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.

In March 2011, the first version of this report was released. This second version is published in order to prepare the key decisional milestone, being the investment decision for FB implementation. The decision for implementation will be based on a set of acceptance criteria. The planning that has been published in March has not been updated since then and remains conditioned to the fulfillment of all acceptance criteria.

The current report contains these parts:

- The CWE FB Capacity Calculation feasibility report based on the 2010-2011 Experimentation performed by TSOs, with five additional weeks of experimentation data compared to the previous report, a new section on the intraday ATC computation from the FB domain, and a new section with some details on backups and fallbacks
- Price/Market impact analysis performed jointly by PXs/TSOs with updated data and new indicators (Paradoxically Rejected Blocks or PRB, computation time analysis, planned sensitivity analysis);
- Analysis of the interactions with the coupling to other initiatives performed jointly by PXs/TSOs;
- A description of the methodology for FRM assessment / model quality study.

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 and 2011. The development of the CWE coordinated NTC/ATC mechanism and the corresponding industrial tools/services to realize this 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 them.

Flow-Based methodology 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. Then the FB method has more physical meaning and is less opaque than the NTC method.
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.

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.
More work will be done up to go-live, and in consultation via a key user group representing the market, to increase the transparency of CWE enhanced FB towards the needs of the market players.

The CWE enhanced FB operational process has been experimented during 2010 and 2011 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 the experimentation presented in this report, 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 and 5 additional weeks from February to July) showed that Day-Ahead Market Welfare and convergence indicators are significantly better with FB constraints than with ATC, whatever the coupling method used (FBMC[1] or FBIMC[2]). Overall, the market impact analysis concludes that FB constraints have a positive impact on the market compared to ATC. It has to be taken into account that these experimentation results have been obtained by using assumptions with respect to the flow reliability margin (FRM) used and to the verification step (this last step, potentially reducing the FB domain for SoS reasons, has not yet been systematically tested by TSOs). The positive impact on the market of FB constraints will have to be confirmed when final results of the on-going work regarding these two assumptions will be available.

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[1] FBMC: Flow Based Market Coupling.
[2] FBIMC: Flow Based Intuitive Market Coupling c.f. Section 3.3.

The TSOs and PXs continue to monitor the impact on the market while the project is ongoing in order to have at least one year of simulation with the final methodology before FB goes live. It will also allow configuring the coupling algorithm (intuitiveness). More precisely, non intuitive situations were found in FBMC. Using FBIMC removes these situations without unacceptable deterioration of other indicators.

CWE FBMC interaction with coupling to other initiatives

CWE FBMC coupling with other initiatives is feasible, regardless of 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).

As FB/ATC hybrid price coupling projects emerge, CWE TSOs and PXs recommend to consider the possibility of taking into account the impact of ATC exchanges in the FB model.

General conclusion

During the 2010-2011 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 compared to ATC because such directions are not permitted anymore;
- further improves 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 FRM analysis has just started and is only based on raw results up to now. Some preliminary results are embedded in this report. These first observations have to be confirmed in the months to come, in order to further assess the quality of the Flow-Based model and to confirm the results both in terms of capacity and in terms of market impact.

The theoretical improvements of FB vs. ATC have been confirmed during the 2010-2011 CWE FB experimentation. From the capacity calculation point of view, CWE TSOs recommend a close monitoring of the results during the parallel run.

Overall, based on the assumptions made and through simulations comparing ATC constraints and FB constraints 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

CWE TSOs will finalize the FRM assessment / model quality study and will implement the corresponding FRM methodology before the beginning of the external parallel run. A report will be published with the findings of the FRM assessment.

The flow based qualification and verification steps will also have to be further worked on in order to reach a common understanding of the FB methodology and its operation, inputs, parameters and procedures.

The CWE TSOs and PXs continue to monitor the impact on the market while the project is ongoing in order to confirm the observations 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. A sensitivity analysis will be performed in order to assess the sensitivity of the results to small variations of the FB parameters.

Until the foreseen Go Live date (mid 2013), CWE PX & TSOs will organize frequent meetings with market parties in order to prepare the actors to FB MC. A technical FB user group including market parties will regularly meet. The topics of discussion will be:

- Practical conditions of the external parallel run;
- Transparency issues;
- Support tools and data interface.

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
DCV	Demand Clearing Volume
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)
Fmax	Maximum allowable flow in a given critical branch
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
LTA	Allocated capacity from LT auctions
MC	Market Coupling
MCV	Market Clearing Volume
NP or NEX	Net Position or Net Export 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
RA	Remedial Action

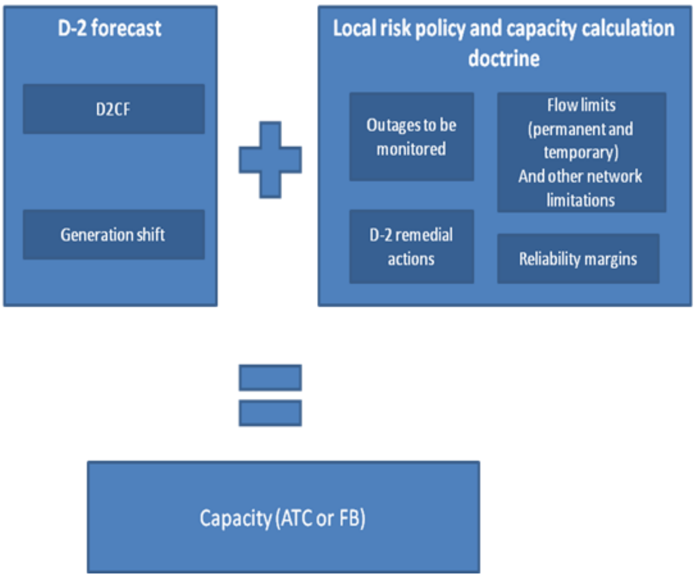
RAM	Remaining Available Margin
R4CA	Regional Coordinated Capacity Calculation and Capacity Allocation
RCA	Party Responsible for Common Activities
SN	Snapshot
SoS	Security of Supply
SWE	South Western Europe (France, Portugal, Spain)
TCV	Total Clearing Volume
TF	Task Force
TRM	Transmission Reliability 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[3], 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.

