling is feasible (coupling to other initiatives). This can be decomposed in elementary scenarios (detailed in annex A), but general properties apply to each scenario.
The different type of couplings to other initiatives, with implicit auctions in place, could be:

- Coupling to initiatives including a DC cable
- Coupling to initiatives including several DC cables

[22] http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_WORKSHOP/Stakeholder%20Fora/Florence%20Fora/PCG/meeting_17_2_pcg_presentation.pdf

- Coupling to an initiative based on an ATC-based area
- Coupling to an initiative based on several ATC-based areas
- Coupling to an initiative based on a FB area

But all these theoretical scenarios bring up the same issues (see annex A), which mainly rely on how to conciliate ATC-based and Flow-Based constraints.

European full Flow-Based Market Coupling is undoubtedly the most efficient scenario, regarding optimization of available capacities to the market, maximization of social welfare, and coordination between TSOs.
But for some parts of Europe, where capacity splitting between borders is not an issue and where loop flows are inexistent or negligible, the NTC approach could be sufficient. Besides, the full European FB MC implementation may have to take pragmatic paths like the interim coupling of both FB and NTC bidding areas. This is what is called FB ATC hybrid[23] price coupling (as detailed in the following chapters).

4.2.2 Compatibility with neighbouring initiatives under explicit auctions

CWE FB MC is compatible with any NTC or FB explicit auctions out of the CWE region:

When several borders influence the same constraints, part of the capacity must be booked for the borders in explicit auctions, and the rest is allocated for the borders in implicit auctions.
Example: FR and DE have to book capacity ex-ante in the CWE FB computation for trades with CH.

Remark: as the same analysis applies to CWE ATCMC compatibility with neighbouring initiatives under explicit auctions, the same level of compatibility is expected from CWE ATCMC and CWE FBMC.

TSOs have described how they plan to calculate the NTCs for each non-CWE NTC border when FB in CWE is operational (cf. 2.6.1).

4.2.3 Compatibility between two different initiatives with implicit auctions (market coupling)

Concerning compatibility with adjacent implicit coupling initiatives independent from CWE, the definitive target remains a single price coupling, but in the meantime CWE FBMC ensures compatibility with these initiatives with one of the following interim solutions:

a) With explicit auctions for the interconnection between the two initiatives: the capacities in each region are split ex-ante between the explicit auctions on the interconnection and the implicit ones within each region.

b) With a tight volume coupling (cf. Figure 22) if the pre-requisite of compatibility between PXs' gate closures of both coupling regions is fulfilled and as long as the volume coupling function takes into account CWE FB constraints and is unique for all coupled zones.

Indeed, in order to couple several price coupling zones, the volume coupling function must be unique. Furthermore, it might be better to run the same algorithm during the Tight Volume Coupling and during the Market Couplings in order to avoid price discrepancies. Note that it does not mean that only one actor should execute the algorithm: it is possible that the same algorithm is run on the same data by many actors.

Remark: as the same analysis applies to CWE ATCMC compatibility with neighbouring initiatives under implicit coupling, the same level of compatibility is expected from CWE ATCMC and CWE FBMC.

[23] This FB ATC hybrid price coupling is a totally different concept than the hybrid ATC volume coupling which was introduced by e-bridge in the NWE coupling study (Analysis of Coupling Solutions for the CWE Region and the Nordic Market). Here hybrid means ATC and FB.

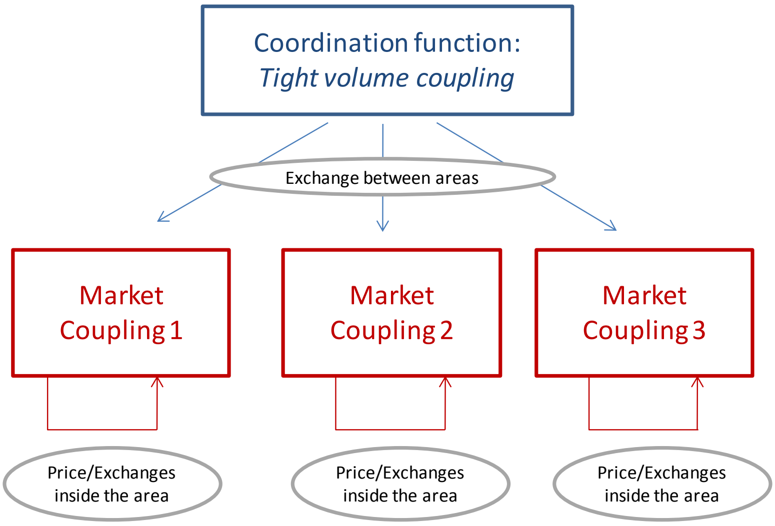


Figure 22: Tight volume coupling system

4.2.4 Concerning the specific case of Interim Tight Volume Coupling between NWE and CWE

In its current state, ITVC uses CWE ATCs (among other data) to perform its volume coupling and cannot use FB constraints instead.

It is not known with certainty whether the NWE enduring solution, supporting FB constraints, will exist before FBMC goes live in the CWE region. CWE TSO and PXs recommend that a solution implementing FB goes live as quickly as possible.

However in case no such solution is available when FBMC goes live, FBMC should be able to go live anyhow. In this case, two decisions are possible:

- Either implement FB into ITVC.
- Or, as ITVC was always meant to be an interim solution, decide not to adapt it to FB constraints. TSOs could submit CWE ATC values consistent with (i.e. within) the CWE FB domain. This is in fact a matter of choosing one set of NTCs inside the FB domain i.e. capacity splitting between borders. This would be a coordinated choice decided at the time it is needed, and its impact will be limited, since the ITVC is an interim solution.

Only in this situation, these propositions would have to be discussed in the context of the Interim Solution Agreement (ISA), for which a specific change control procedure will be put in place.

To get an idea of the discrepancies that may be induced by not having an adapted method (either sending ATCs derived from FB domain to ITVC or implementing FB into ITVC), the following test was performed: As ITVC is a volume coupling, it is based on the computation of the flows on connections between Nordic countries and CWE countries. A good indicator of the tightness of the volume coupling is the frequency of situations in which the energy flows from a high price area to a low price one. With the simulations presented in section 3, it is possible to compare this indicator with the historical results (ATCMC) and in the case FBMC had been in place with ITVC still using ATCs. The results are given in the table below:

	DE-DK1 flow		DE-DK2 flow	
	ATCMC	FBMC	ATCMC	FBMC
Frequency of adverse flows	19%	27%	1%	19%
Average price spread in case of adverse flows	0.09 €	2.83 €	0.03 €	2.73 €
Maximum price spread in case of adverse flows	1.21 €	13.10 €	0.07 €	18.52 €

The price spread is significantly increased on both links between Germany and Nordic countries[24]. However, this is not conclusive on the feasibility of ITVC using ATCs derived from FB domain. Indeed, it is possible to design a new way to compute ATCs within a FB domain with a better ex-ante market splitting, for example by using the tendency of the market during the previous days. Note that the simulation of such a method requires running ITVC with ATCs different from the historical ones.

[24] The simulations were done before the integration of Norned into ITVC.

4.2.5 Concerning the specific case with CEE and introduction of price coupling

In this chapter we consider introducing implicit auctions within the CEE region in its current state of integration (FB explicit coupling) and link it with CWE FBMC[25].

We could imagine a full inclusion of CEE in CWE FBMC in one step. This would mean one single FBMC covering both regions, adding all CEE bidding areas at the same time. Note that this is not what has been foreseen in the EC coupling roadmap (cf. Figure 21 Florence forum roadmap). Hopefully, today CEE and CWE produce the same FB parameters in terms of output, but FB parameter calculation processes are different in CWE and CEE. In this context the most refined methodology of the two should be used. CWE TSOs want to stress this out: FB qualification and FB validation phases in operational process are of utmost importance, for security of supply and capacity maximization.

But as previously said, this scenario is quite unlikely to happen. We may see sequential coupling: CEE bidding areas joining CWE price coupling one after the other. In this case what would be the scope and the pertinence of CEE explicit FB allocation?
For example, let's consider Czech Republic and Slovakia bidding areas joining CWE MC, as proposed in the EC coupling roadmap. The capacity between Germany and Czech Republic would be allocated within CWE MC and not anymore within CEE FB explicit allocation. In this scenario Poland would be separated from the rest of other uncoupled CEE bidding areas (i.e. Austria, Hungary and Slovenia). Sequential inclusion of CEE bidding area in CWE MC would mean dismantling CEE explicit FB allocation.

4.3 FB ATC hybrid price coupling

What is called "FB ATC hybrid price coupling" is a single price coupling including both FB and ATC constraints, depending on the area. The different possible scenarios of such situations (coupling between FB and ATC areas) are listed in section 5.10, such as scenarios CWE+UK and CWE+Nordic countries.
The difficulty in a hybrid model is to take fairly into account the influence of one model over another: if a critical branch is influenced by an ATC transaction (which might be the case in a meshed grid), not taking into account the influence of the ATC transaction on this branch is sub-optimal, since there is then a need to book some margin on the critical branch for the ATC transaction and give the remaining margin to the flow-based market coupling.

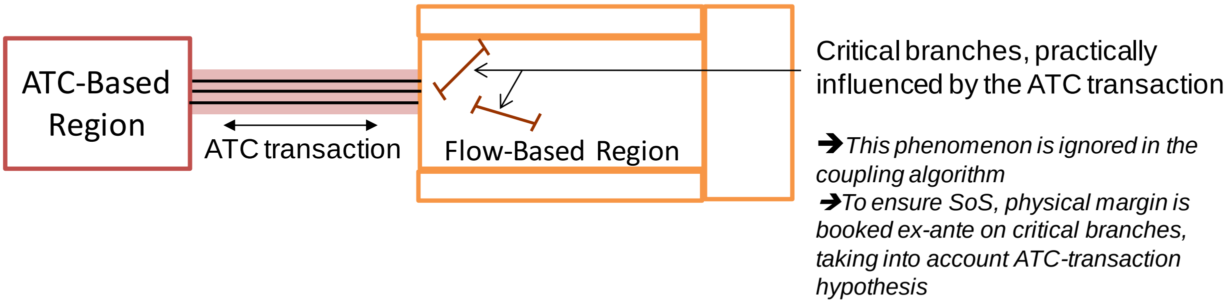
FB ATC hybrid price coupling has two variants, depending on whether the commercial exchanges over the ATC borders are taken into account in the FB model or not. The advantages and the consequences of taking into account the net positions of the ATC bidding area into the flow-based model will be addressed in this chapter.

For example, in CWE, it makes a huge difference for the French grid whether to import 2000 MW from the United Kingdom or to export 2000 MW to the United Kingdom. In the capacity calculation process done ahead allocation, TSOs need to take hypothesis on the direction of the FR-UK exchange in order to take into account its impact on critical branches. If the real FR-UK ATC transaction influence on the critical branches is not taken into account during the allocation phase (through the coupling), booking some margin on the critical branches is needed in order to ensure the Security of Supply. However this margin might not be used, depending on the allocated ATC transaction: this is clearly a waste of capacity.
Here we take the example of a DC cable, but this is general to all ATC-based borders, AC or DC connected, as long as they influence critical branches in the Flow-based Area (see Appendices 5.10 and 5.11).

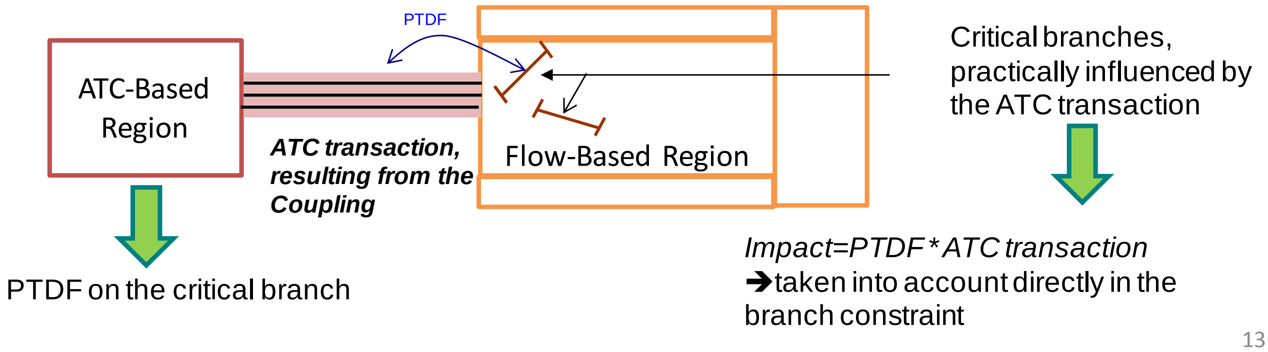
In the coupling algorithm, two approaches are possible, and it is mainly a question of modelling in the algorithm:

- The "rough" FB ATC hybrid price coupling: realized ATC transactions are not taken into account in the physical margins of critical branches in the FB model. Therefore, in order to guarantee SoS, the most constraining case of allocated ATC has to be booked in advance in the physical margins of critical branches in the FB model.