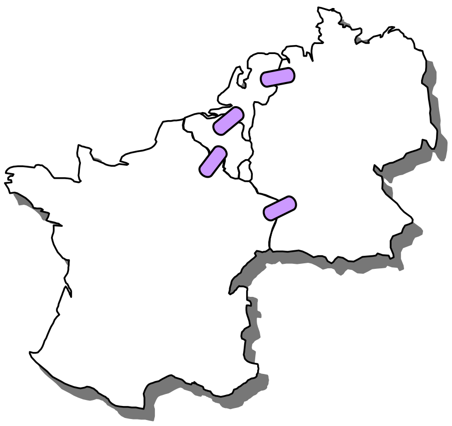


The formal recommendation of the ENTSO-e AHAG capacity calculation project for Day-Ahead as currently integrated in the framework guidelines CACM is Flow-Based for meshed grids, while ATC could be used for borders where distribution of power flows over the interconnecting lines is only slightly influenced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

[3] Different contingencies may appear: tripping of a single line or of a generation unit are 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[4] 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

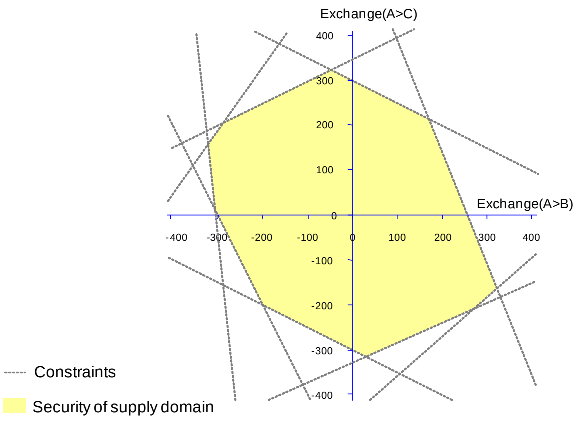
So **no** physical interconnectors between Germany & Belgium

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.

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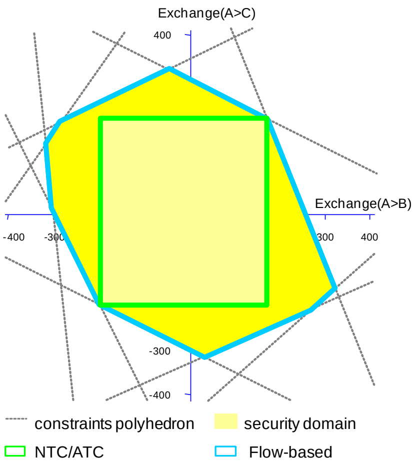
[4] Luxembourg is part of CWE, but there is no specific Luxembourg bidding area.

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 and 2011. 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, in the likely market directions (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)

Confirmation of the fulfilment of these targets is pending the outcome of the FRM study (see 2.2.4 & 5.6) as well as the further elaboration of the flow based qualification and verification steps.

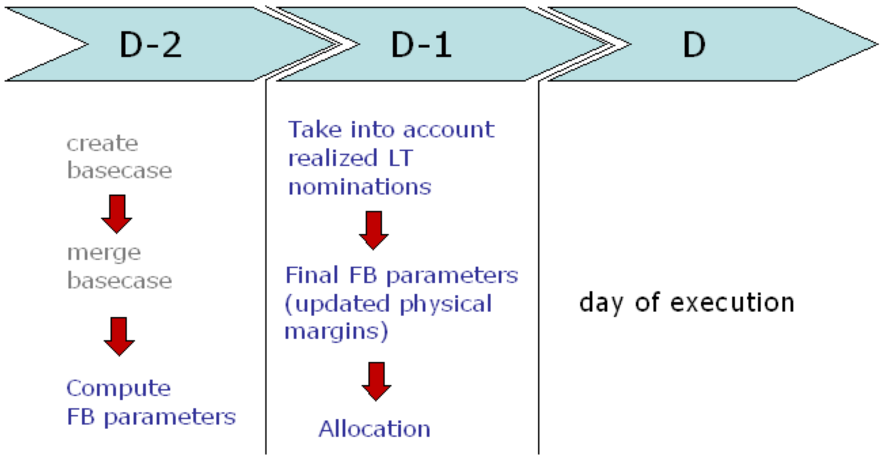
2.2 CWE Enhanced FB operational process

This chapter aims at describing the CWE Enhanced FB operational precoupling process[5], which was experimented by key-users during one year to prove its feasibility.

The final output of this precoupling process are the 24 sets of anonymous 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).

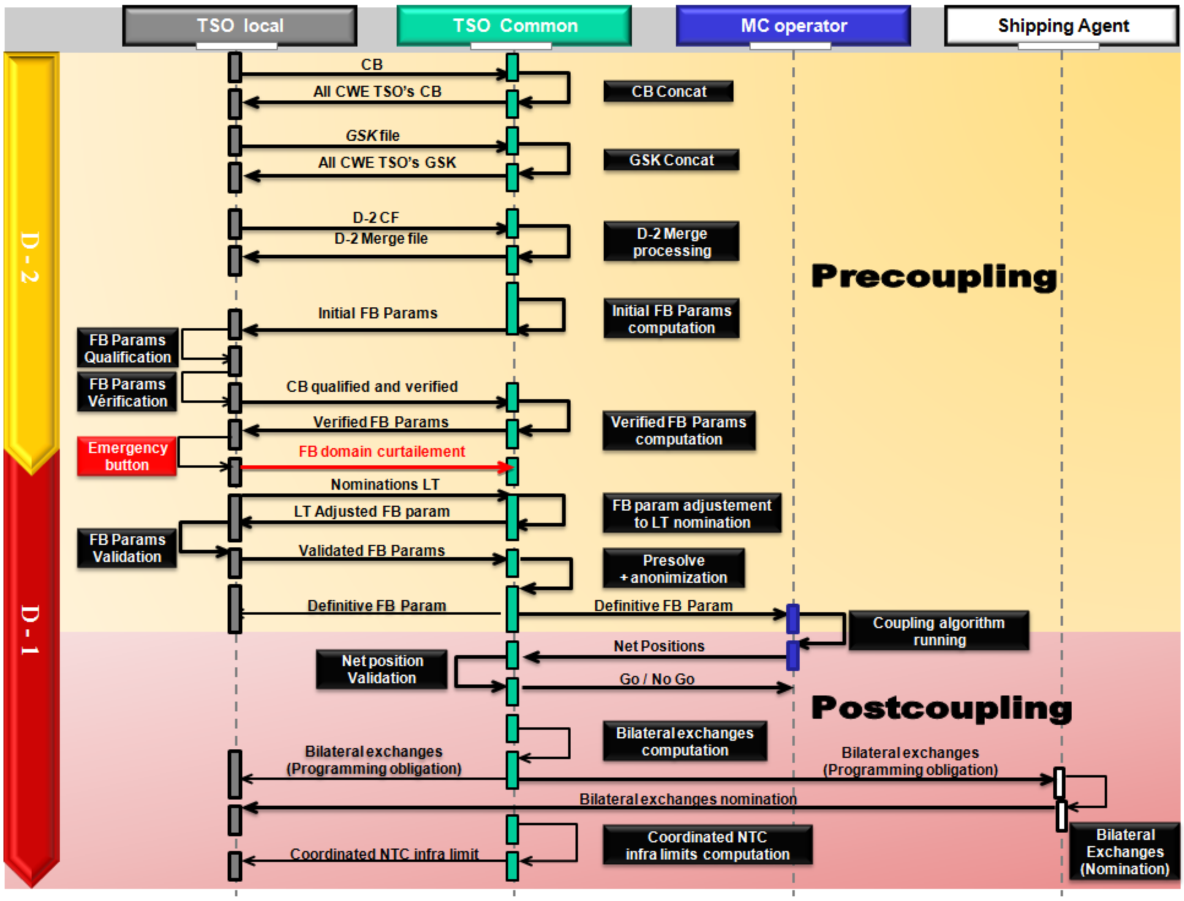
2.2.1 CWE Enhanced FB operational process overview

Hereunder a macro vision of the FBMC process is depicted:



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

[5] 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 and 2011 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 + anonymization.
  - 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[6]
- 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.

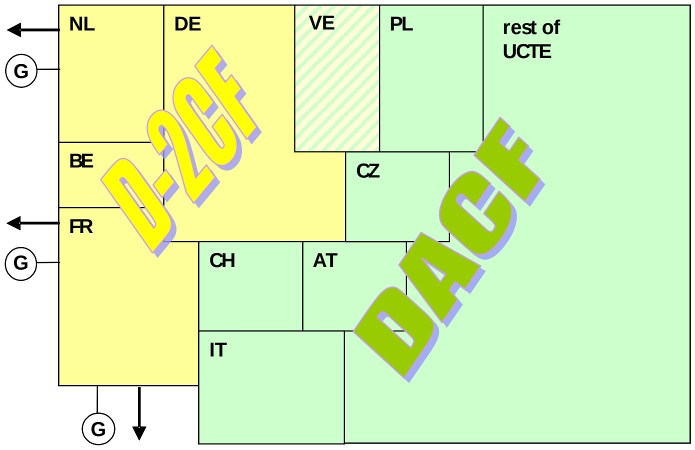
D-2CF files have to be balanced in terms of production and consumption, in coherence with the reference exchanges, i.e. any variation on the loads of a control area must be compensated by a consistent adjustment of the generation output in the same area.

[6] 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.

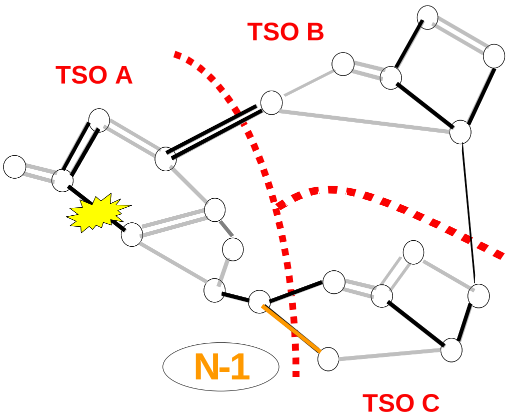
Note: the merging activity is not a fully automatic one and comprises a sanity check (UCTE format compliance, tie-lines status, country balance) of each individual file with a specific operational procedure in case of inconsistencies.

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

  During the experimentation, TSOs have used a default value of 10% of Fmax for these margins. A study is currently running to assess the real individual values of these margins. (See also FRM in section 5.6).

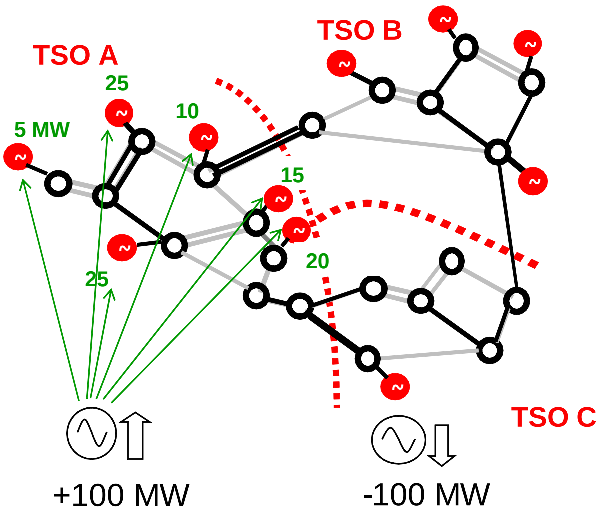
Besides critical branches, which are active power flow-related limits only, other specific limitations are necessary to guarantee a secure grid operation such as the ELIA import stability limit of 4500 MW (value used for test/experimentation purposes).
Import limits declared by TSO are taken into account 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 5.7, 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:

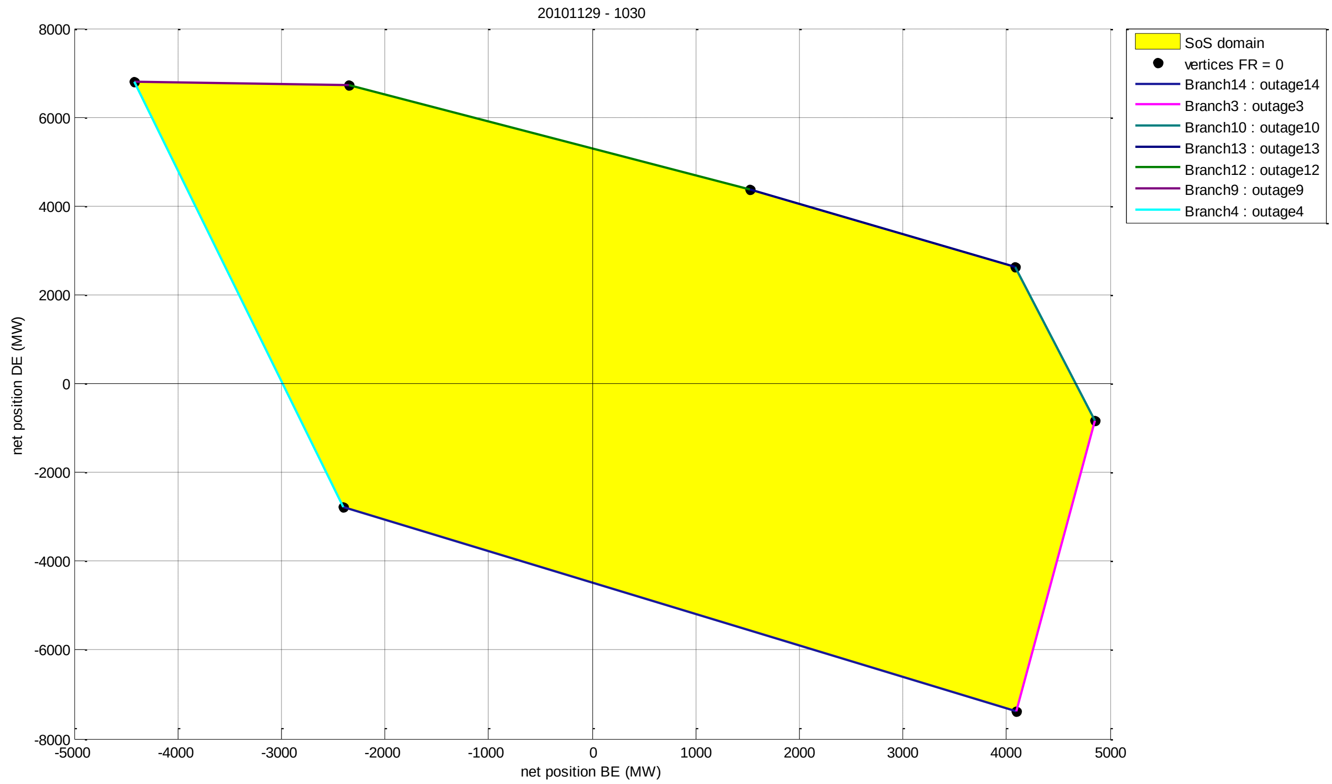
- The **Available Margin** on a critical branch:
  Margin = Fmax - Fref - FRM

  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 2010-2011 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 11 on page 26).