[25] Note that problems exposed here are related to the simultaneous coupling of an implicit zone with an explicit zone, and are therefore similar whether CWE uses ATCMC or FBMC. The fact that CEE uses FB constraints to describe its security domain as CWE may do, does not alleviate these problems.



- The "advanced" FB ATC hybrid price coupling: the influence of realized ATC transaction on the physical margins of the critical branches in the FB model is taken into account during allocation. Thus no priority is given to ATC transaction regarding FB transaction: the market fully decides about the usage of the physical margin without booking a part of physical margin for one specific border in advance. This approach uses the valuable information of the allocated ATC transaction, whereas the "rough" approach does not.



4.3.1 Detail of "rough" FB ATC hybrid price coupling:

The overall net position is the sum of the "Flow-Based net position" (resulting from FB constraints) and the incoming ATC-Based exchanges (resulting from the ATC constraints). ATC exchanges can be done through AC or DC connections. DC connections and AC connections are considered separately for the sake of clarity.

$$\forall A \text{ zone}$$
$$\text{Sale}_A - \text{Purchase}_A = \text{Net Position}_A = \text{Net Position}_A^{FB} + \sum_{\substack{I \text{ zone} \in \text{AC connected area}, \\ I \neq A}} \text{Exchange}_{A \to I} + \sum_{c \in \text{cable DC}} \text{Exchange}_{c \to A}$$

The variables $\text{Net Position}_A^{FB}$ have to satisfy flow-based constraints and the variables $\text{Exchange}_{A \to i}$ should satisfy ATC constraints:

- The commercial exchanges over each ATC border have to satisfy ATC limits:
  $\forall A, B \text{ zones} : -\text{ATC}_{B \to A} \leq \text{Exchange}_{A \to B} \leq \text{ATC}_{A \to B}$
- For each bidding area, the "FB net position" has to satisfy FB constraints:
  $\forall k \text{ critical branch} : \sum_A \text{PTDF}_A^k \cdot \text{NetPosition}_A^{FB} \leq \text{Remaing Available Margin}^k$

  In this constraint, we clearly see that the influence of ATC transaction (through PTDFs) on the critical branch is ignored.

4.3.2 Detail of "advanced" FB ATC hybrid price coupling:

The only difference between the model detailed above lies in the last equation describing the FB constraints. To take into account the influence of all realized ATC transactions (influence of the variation of ATC net positions on the continental Europe synchronous area (AC connected) and the influence of the variation of injection from DC cable on the continental Europe synchronous area), the FB constraint should apply to the overall net position:

$$\forall k \text{ critical branch,}$$
$$\sum_{A \text{ zone} \in \text{AC connected area}} \text{PTDF}_A^k \cdot \left(\text{Net Position}_A^{FB} + \sum_{\substack{I \text{ zone} \in \text{AC connected area},\\ I \neq A}} \text{Exchange}_{A \to I} + \sum_{c \in \text{DC cables}} \text{Exchange}_{c \to A} \right)$$
$$+ \sum_{c \in \text{DC cables linked to AC connected area}} \text{PTDF}_c^k \cdot \text{Exchange}_c \leq \text{Remaing Available Margin}^k$$

This equation can be summed up into:

$$\forall k \text{ critical branch,}$$
$$\sum_{A \text{ zone} \in \text{AC connected area}} \text{PTDF}_A^k \cdot \text{Overall Net Position}$$
$$+ \sum_{c \in \text{DC cables linked to AC connected area}} \text{PTDF}_c^k \cdot \text{Injection from the DC cable} \leq \text{Remaing Available Margin}^k$$

It means that each zone of the AC connected area (like continental Europe) and each DC cable connected to it have PTDFs, even if they do not use the FB methodology. Indeed, the computation of the PTDFs for cables and for ATC-based areas can be done by the members of the FB area (since it influences their own critical branches).
If we do not apply this "advanced" hybrid coupling, TSOs must take the worst hypothesis of ATC exchange when computing FB parameters, in order to guarantee the SoS. With the advanced hybrid coupling, no hypothesis is made. Indeed the ATC transaction is computed simultaneously, taking into account its influence on all critical branches of the FB model.

To sum up the important ideas of the "advanced" ATC-FB hybrid price coupling, an important point should be stressed here:

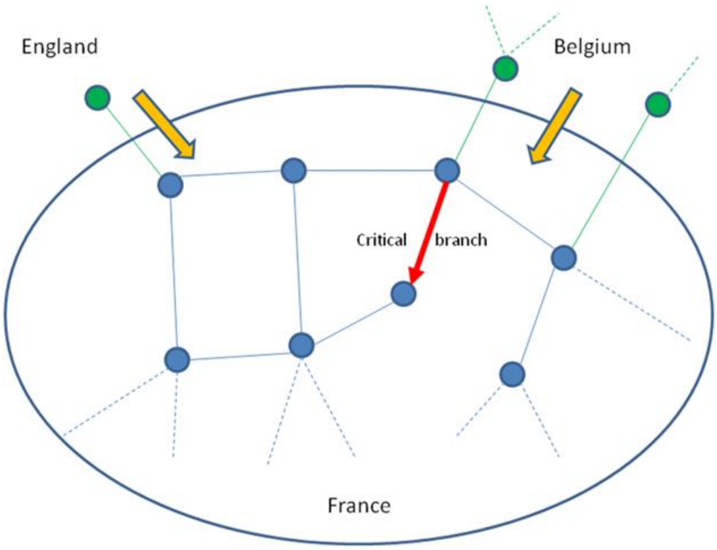
- For ATC transaction in a synchronous area (through AC connections), what is important is the influence of the net position of the area on the FB model (and not the transaction ATC itself): the overall net position of the ATC area is to be considered.
- For ATC transaction on a DC cable, what is important for the FB model is the injection (coming from the DC cable) in the synchronous area: the ATC transaction over the DC cable is to be considered.

We can enlarge the concept to several DC links or AC connections. The principle is always the same: for each ATC hub connected directly to a FB area, we need to take into account the influence of this transaction on the critical branch of the FB zone.
Besides:

- For an ATC-based zone connected with a DC cable: the PTDF is computed without grid model or GSK for the zone (influence of 1 additional MW on the substation connecting the DC cable on all critical branches of the FB zones)
- For an ATC-based zone connected with one or more AC connections: The PTDF is computed using a grid model (D2CF) and a GSK.

4.3.2.1 Advantages and consequences of advanced approach:

- **Advantages**
  a) Going back to the example with the France-Great-Britain interconnection: with the "rough" approach, RTE has to split capacity between Great-Britain and the other borders ex ante (This is done today in RTE NTC calculation). With this schematic representation:



When RTE computes UK→FR and BE→FR capacities, RTE has to make sure that the physical flow on the critical branch will be lower than the maximum flow (in accordance with its capacity calculation risk policy).
If the "rough" approach is in operation, RTE must dedicate some physical margin on the critical branches to import from/export to UK in order to guarantee the SoS.
If UK exports the maximum available to FR then the maximum available flow may be reached on the critical branches. But in the case the outcome of the market coupling is an export from France to the United Kingdom, some physical margin is left on the critical branch, which could have been used to increase BE→FR commercial exchanges. This leads to a suboptimal output.

The "advanced" approach solves this limitation. Unused capacity is not wasted: it allows netting on different borders. This results overall in more capacity and a better use of scarce resources. This is in fact an enlargement of FB main advantage to neighbouring ATC borders.
This type of situation would occur often in hybrid FB ATC coupling as it occurs as soon as a critical branch in a given FB zone is influenced by an ATC transaction.

  b) This allows more data exchange and a better vision of neighbouring grids (D2CF and GSK are needed[26] to compute the PTDFs of the ATC-based zone)

- **Consequences**
  Concerning the "side effect" of the "advanced" approach: the behaviour of ATC borders concerning coupling high level properties switches from an ATC perspective to a FB one: there could be different prices on each side of an ATC border whereas the exchange over this border is not equal to the ATC, because the limiting element is a critical branch of the FB model[27].Besides, if the intuitiveness is not enforced on the ATC-path, situations can happen where prices are non-intuitive on both side of an ATC-path.

4.3.2.2 Feasibility of "advanced" approach:

Cosmos can handle configurations, the "rough" and the "advanced" one.

[26] GSK and D2CF are needed for meshed and synchronous areas only.
[27] Example: FR-UK commercial exchange 1600MW (capacity is 2000MW) and Price UK – Price FR = 10€/MWh.

4.4 Conclusion

CWE MC coupling with other regions is feasible, whatever the type of extension (AC/DC area, FB or ATC, implicit or explicit). Indeed, among the different possible scenarios of coupling, no blocking problems are identified:

- Compatibility between different allocation methods is ensured: CWE FBMC is compatible with neighbouring explicit auctions or with another region under implicit auctions.
- Compatibility between different capacity calculation methods is ensured: in target solutions of single price coupling, the algorithm can take into account both FB and ATC constraints, and ensures compatibility between FB areas and ATC areas.

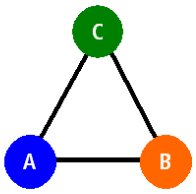
In hybrid coupling combining both ATC and FB constraints, special attention should be paid to the way the influence of ATC transactions on the FB model is taken into account:

- Either before the coupling, by booking some physical margin on the influenced critical branches, using ATC-transaction hypothesis.
- Or during the coupling, by taking into account directly in the FB model the influence of the realized ATC transaction (resulting from the coupling). This solution of "advanced" FB ATC hybrid price coupling appears to be the best one from a theoretical point of view.

5. Appendices

5.1 Capacity Domain representations: security of supply, ATC and FB

The purpose of this section is to introduce the Security of Supply (SoS) domain and the NTC splitting principle, in a pedagogical way. Let us consider 3 interconnected countries: A, B, and C.



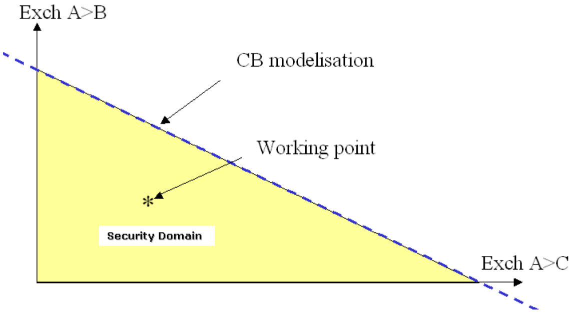
Security of Supply domain (based on 1 critical branch)

If we consider a critical branch in country A where:

- flows are only impacted by the $Exchange_{A\rightarrow B}$ and $Exchange_{A\rightarrow C}$ and the corresponding PTDF factors are $PTDF_{A=>B}$ & $PTDF_{A=>C}$
- the available margin is positive

In the exchange domain the constraint associated to this critical branch can be described by:

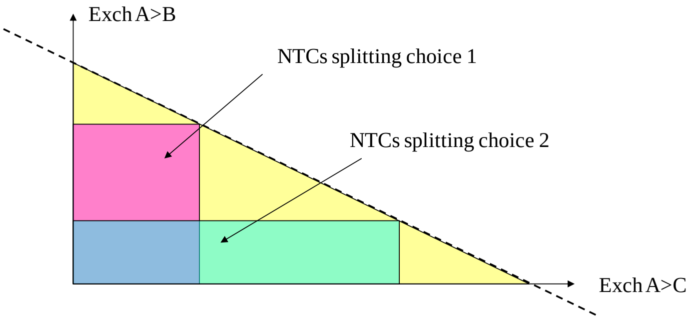
$PTDF_{A\rightarrow B} \,.\, Exchange_{A\rightarrow B} + PTDF_{A\rightarrow C} \,.\, Exchange_{A\rightarrow C} \leq Margin$



In the exchange domain that is shown in the graph, this constraint describes a straight line.