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 2010-2011 FB experimentation and are the main improvement from the 2008 classical CWE FB capacity calculation method to the 2010-2011 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 details 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 LTA 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[7].

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).

This step has not been systematically tested during the experimentation. This means that the results presented in this report do not systematically take this possible reduction step into account. TSOs are still working on the practical way to implement this verification step operationally before the beginning of the external parallel run.

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

Note 2: In the FB parameter verification phase the FB domain might be 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 5.4.

2.2.9 "Emergency reduction button"

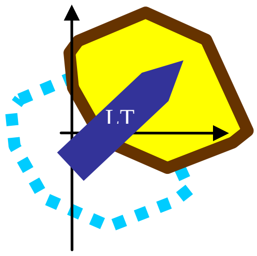
In case of critical conditions, TSOs need to be able to modify as quickly and simply as possible the FB domain offered to the market. This is for example the case when a major outage occurs in the night between D-2 and D-1. In such a situation, TSOs have the possibility to add maximum export limits and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

Note: This function has not been tested yet by TSOs during the 2010-2011 experimentation.

[7] 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.

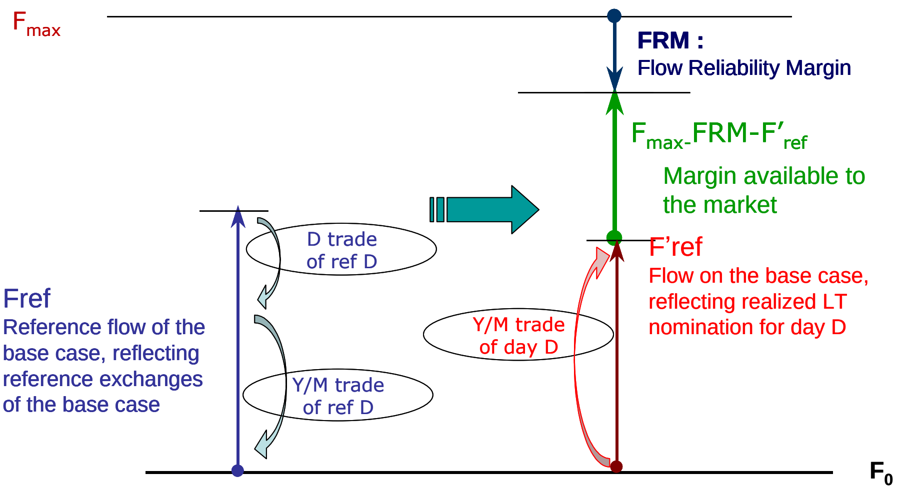
2.2.10 LT Adaptation + D-1 Validation + Presolve + Anonymization

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.

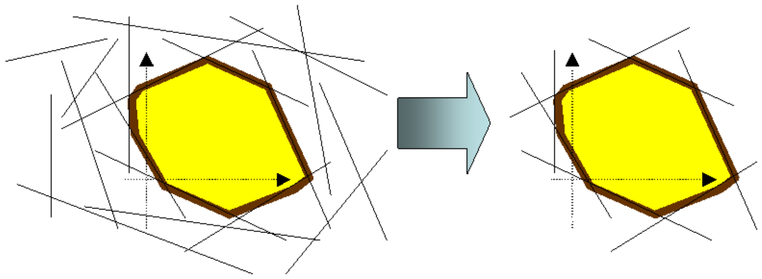


  Note: this process is equivalent to today's ATC computation for NTC and LT nominations (see also section 5.2):

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

- **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.

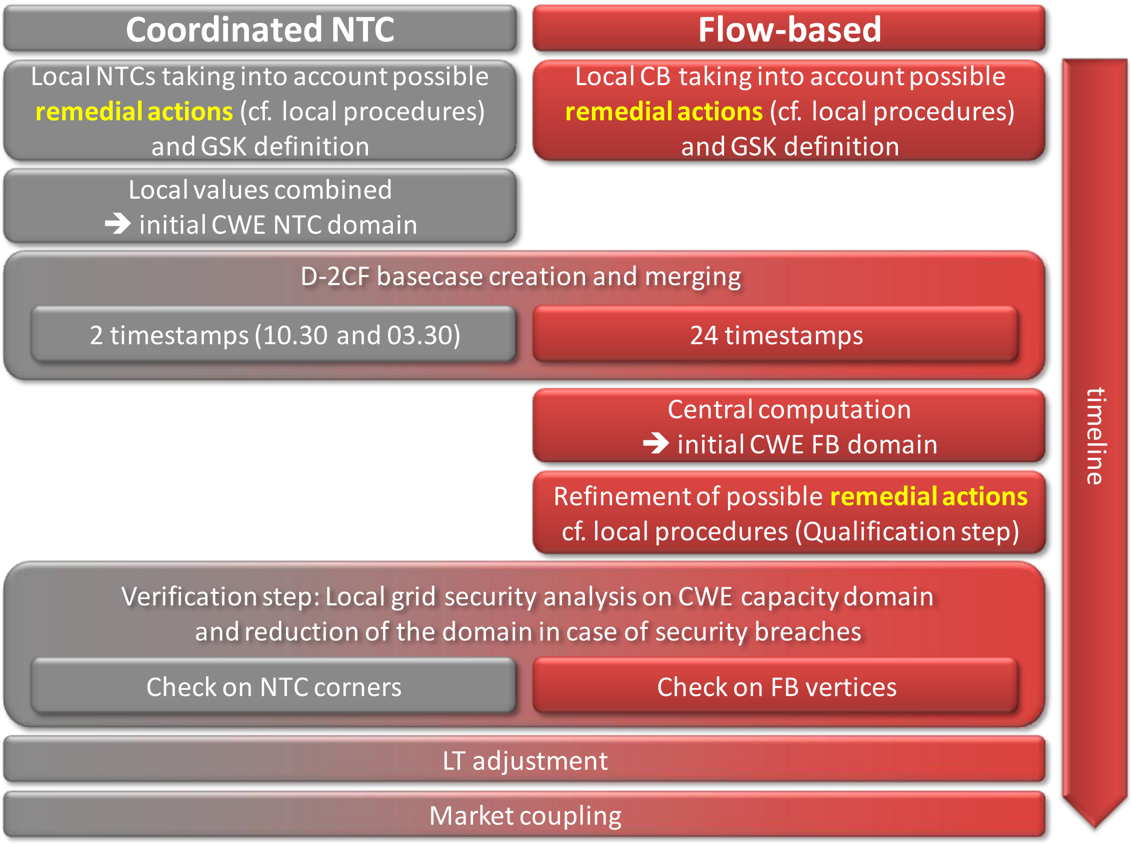
- **Anonymization of FB parameters:** before sending the input data to the MC system, the names of the critical branches are anonymized.

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

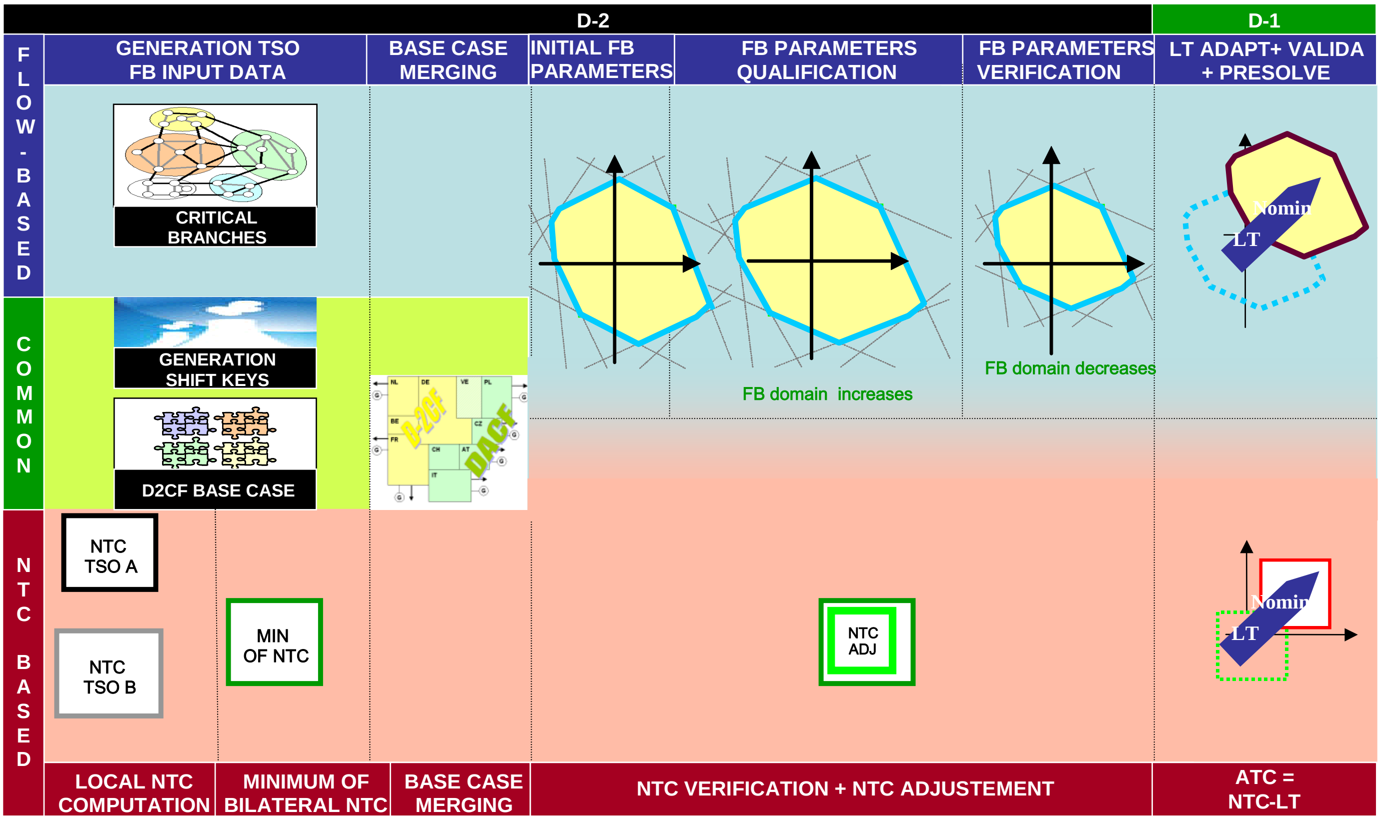
$$\begin{bmatrix} \\ PTDF \\ matrix \\ \\ \end{bmatrix} \cdot \begin{bmatrix} NE_{BE} \\ NE_{DE} \\ NE_{FR} \\ NE_{NL} \end{bmatrix} \leq \begin{bmatrix} F_{\max 1} \\ F_{\max 2} \\ \vdots \\ F_{\max p} \end{bmatrix} - \begin{bmatrix} F_{ref\,1}' \\ F_{ref\,2}' \\ \vdots \\ F_{refp}' \end{bmatrix} -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

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)