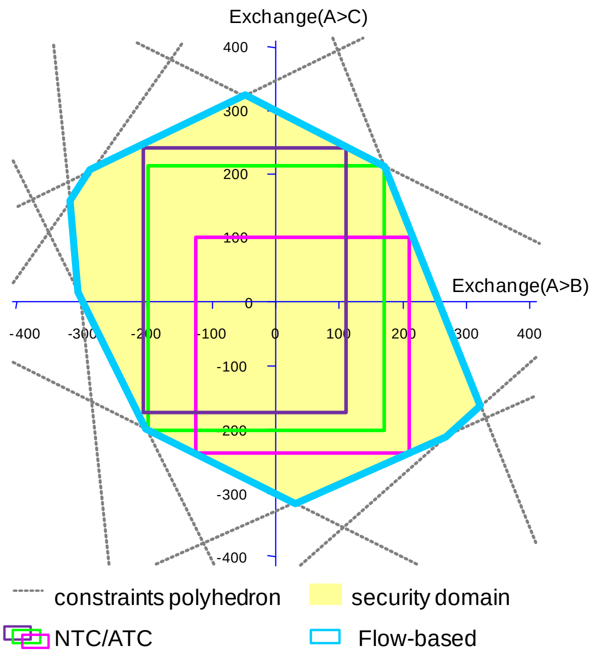
NTC splitting principle (based on a domain defined by 1 critical branch)

The figure below clearly indicates that the NTCs are just a choice to be made by the TSO within the domain defined by the critical branch.



Security of Supply domain (multiple critical branches)

The SoS domain is of course not defined by one critical branch only. In the graph below a more realistic view of the SoS domain is depicted, with three NTC-splitting options inside.

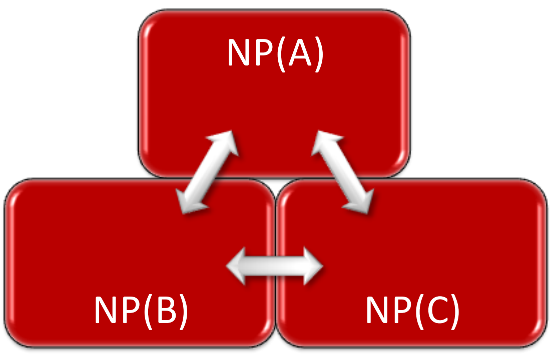


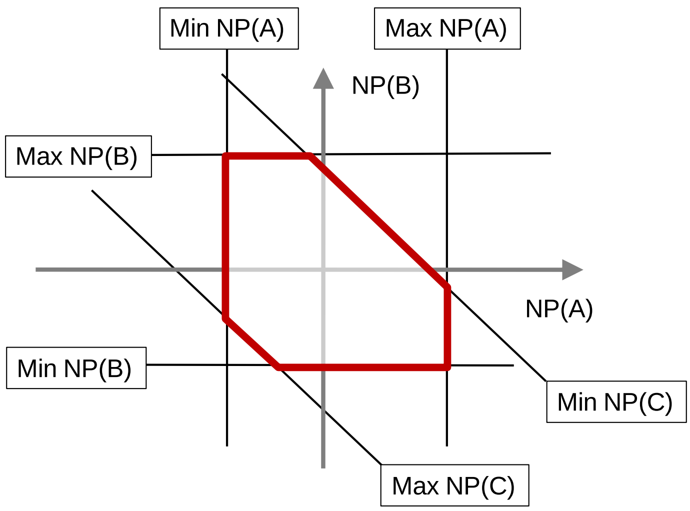
Please note that the FB domain is the SoS domain, whereas the NTC domain is one of the possible choices (of which three have been shown in the figure above) within the FB domain. For a practical figure, the reader is referred to section 2.2.6.

Previously we compared the FB and the ATC domain in a pedagogical way with bilateral exchanges on the axes. The added value of this approach is that the ATC domain for a three-country example can be represented as a square or rectangle, which eases the explanation of the corner concept, and the simultaneity principle.

In FB it is more logical to refer to net positions, as the FB constraints are a linear combination of the net positions. Therefore, a short description is given hereunder how the ATC domain looks like when it is visualized on axes that represent net positions instead of bilateral exchanges.

We will start we a three-country example, where the sum of the net positions equals zero: NP(A)+NP(B)+NP(C) = 0.





ATC and FB domain for CWE

The FB and ATC domain for the four countries of CWE can be represented as 3-dimensional bodies[28]. In the graph hereunder, both the ATC and FB search space are depicted in the same graph.

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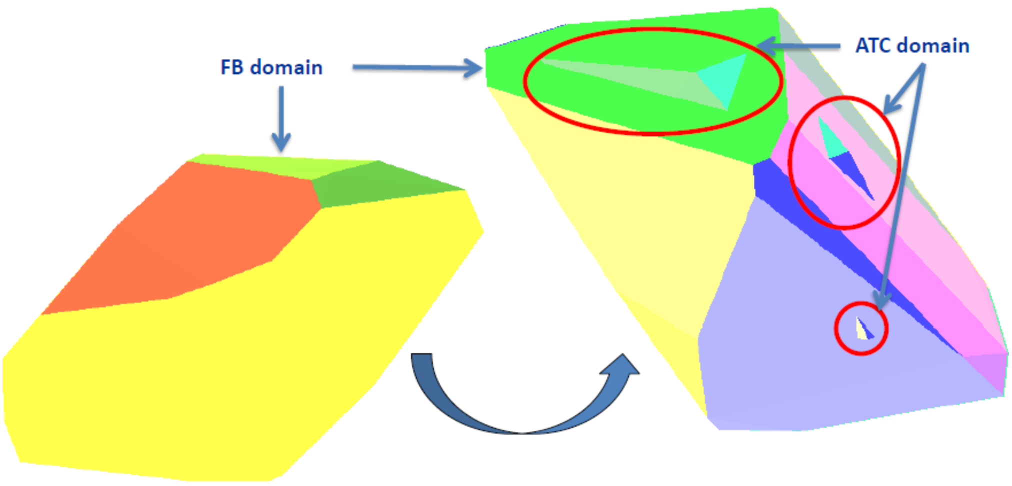
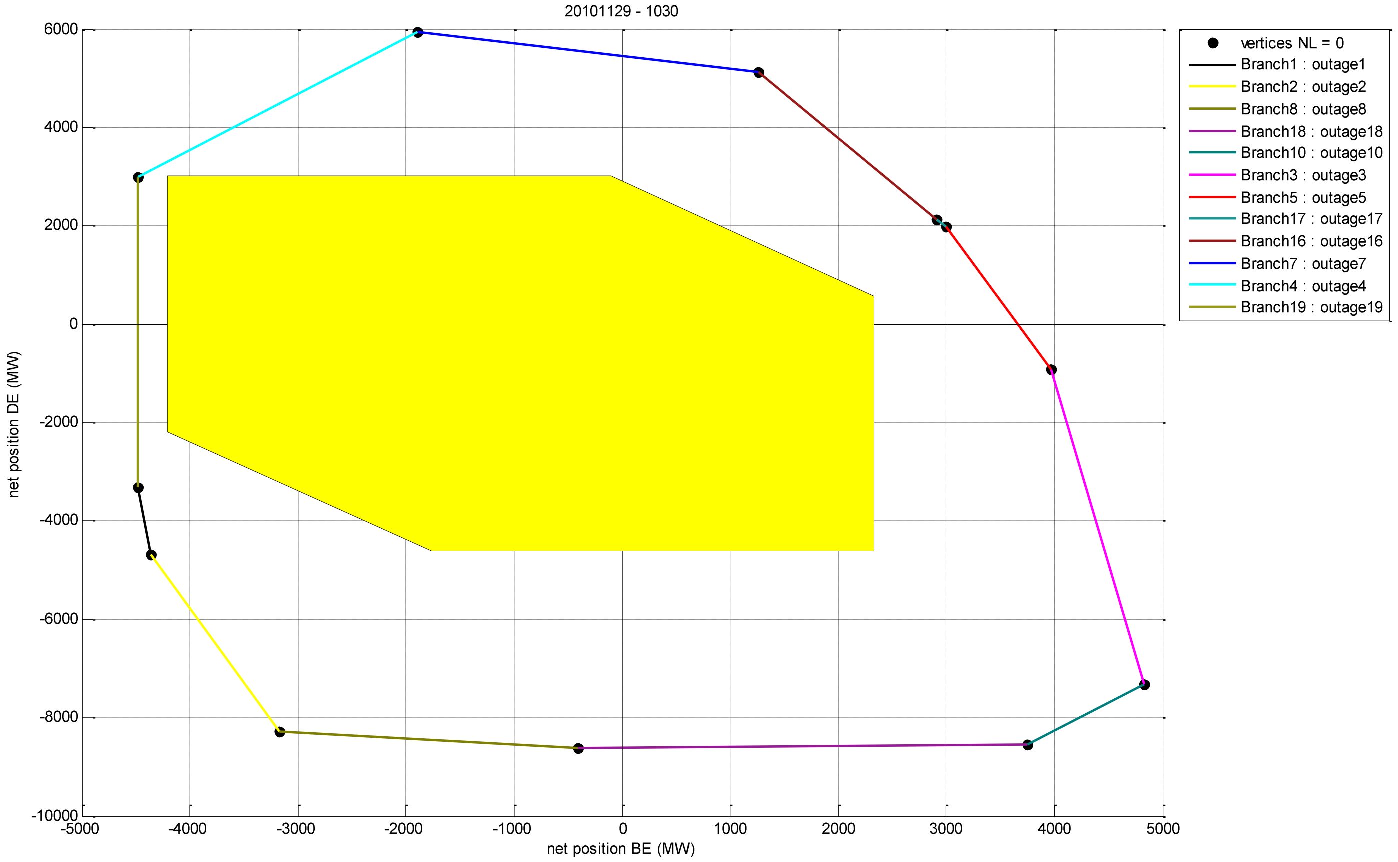
28 Because the sum of the 4 CWE net positions equals zero, one net position can be written as a combination of the three remaining ones:

$NE_{BE} + NE_{DE} + NE_{FR} + NE_{NL} = 0 \quad \rightarrow \quad NE_{FR} = -NE_{BE} - NE_{DE} - NE_{NL}$

This property makes that the search space can be visualized as a three-dimensional body, of which the volume can be determined.



When a slice of these 3-dimensional bodies is made, the figure as shown hereunder could result (practical example of November 29, 10.30, 2010). The yellow polygon represents a slice of the ATC domain, whereas the slice of the FB domain is illustrated by means of its limiting critical branches.



In the following, the shape of the ATC domain will be explained.

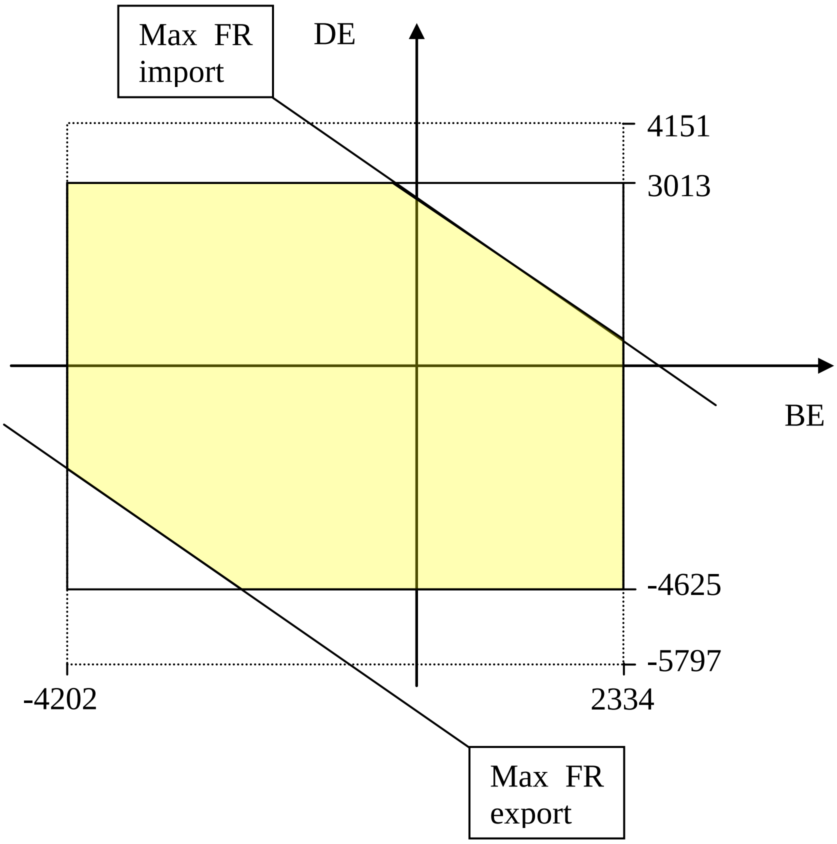
For this day and timestamp the following ATC values applied:

	BE=>FR	BE=>NL	DE=>FR	DE=>NL	FR=>BE	FR=>DE	NL=>BE	NL=>DE
29-11-2010 10:30	898	1436	2011	2140	3202	3189	1002	2608

- On the x-axis is the BE net position.
  - The max export equals: BE>FR + BE>NL = 898 + 1436 = 2334.