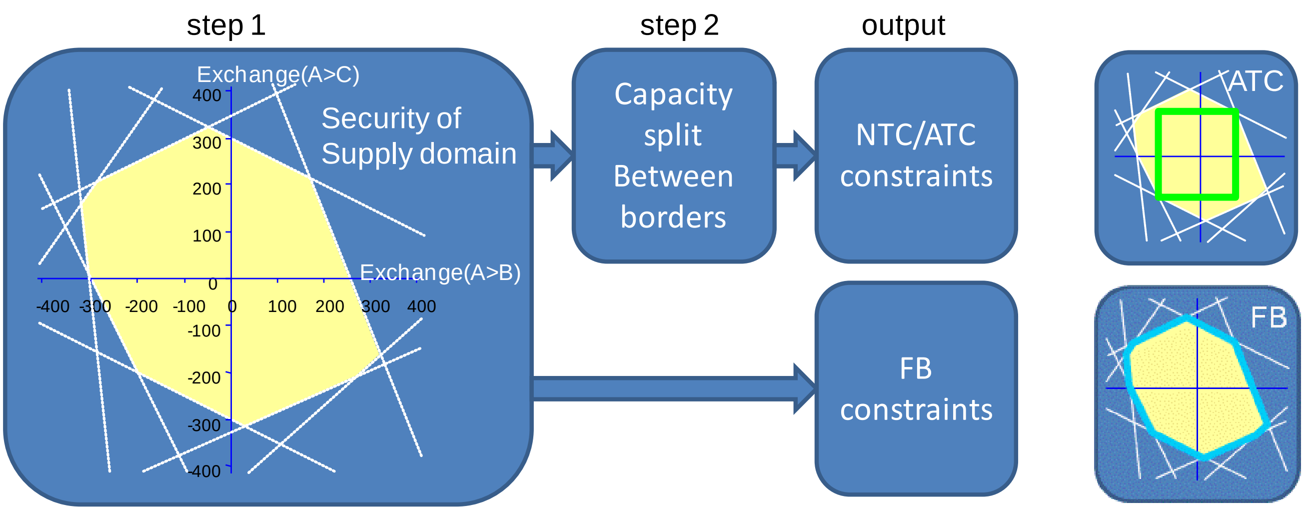


2.3 Increase of the capacity space offered to the market

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

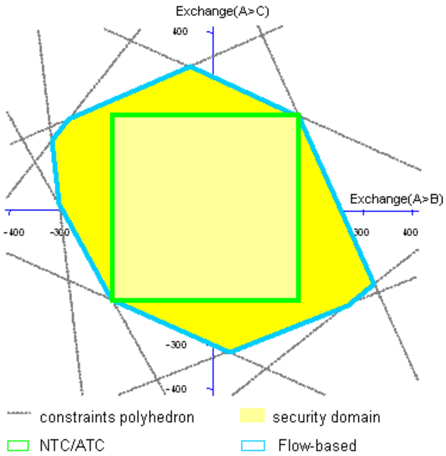
- The NTC/ATC constraints are a choice made by the TSO inside of this security domain: the TSO needs to make a choice on how to split the capacity among its borders
- The FB domain is the security domain itself; in FBMC the final capacity split between borders is not a choice of the TSO, but is market 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[8].

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[9] 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?

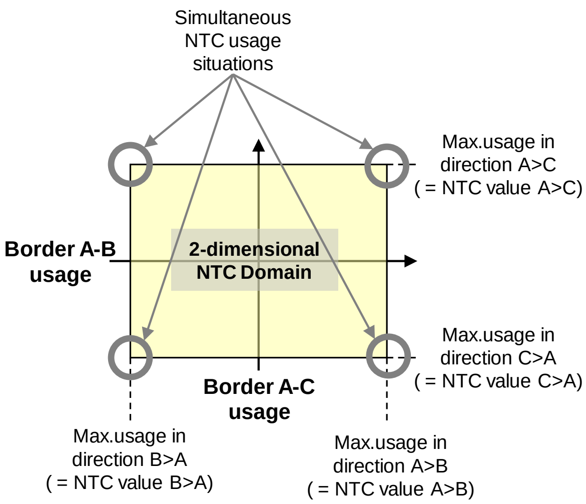
Reminder of ATC corners concept

---

[8] Market Coupling is a constrained optimization procedure (cf Section 5.11):
- 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

[9] 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[10].

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:

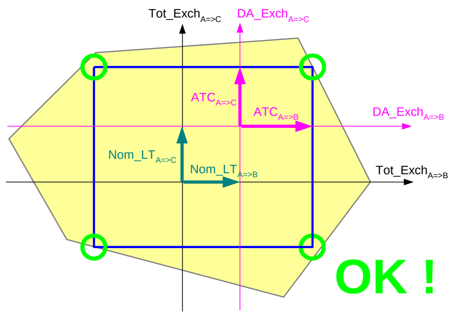
$$[\text{PTDF}][\text{Net Position}]=[\text{Flow}]$$

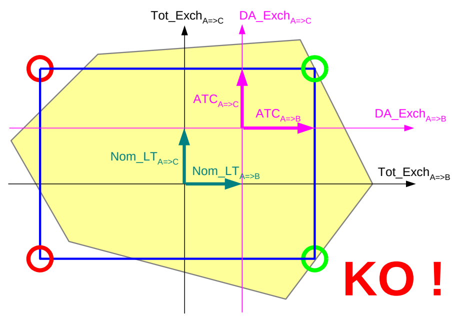
If for a corner, the calculated flows on each critical branch are smaller than or equal to the RAM (Remaining Available Margin), the corner is within the FB search space.

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:

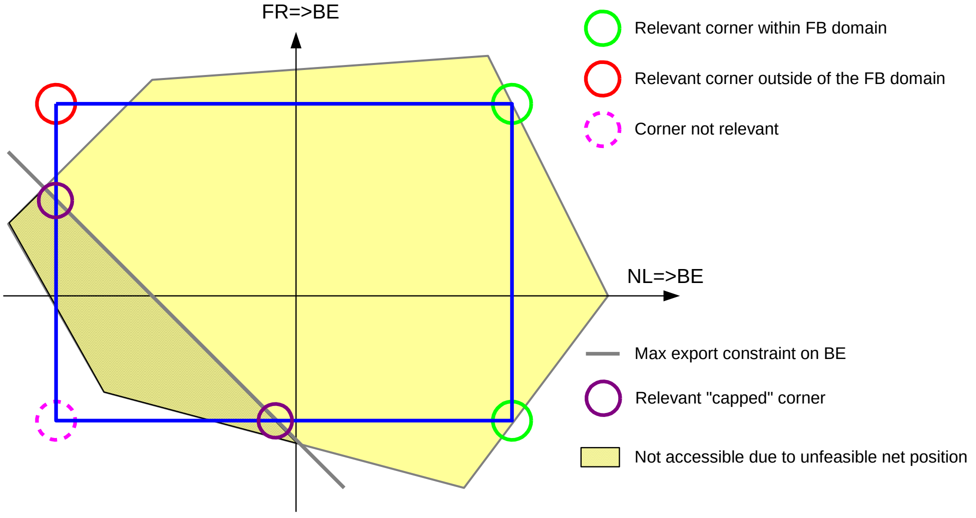
			Distance per critical branch and corner (in MW)															
Timestamp	**Outage Name**	**Branch Name**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
YYYY_MM_DD_HH	**Outage 1**	**Branch 1**	1955	2312	1323	1584	581	211	-50	938	1942	952	1680	-420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

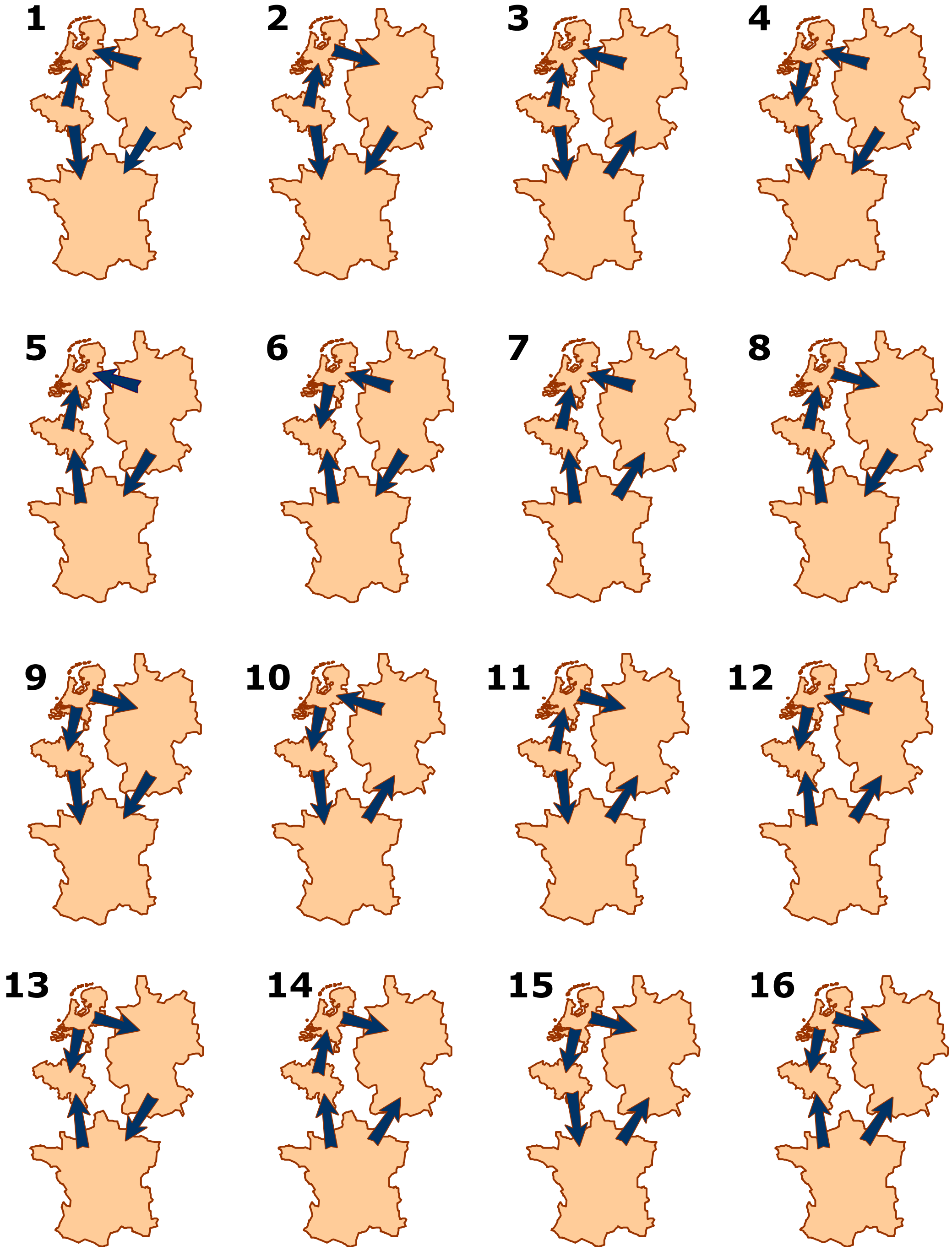
[10] For one bidding area, the net position is the sum of the commercial exchanges with this bidding area.

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. However in current ATC methods the probability of reaching the unlikely direction is very low and ATCs are not limited for these 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. In FB methods, the notion of unlikely corners disappears, therefore the capacity domain is not limited by unlikely conditions. This is one of the main drawbacks 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:

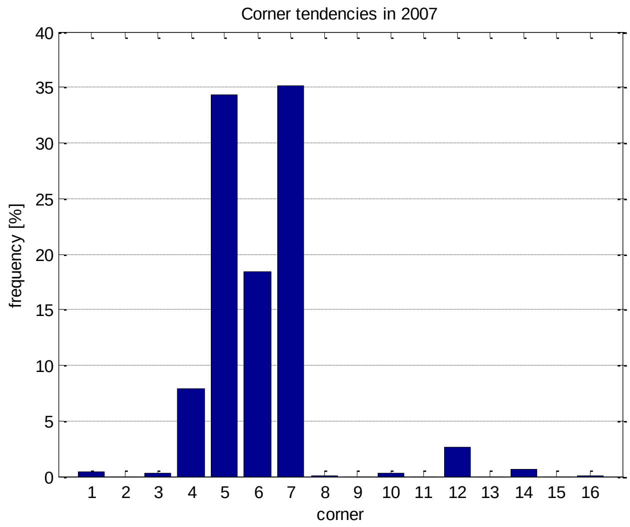


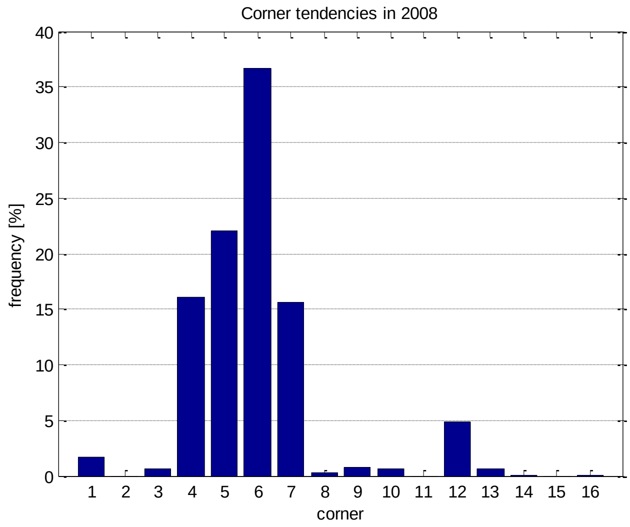
Based on the concept of the CWE corners, we can introduce the notion of corner tendency for a set of netted CWE bilateral exchanges: a set of CWE bilateral exchanges is considered as having a "corner #n tendency", if the bilateral exchanges have the same direction as the NTCs of corner #n.

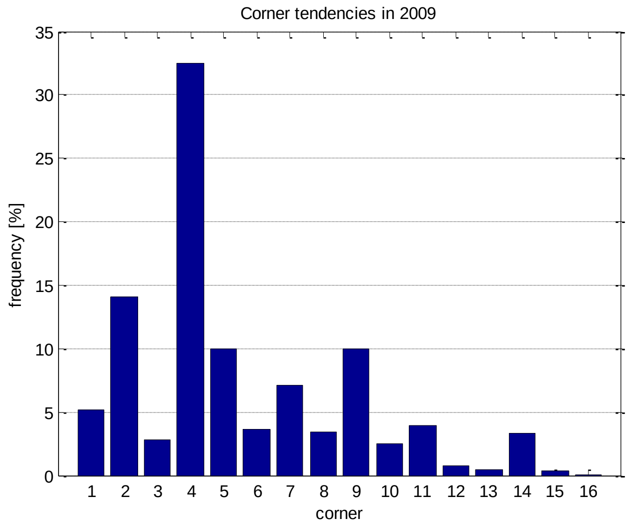
Example: corner 7 is [FR=>BE, FR=>DE, BE=>NL, DE=>NL], hence the following set has a "corner 7 tendency"