- The max import equals: FR>BE + NL>BE = 3202 + 1002 = 4204.
- On the y-axis is the DE net position.
  - The max export equals: DE>FR + DE>NL = 2011 + 2140 = 4151.
  - The max import equals: FR>DE + NL>DE = 3189 + 2608 = 5797.

Let's put this rectangle (dashed) in a figure:



But we need to respect other constraints as well. On the z-axis, the NL net position is imagined: in this case it has a zero value. So what NL enters, e.g. DE>NL, needs to leave NL as well: NL>BE. As the latter value is lower than the ATC value DE>NL, it puts an additional constraint on the DE net position.

- On the x-axis is the BE net position.
  - The max export equals: BE>FR + min(BE>NL,NL>DE) = 898 + min(1436,2608) = 2334.
  - The max import equals: FR>BE + min(NL>BE,DE>NL) = 3202 + min(1002,2140) = 4204.
  - Both values remain unchanged.
- On the y-axis is the DE net position.
  - The max export equals: DE>FR + min(DE>NL,NL>BE) = 2011 + min(2140,1002) = 3013.
  - The max import equals: FR>DE + min(NL>DE,BE>NL) = 3189 + min(2608,1436) = 4625.

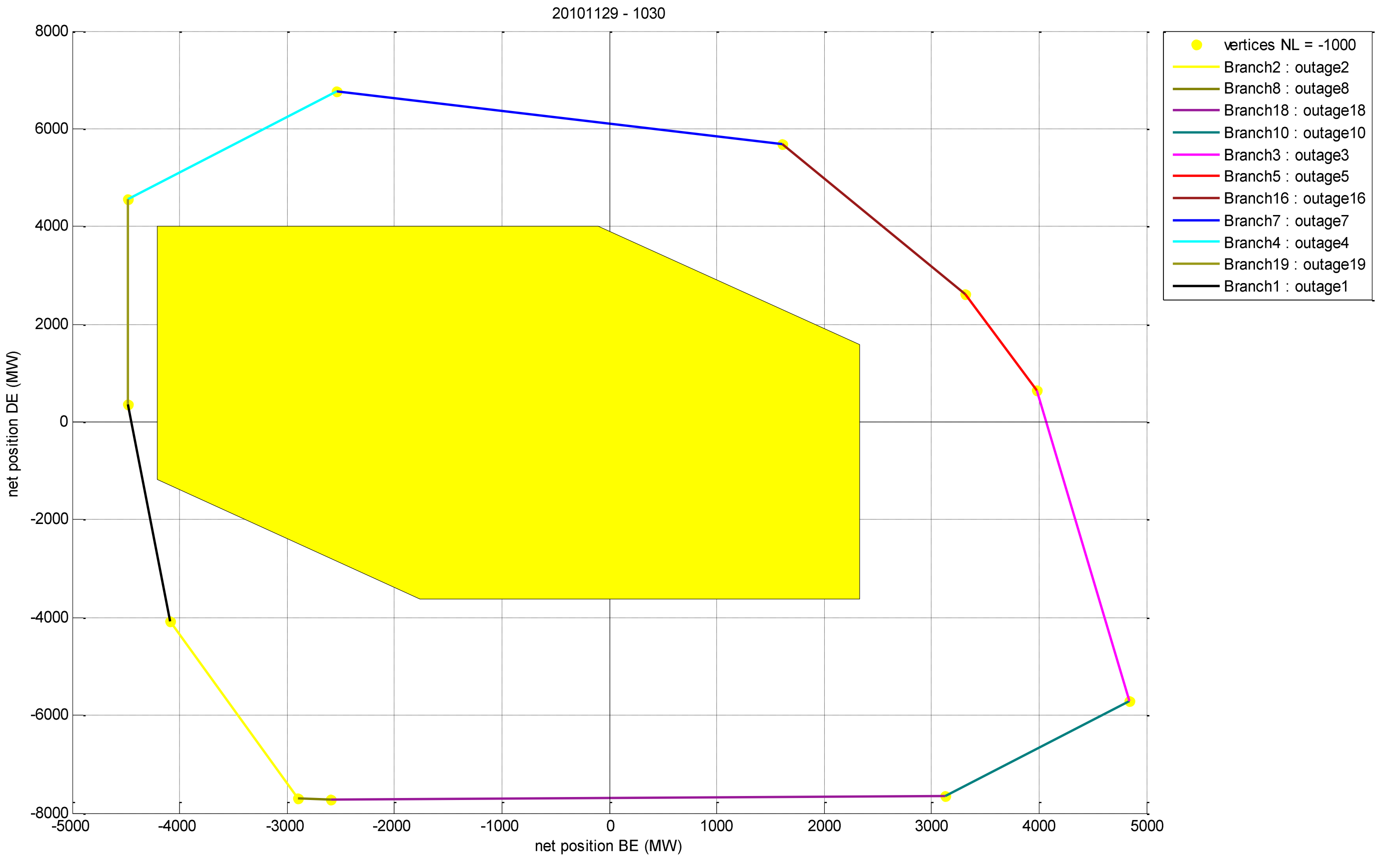
So the figure reduces, as shown by the solid rectangle in the graph above.

The FR net position is the dependent variable in this case: NP(NL)+NP(BE)+NP(FR)+NP(DE) = 0. With the NL net position being zero, we get: NP(BE)+NP(FR)+NP(DE) = 0.

- The extreme FR net positions are:
  - The max export equals: FR>DE + FR>BE = 3189 + 3202 = 6391.
  - The max import equals: DE>FR + BE>FR = 2011 + 898 = 2909.

Those are two additional constraints as shown by the lines in the figure above.

The domain limited by the above-mentioned constraints is the yellow-colored ATC domain.
Hereunder, the same example is repeated, but now with an NL import position of 1000 MW.



The only difference with regard to the previous exercise is that what NL enters, e.g. DE>NL, needs to leave NL as well, except for the 1000 MW import that remains in NL. This means that if the value (NL>BE+1000) is lower than the ATC value DE>NL, it puts an additional constraint on the DE net position.

- On the x-axis is the BE net position.
  - The max export equals: BE>FR + min(BE>NL,NL>DE+1000) = 898 + min(1436,2608+1000) = 2334.
  - The max import equals: FR>BE + min(NL>BE,DE>NL-1000) = 3202 + min(1002,2140-1000) = 4204.
  - Both values remain unchanged.
- On the y-axis is the DE net position.
  - The max export equals: DE>FR + min(DE>NL,NL>BE+1000) = 2011 + min(2140,1002+1000) = 4013.
  - The max import equals: FR>DE + min(NL>DE,BE>NL-1000) = 3189 + min(2608,1436-1000) = 3625.

The result for this 1000 MW NL import scenario is that the figure, compared to the one with the zero NL import position, is shifted with +1000 MW on the y-axis (the DE net position).

5.2 Translation of capacity domains (FB and ATC)

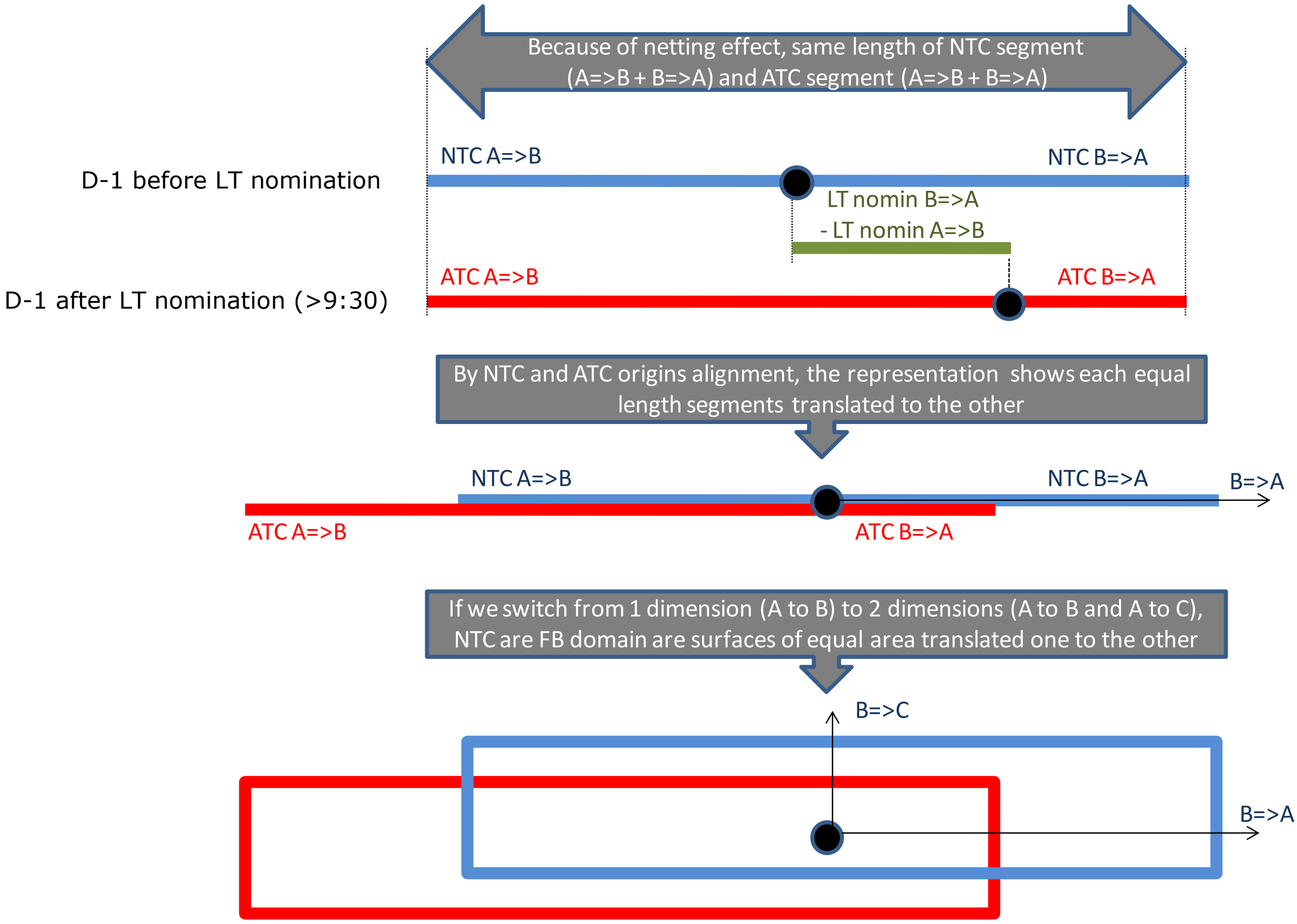
The following figure shows for two bidding areas A and B, that:

1) length of the NTC domain = $NTC_{A=>B}$ + $NTC_{B=>A}$ is the same as the one of ATC domain = $ATC_{A=>B}$ + $ATC_{B=>A,}$ after the adjustment to long-term nominations (because of netting);

2) by keeping the same origin, both equal length segments are translated one to the other;

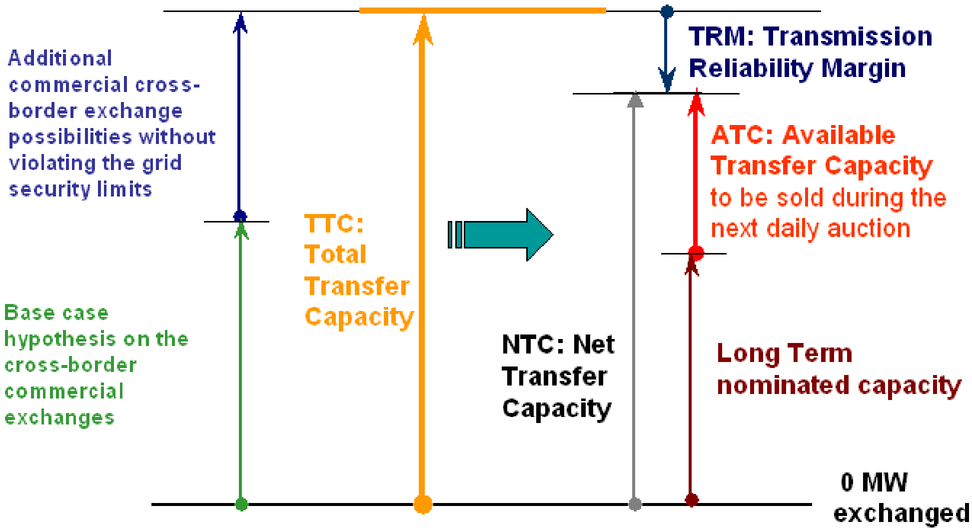
3) extension of the principle described above with three bidding areas (A, B and C).

Note: the same logic applies also to any other kind of adjustment (for example from D-1 ATC to ID ATC after application of bilateral exchanges nominations from the market coupling).

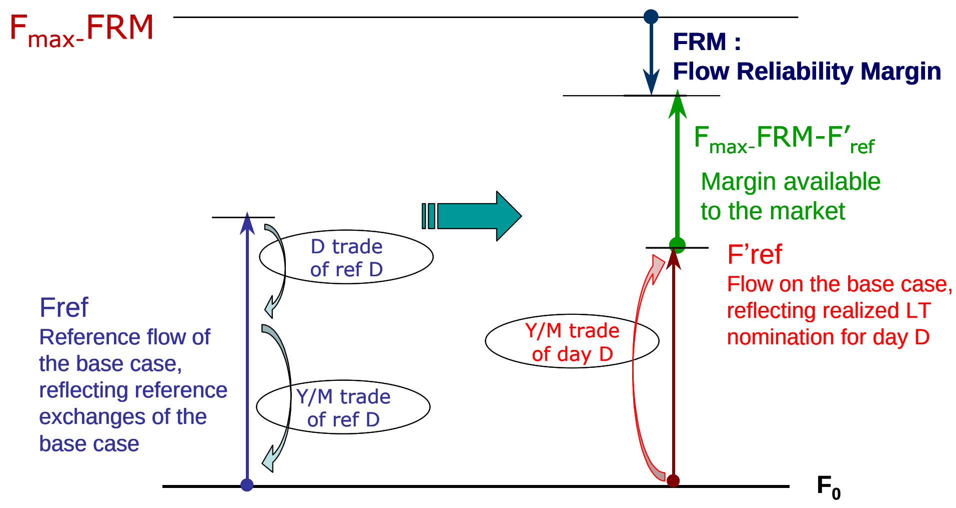


The adjustment of NTC and FB to long-term (yearly and monthly) nominations is represented in the following schemas.

In ATC:



In FB:



The following parallelisms appear:

Expression of…	In ATC model	In FB model
… the limitations due to the grid	Trade between two neighboring hubs	Physical flow on a critical branch
… the maximal capacity	Total Transfer Capacity (TTC)	Maximum physical flow (Fmax)
… the security margin	Transmission Reliability Margin (TRM)	Flow Reliability Margin (FRM)

5.3 How net position limitations are taken into account

The Elia 4500 MW import limitation can be written as a constraint on the Belgium net position: NP(BE) ≥ -4500 MW. It can also be written as a matrix expression, similar to that of the FB parameters:

$$-1,0,0,0 \begin{bmatrix} NP_{BE} \\ NP_{DE} \\ NP_{FR} \\ NP_{NL} \end{bmatrix} \leq 4500$$

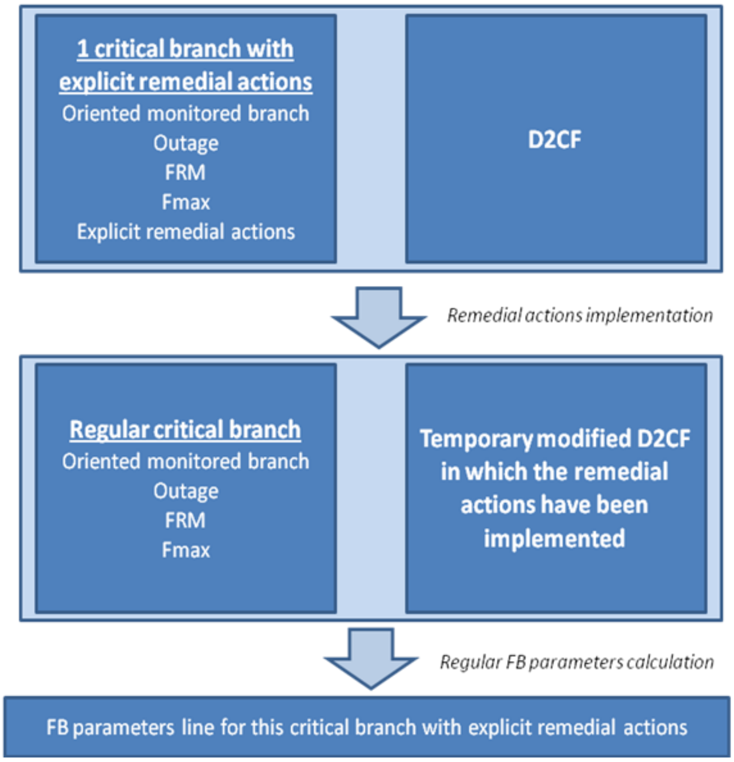
The 4500 MW appears as the available margin, and [-1,0,0,0] as the PTDF coefficients. Adding net position limitations only consists of adding lines to the FB parameters. Note that the net position should be adapted to long term nominations as well.

5.4 How the remedial actions can be taken into account during FB parameter calculation

Refinement of the FB search space by incorporating the impact of remedial actions can be established in three ways:

- Bi-directional enlargement of the Fmax value (the Fmax increase equals the calculated influence of the remedial action)
- Mono-directional enlargement of the Fmax value, allowing a TSO to take into account the impact of remedial actions in only one direction
- Or by expliciting each remedial action and associating them to the critical branches definition (this allows to take into account PTDF modifications for topological remedial actions). In this case the exact influence of the remedial action is determined by the FB parameter calculation tool.

Hereunder the logical concept of how explicit remedial actions are handled within the FB parameters calculation is visualized:



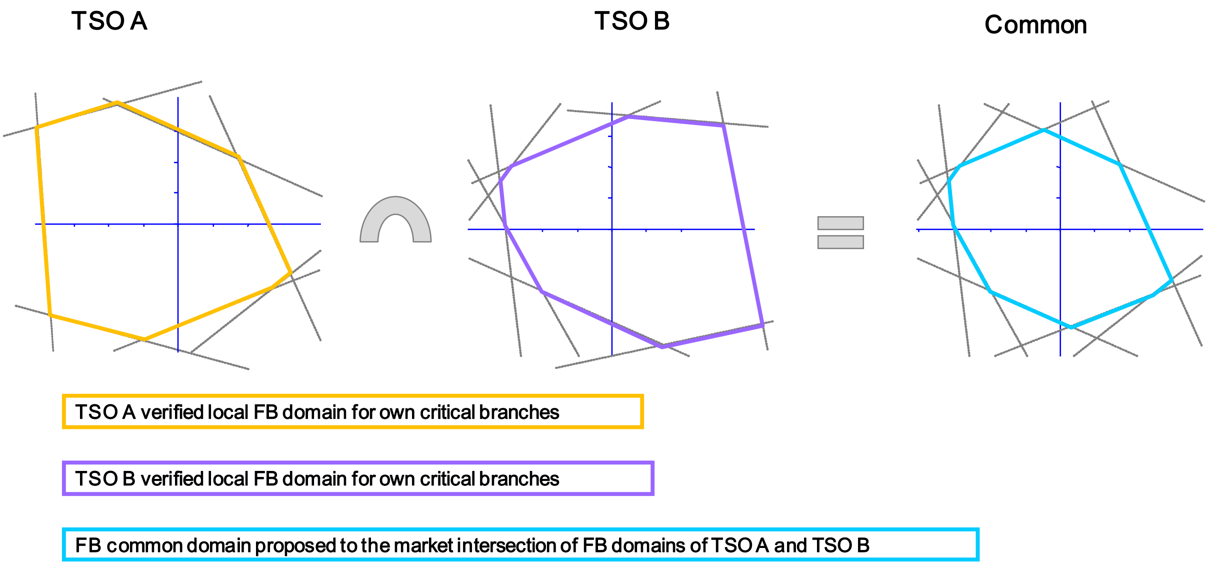
5.5 How the TSO will run D-2 “FB qualification” and “FB verification” without interfering with neighbouring TSO’s operational timing

For operational feasibility it is very important that there is no need to compute intermediate FB parameters (by the responsible for common activities) between the D-2 processes “FB qualification” and “FB verification”. TSO A will be able to work on its FB verification without waiting for TSO B’s results of the FB qualification.

Therefore, the FB qualification and FB verification are to be done only with the TSO’s own CBs and not with CBs of the neighbouring TSOs, so that, at the end of this local process, a TSO locally verified FB domain is produced.

The common final FB domain is obtained through the intersection of all TSO locally verified FB domains. The Security of Supply of this common FB domain is granted since all the vertices of the TSO locally verified FB domains are included within the common FB domain.

Example with only 2 TSOs:

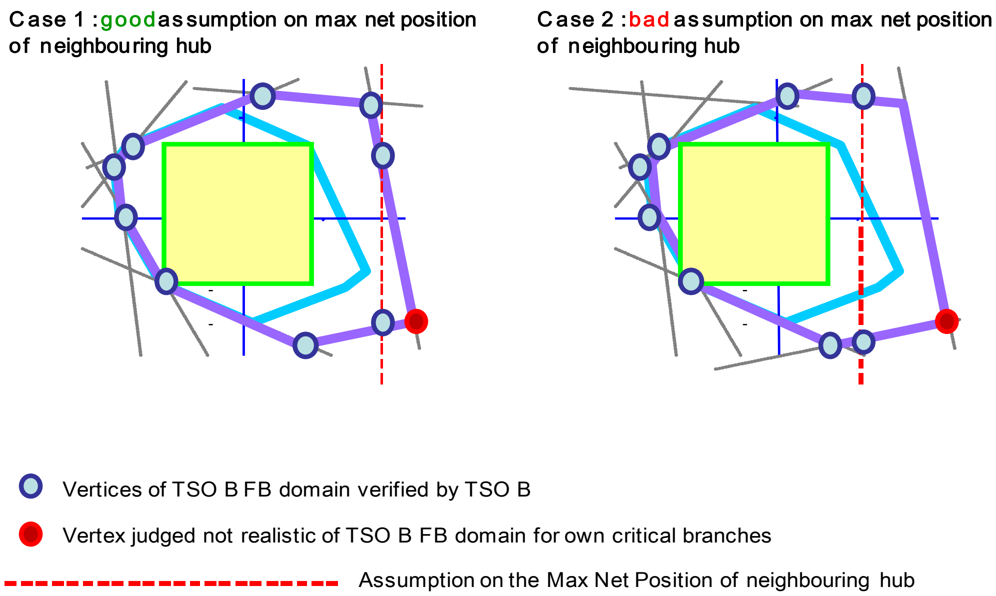


Remark: if by using only the own CBs, in the local FB domain, some vertices seem not to be realistic, then this TSO can:

- cap the net positions of neighbouring TSOs to realistic values
- or use the initial CB inputs of the neighbouring TSOs (of the initial FB parameters computed by the RCA) with increased Fmax to anticipate the qualification effect in the CB of the neighbouring TSOs

This usage of NP capping values or assumptions on CBs of the neighbouring TSOs are the local responsibility of the TSO doing the verification of his local FB domain and it is highly recommended that the assumptions made are checked ex-post with the definitive common FB domain in order to detect mistakes and improve these settings for future usage.

Example where TSO B caps the neighbouring max net position:



5.6 General possible improvements concerning capacity calculation

During the FB experimentation, CWE TSOs have been able to identify possible improvements concerning their capacity calculation in general (ATC or FB). One of those concerning the intraday capacity calculation as presented in section 2.6.2, the other improvements are highlighted hereunder:

- **D2CF quality.**
  In the current coordinated ATC process, the D2CF is used for capacity verification. In FB however, D2CF will be used directly for the capacity calculation, therefore the D2CF quality is more critical. CWE TSOs are aware of this, and have planned to monitor the quality of the D2CF as a part of the 2011 FB experimentation. The envisaged checks concern the verification of each hypothesis used to build the local D2CF files, such as outages, PST tap positions, main substation topology, and so on.
- **Need for improved coordination of cross-border remedial actions.**
  An improved coordination of cross-border remedial actions enhances the security of supply and can increase the capacity that can be offered to the market. Information sharing among the TSOs is a key issue here. Shared procedures, indicating amongst others which remedial actions should be applied for the capacity calculation stage, are required to facilitate this. However this is not a quick win, given all the underlying legal issues to consider.

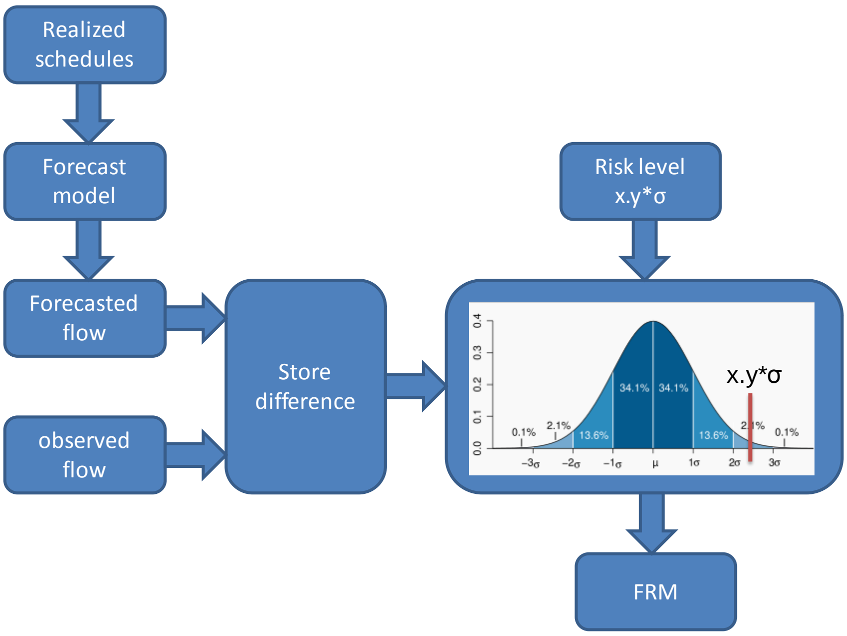
5.7 FRM settlement / model quality study

The uncertainty involved in the flow-based process must be quantified and discounted in the allocation process, in order to prevent that on day D the TSOs will be confronted with flows that exceed the maximum allowed flows. Therefore, for each critical branch a Flow Reliability Margin (FRM) has to be defined, that quantifies at least how the before-mentioned uncertainty impacts the flow on the critical branch. Inevitably, the FRM reduces the remaining available margin (RAM) on the critical branches because a part of this free space must be reserved to cope with these uncertainties. The remaining available margin for each critical branch that can be given to day-ahead allocation by the market coupling, is defined as:
RAM = Fmax - Fref' - FRM.

The FRM is a margin taken on the critical branch flow to take into account:
- uncertainties inherent to a D-2 capacity calculation process
- unintentional flow deviations due to operation of load-frequency controls
- uncertainties in data collection and measurement

There is one FRM value in MW per critical branch. Prior to FB implementation in CWE, but also once it will be live, an FRM continuous statistical refinement is to be done through comparison per CB of:
- observed flows (snapshot flows)
- and flows estimated by the FB model based on realized schedules

The basic idea behind the FRM determination is to quantify the uncertainty by comparing the forecast, i.e. the FB model, with the observation of the corresponding timestamp in the real time, by making a snapshot (SN) of the transmission system. This is illustrated in the graph below. In order to be able to compare the observed flows (from the SN) with the predicted flows, the FB model is fed with the realized schedules at the time of the SN. The differences between the observations and predictions are stored in order to build up a database that allows us to make a statistical analysis on a significant amount of data. Based on a predefined risk level, the FRM values can be computed from the distribution of flow differences between forecast and observation.



By following the approach illustrated above, all uncertainties within the FB process are taken into account and monitored for the FRM determination. As such, it will provide a reference to monitor future changes/improvements in part of the process and/or the input data. We would like to underline here that the FRM in itself does not give an absolute indication of the 'quality' of the FB approach.

Note: the process described above and these fine-tuned FRM values will be evaluated by the FB WG during the implementation phase in 2011; the FRM values can be evaluated as soon as the statistical database is sufficient for this purpose. Until that time, as is the case for this report as well, the FRM is evaluated locally by each TSO with its own expertise and taking into account the recommendations of the former CWE R4CA (Regional Coordinated Capacity Calculation and Capacity Allocation) working group with regard to the FRM estimations.

5.8 Determining GSK

Behind the GSK topic there are two issues often mixed up.

The first one is the zonal one: market players bid on a bidding area without specifying which unit is attached to the bid. This is portfolio bidding in contrast to unit bidding. The European electricity market is zonal by nature, in opposition to a nodal market. All the drawbacks, problems and inefficiencies of a nodal market will not be detailed in this document. TSOs handle the uncertainty linked with portfolio bidding with dedicated processes. This uncertainty concerning the generation location in D-2 exists both under ATC and FB.

The second one is the fact that GSKs are linear. If a TSO would know for each increase or decrease of net position of their hub, which unit would start and stop and in which order, the TSO would still have to linearize those profiles to create a GSK. As these profiles are unknown, the TSOs focus on flow handling. In the FB verification step of the process, the TSOs have the possibility to implement best guesses of merit orders in order to overcome the linearity limitation of the GSK.

In the following paragraphs the TSOs specify the way in which their operational GSK is produced.

5.8.1 RTE

RTE puts its best efforts to anticipate the best generation pattern for France in D+2 and puts its forecast in the D2CF.

Then, in order to avoid unwanted behaviour of the GSK on major critical branches, RTE excludes some generating units from the French GSK. This applies, for example, for the 5200 MW nuclear power plant (Cattenom) connected to the Vigy substation. There is a double 380 kV tie line with Germany starting from Vigy (Vigy Ensdorf); Vigy Ensdorf is a major critical branch when France is exporting. In the case where there is 5200 MW generated in Cattenom in the basecase, and with a non-zero Cattenom GSK coefficient, the flow-based model with France exporting would assume a higher generation output in Cattenom than possible: the critical branch Vigy Ensdorf would be wrongly loaded leading to virtual congestions and resulting in a loss of social welfare. That is why RTE prefers to exclude all units close to CWE borders and to handle those in the D2CF and through variants.

Apart from the excluded units, RTE uses a GSK based on pro-rata of the units in the base case. This is acceptable since the remaining units in the French GSK are far away (in terms of electrical distance) from CWE critical branches.

5.8.2 German TSO (Amprion, EnBW, TenneT GmbH)

Amprion, EnBW and TenneT GmbH include only power plants in the GSK that are very quick and flexible in changing the electrical power output. From this it follows that the GSKs from Amprion, EnBW and TenneT GmbH contain the following types of power plants: gas/oil, pumped-storage and hard-coal. The GSK values vary between peak- and off-peak hours.

5.8.3 Elia

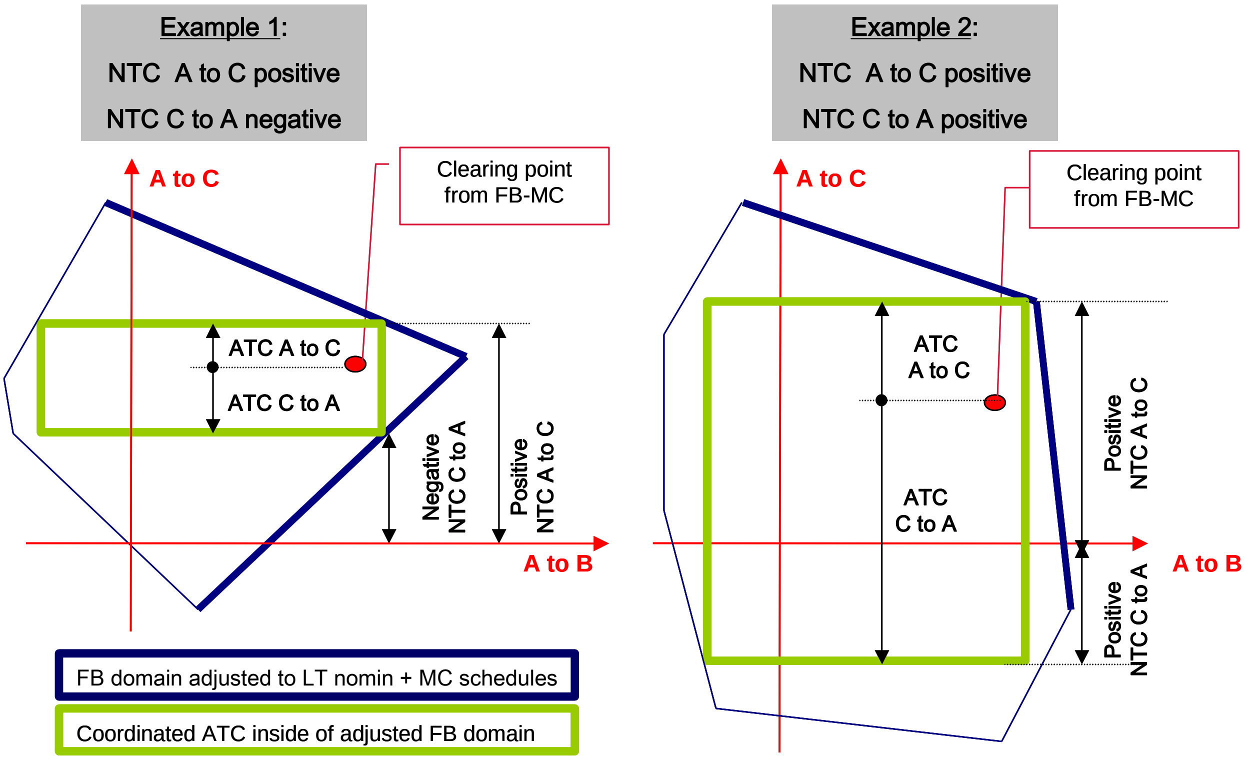
Elia includes in its GSK all flexible and controllable generation units connected to its grid. As their behaviour is different from other classical units, nuclear power plants and pump stations are excluded from this GSK. As a consequence, the GSK of Elia only includes classical generation units connected to voltage levels lower than 380 kV.

5.8.4 TenneT B.V.

The GSK for the TenneT control area contains all secondary control units above 60 MW. The decision to use all secondary control units is based on an analysis of their influence on the cross-border flows and share in total generation. TenneT has no access to the merit order of units, however the list of units that appear in the GSK is evaluated by the operators on a daily basis for known outages. Using this selection of large generators has the advantage that the GSK influence is spread evenly over the grid area.

5.9 Calculation of ID ATC and not ID NTC

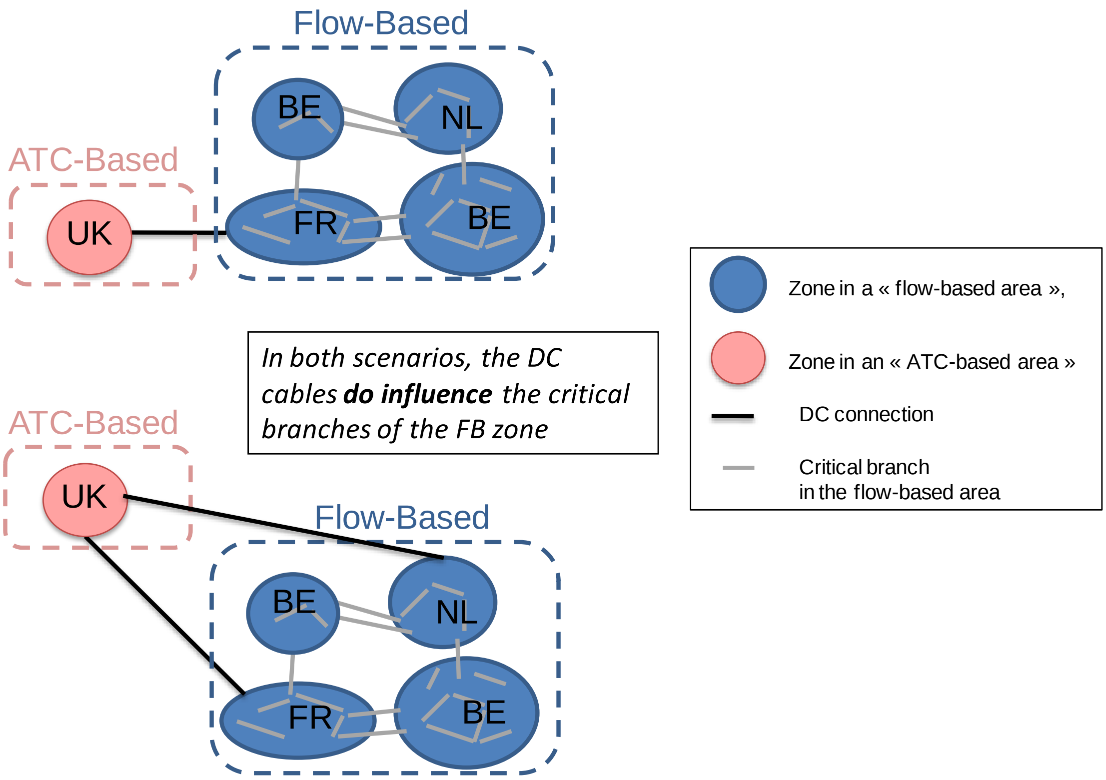
After switching to FB in D-1, ID ATCs are computed and not ID NTCs (since in some cases it would lead to negative NTCs, as illustrated in the figures below). This is the consequence of giving the whole implicit FB domain to the market in D-1, including possible areas that cannot be reached by any set of D-1 NTC.



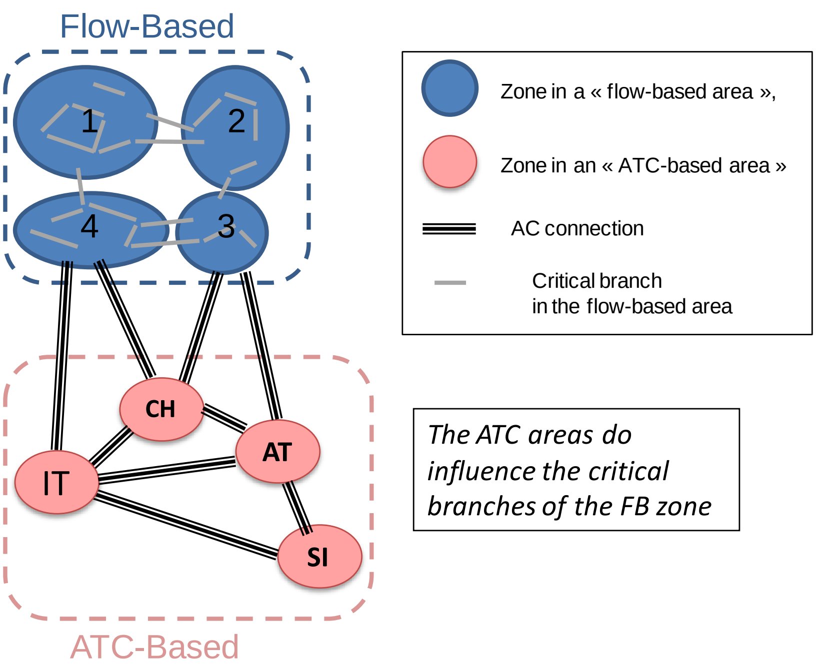
5.10 Elementary scenarios of coupling to other initiatives

Here we listed the different elementary scenarios of ATC-FB hybrid coupling which could be foreseen. But in all these theoretical scenarios, the main issues are the same.

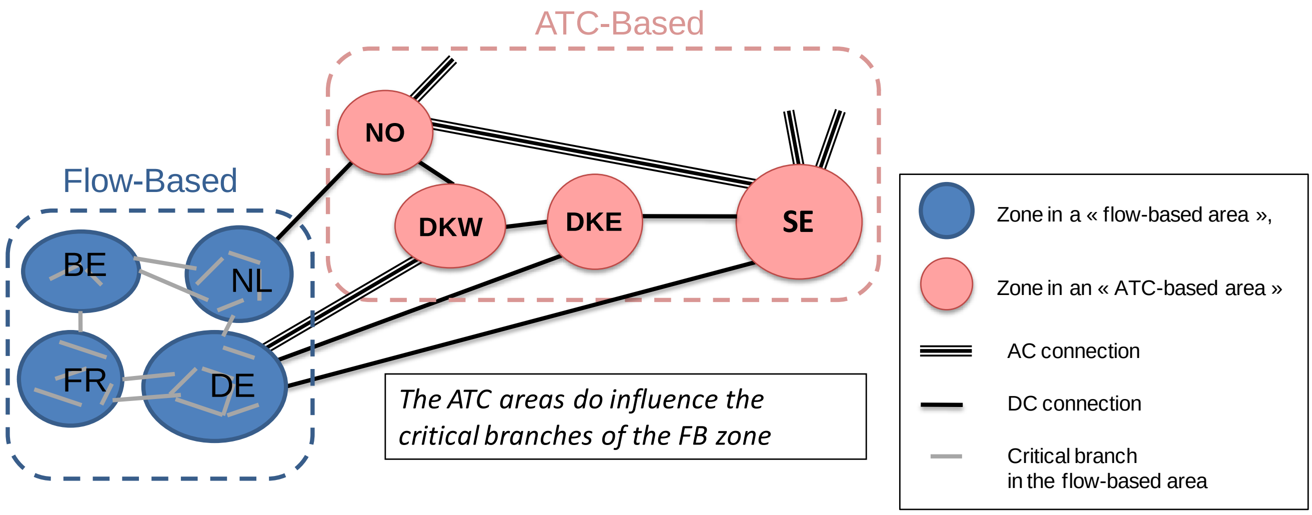
5.10.1 CWE+UK (FB area + ATC area with DC cables)



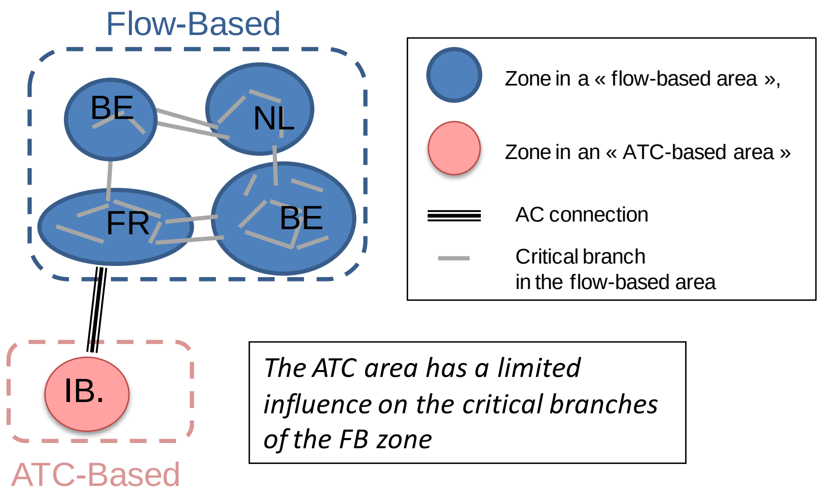
5.10.2 CWE+CSE (FB area + ATC area with AC connection)



5.10.3 CWE+ NWE (FB are + ATC area with AC and DC connections)



5.10.4 CWE+Iberian peninsula



5.11 What is the "advanced" hybrid ATC FB price coupling: Examples

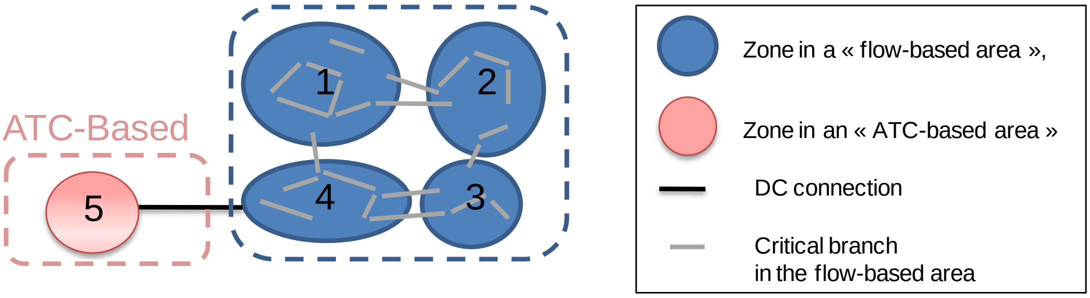
The annex details the approach of "advanced" hybrid ATC FB price coupling. For the sake of clarity, we will detail three examples:

1. A flow-based area connected with an ATC zone, through a DC cable (CWE + IFA)
2. A flow-based area connected with an ATC-based synchronous area (CWE + CSE)
3. A flow-based area connected with an ATC-based area, with both AC and DC cables (CWE + Nordic countries)

Any European possible coupling scheme can be decomposed based on the three previous elementary examples.

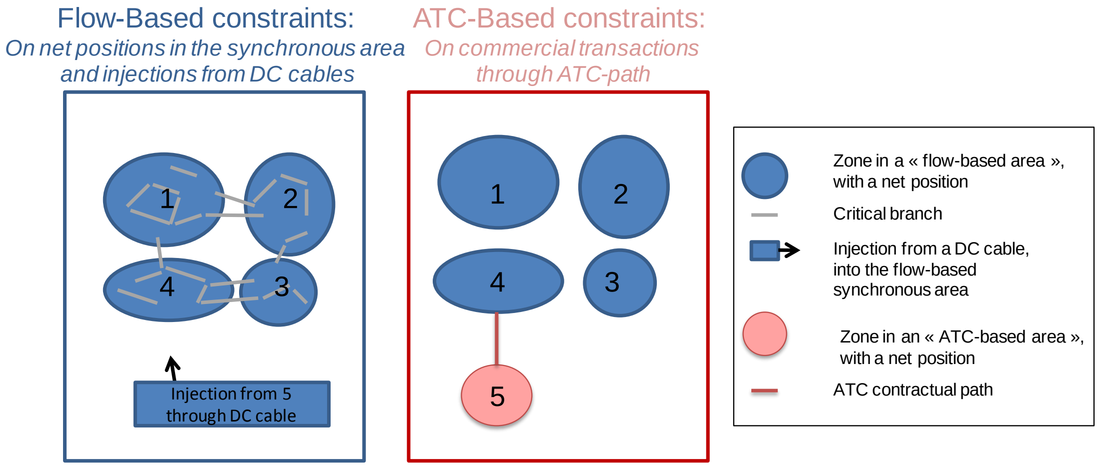
An introduction to the "advanced" hybrid ATC-FB price coupling method is given in section 4.3.2

5.12 A FB area connected with an ATC zone, through a DC cable (CWE + IFA)



We need to consider the constraint of the maximum allowable exchange on the cable, and also the influence of exchange through this cable in the flow-based model (on the different critical branches of the flow-based area). In fact, we need to see the influence of the injection from this cable in the flow-based synchronous area.

Schematically we need the combination of the two kinds of constraints (flow-based and ATC-based):



Let us develop the general equations above, applied to the example:

- **Definition of the net positions:**

$$\begin{cases} \text{For } A = 1,2,3 : \text{sale}_A - \text{purchase}_A = \text{Net Position}_A^{FB} \\ \text{sale}_4 - \text{purchase}_4 = \text{Net Position}_4^{Flow-based} + \text{Exchange}_{5\to 4} \end{cases}$$

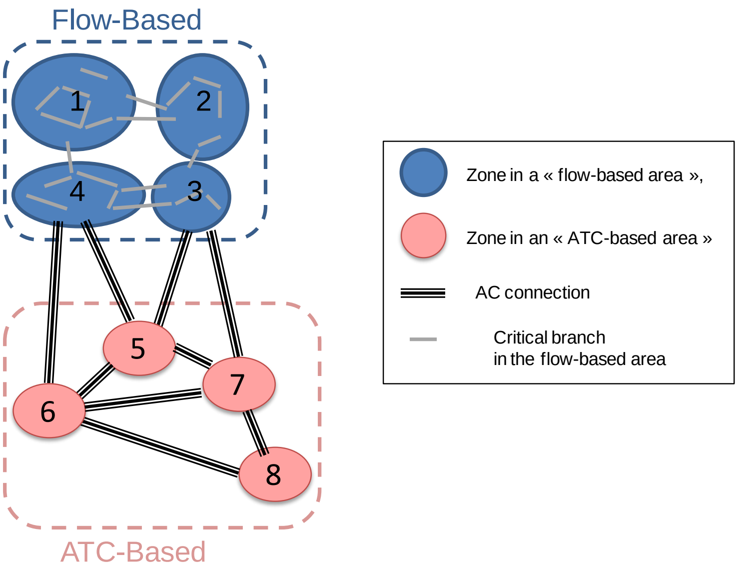
- **Flow-Based constraints:**

$$\sum_{A=1,2,3} \text{PTDF}_A^k \cdot \text{Net Position}_A^{FB} + \text{PTDF}_4^k \cdot (\text{Net Position}_4^{FB} + \text{Exchange}_{5\to 4})$$
$$+ \text{PTDF}_{cable\,5\to 4}^k \cdot \text{Exchange}_{5\to 4} \le \text{RAM}^k$$

- **ATC-based constraints:**

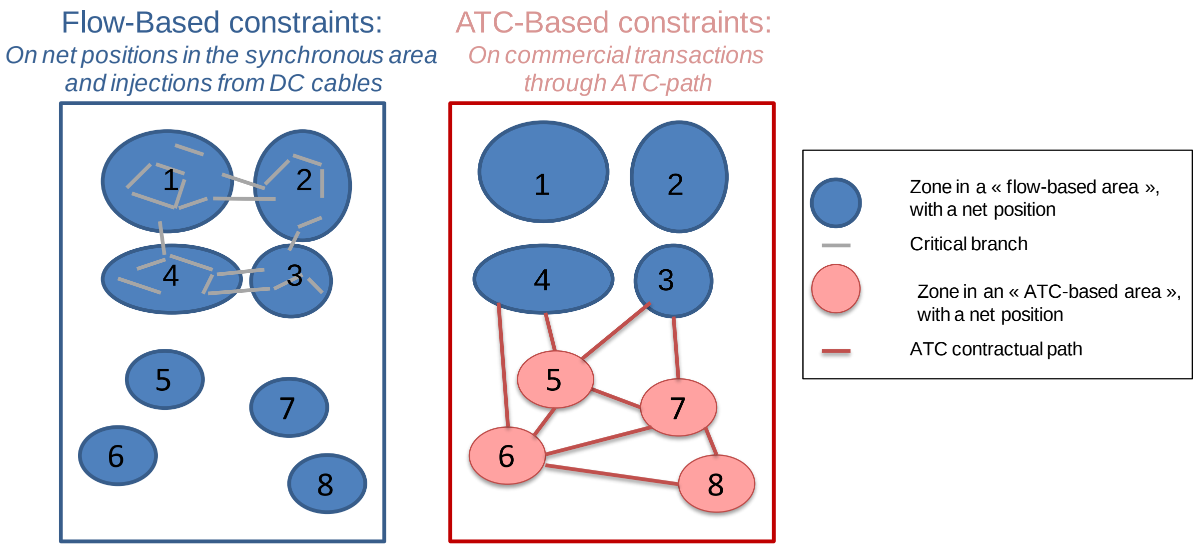
$$\text{ATC}_{5\to 4}^{DOWN} \le \text{Exchange}_{5\to 4} \le \text{ATC}_{5\to 4}^{UP}$$

5.13 A FB area connected with an ATC-based synchronous area (CWE+CSE)



We need to consider the constraint of the maximum allowable exchange on each ATC-path, and also the influence of the net position of each ATC zone (resulting from ATC exchange) on the different critical branches of the flow-based area.

Schematically, we need:



Again, the general equations apply for each zone:

- Definition of the net position (taking into account the net position resulting from flow-based constraints and the ATC exchanges)
- The flow-based constraints: optimisation of overall net position (“FB net position” and ATC exchanges), taking into account the influence of ATC transactions
- The ATC-based constraints

Let us develop the general equations above, applied to the example:

- **Definition of the net positions**

$$\begin{cases} \text{For } A=1,2: \text{sale}_A - \text{purchase}_A = \text{Net Position}_A^{FB} \\ \text{sale}_3 - \text{purchase}_3 = \text{Net Position}_3^{FB} + \text{Exchange}_{5\to 3} + \text{Exchange}_{7\to 3} \\ \text{sale}_4 - \text{purchase}_4 = \text{Net Position}_4^{FB} + \text{Exchange}_{5\to 4} + \text{Exchange}_{6\to 4} \end{cases}$$

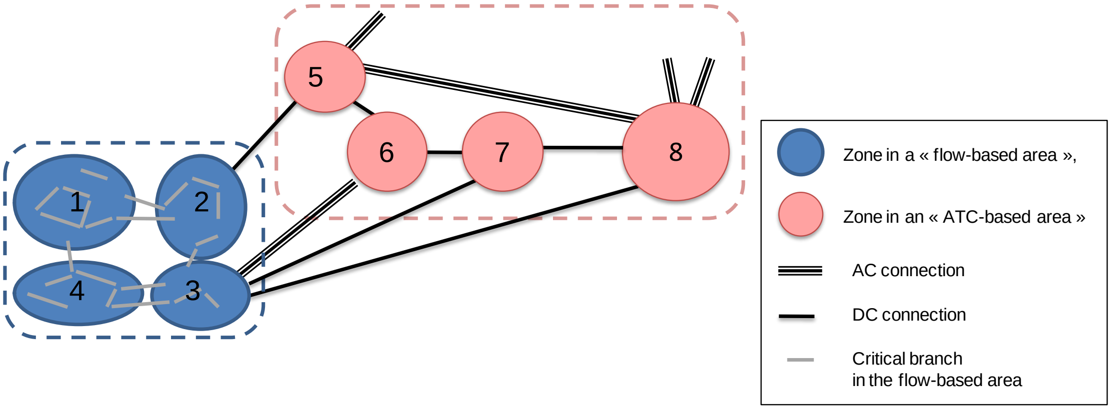
- **Flow-Based constraints**

$$\sum_{A=1,2,} \text{PTDF}_A^k \cdot \text{Net Position}_A^{FB} + \text{PTDF}_3^k \cdot (\text{Net Position}_3^{FB} + \text{Exchange}_{5\to 3} + \text{Exchange}_{7\to 3})$$
$$+ \text{PTDF}_4^k \cdot (\text{Net Position}_4^{FB} + \text{Exchange}_{5\to 4} + \text{Exchange}_{6\to 4}) +$$
$$\sum_{A=5,6,7,8} \text{PTDF}_A^k \cdot (\sum_{A\neq I} \text{Exchange}_{A\to I}) \leq RAM^k$$

- **ATC-based constraints:**

$$\forall i \to j \text{ ATC contractual path}:$$
$$\text{ATC}_{i\to j}^{DOWN} \leq \text{Exchange}_{i\to j} \leq \text{ATC}_{i\to j}^{UP}$$

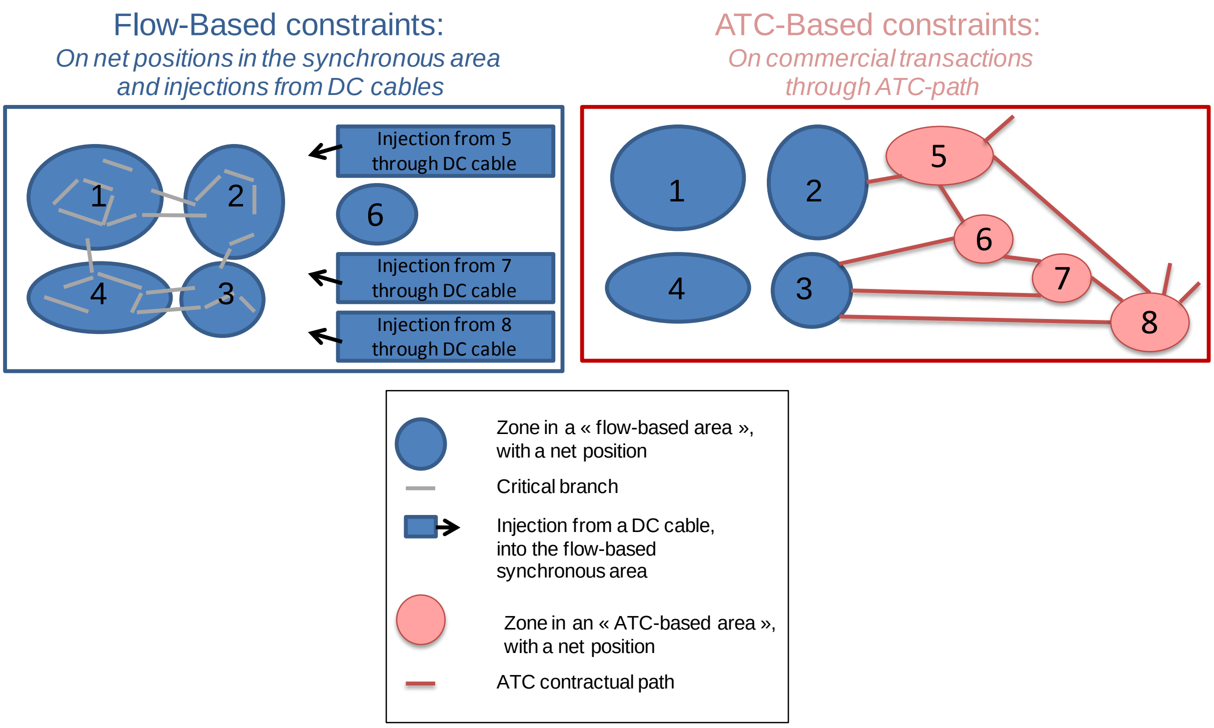
5.14 A FB area connected with an ATC-based area, with both AC and DC cable (CWE+Nordic countries)



We need to consider:

- The constraints of the maximum allowable exchange on each ATC-path, and also the influence of the net position of each ATC zone (resulting from ATC exchange) on the different critical branches of the flow-based area.
- The constraints of the maximum allowable exchange on the DC cables, and also the influence of exchanges through these DC cables on the different critical branches of the FB area, or more precisely the influence of the injections from these cables in the FB synchronous area.

Schematically:



Let us develop the general equations, applied to the example:

- Definition of the net position:

$$\begin{cases} \text{For A} = 1,4: \text{sale}_A - \text{purchase}_A = \text{Net Position}_A^{FB} \\ \text{sale}_2 - \text{purchase}_2 = \text{Net Position}_2^{FB} + \text{Exchange}_{\text{DC Cable } 5\to 2} \\ \text{sale}_3 - \text{purchase}_3 = \text{Net Position}_3^{FB} + \text{Exchange}_{6\to 3} + \text{Exchange}_{\text{DC Cable } 7\to 3} + \text{Exchange}_{\text{DC Cable } 8\to 3} \\ \text{For A} = 5,6,7,8: \\ \text{Sale}_A - \text{Purchase}_A = \sum_{I\neq A} \text{Exchange}_{A\to I} \end{cases}$$

- Flow-Based constraints

$$\begin{aligned} &\sum_{A=1,4} \text{PTDF}_A^k \cdot \text{Net Position}_A^{FB} \\ &+ \text{PTDF}_2^k \cdot (\text{Net Position}_2^{FB} + \text{Exchange}_{\text{DC Cable } 5\to 2}) \\ &+ \text{PTDF}_3^k \cdot (\text{Net Position}_3^{FB} + \text{Exchange}_{6\to 3} + \text{Exchange}_{\text{DC Cable } 7\to 3} + \text{Exchange}_{\text{DC Cable } 8\to 3}) \\ &+ \text{PTDF}_6^k \cdot (\sum_{I\neq 6} \text{Exchange}_{6\to I}) \\ &+ \text{PTDF}_{\text{Cable } 5\to 2}^k \cdot \text{Exchange}_{\text{DC Cable } 5\to 2} + \text{PTDF}_{\text{Cable } 7\to 3}^k \cdot \text{Exchange}_{\text{DC Cable } 7\to 3} + \text{PTDF}_{\text{Cable } 8\to 3}^k \cdot \text{Exchange}_{\text{DC Cable } 8\to 3} \\ &\leq \text{RAM}^k \end{aligned}$$

- ATC-based constraints:

$\forall i \to j$ ATC contractual path :

$$\text{ATC}_{i\to j}^{DOWN} \leq \text{Exchange}_{i\to j} \leq \text{ATC}_{i\to j}^{UP}$$