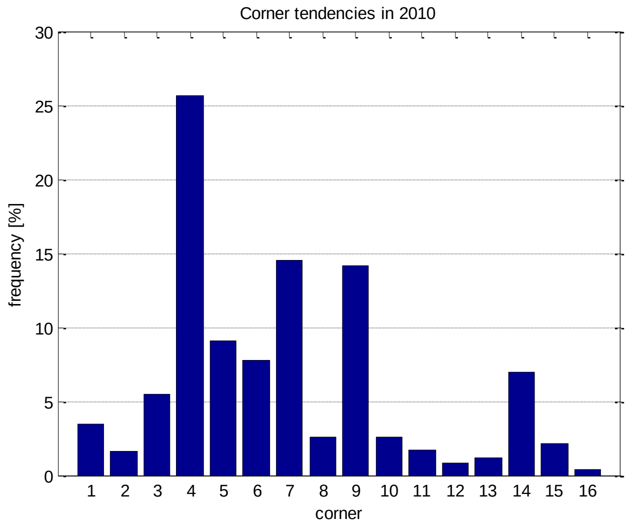
- FR=>BE = 500 MW
- FR=>DE = 1000 MW
- BE=>NL = 850 MW
- DE=>NL = 1150 MW

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[11] 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.

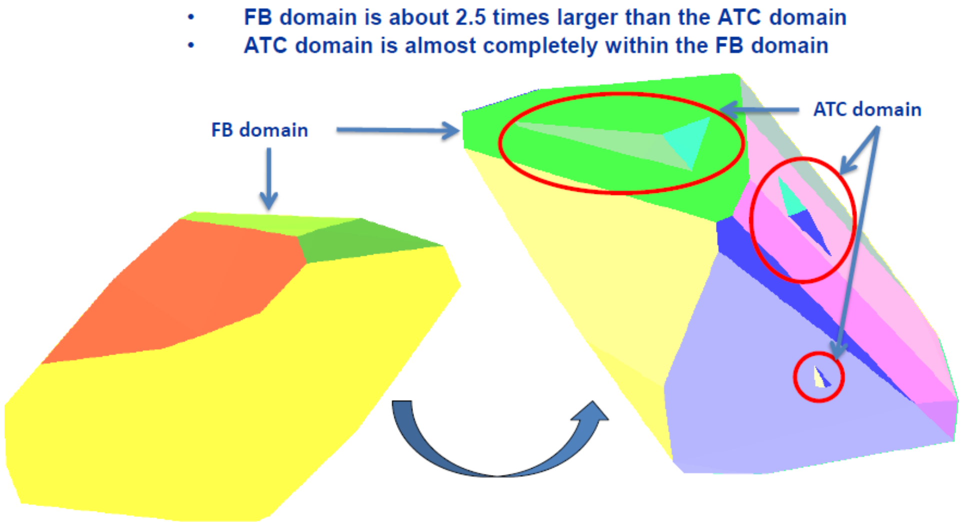
Example: *Timestamp 2/3/2010 10h30 of the FB experimentation. The three-dimensional bodies of both the ATC and FB search space for this timestamp are depicted in one graph. The volumes of both the ATC and FB search space are*

[11] 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.

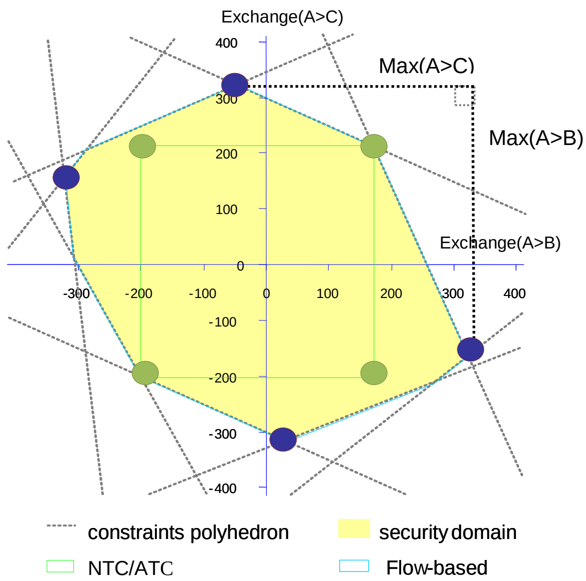
computed, as well as the volume of the intersection of the two; if the latter figure equals the volume of the ATC domain, this indicates that the ATC domain is fully included in the FB one.



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**[12] 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

[12] 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.

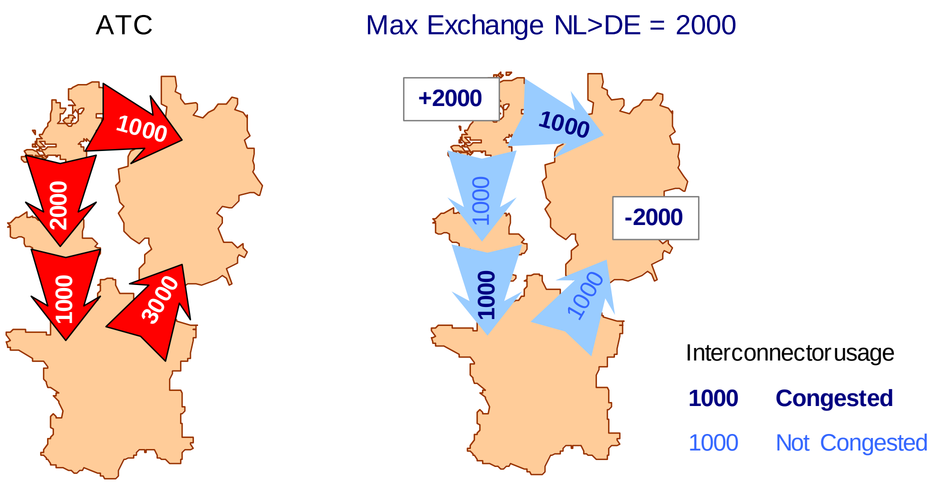
value on the y-axis indicated by the blue dot on top of the graph) cannot occur at the same time as a maximum bilateral exchange from A to B (the value Max(A>B): the value on the x-axis indicated by the blue dot on the right of the graph), as the combination of those values (the dashed square) is outside 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 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($ATC_{NL>BE}$, $ATC_{BE>FR}$, $ATC_{FR>DE}$)

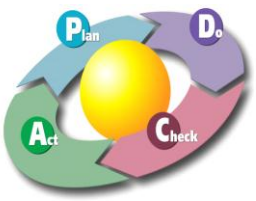


Example indicator values for one specific timestamp

		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 2010-2011 Enhanced FB experimentation cycles

The FB experimentation was performed during the years 2010 and 2011, 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 From	Business Dates To	Initial FB parameters	Qualified FB parameters	Remarks
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	
13	28/2/11	6/3/11	24 TS /day	24 TS /day	
14	4/4/11	10/4/11	24 TS /day	24 TS /day	
15	9/6/11	15/6/11	24 TS /day	24 TS /day	
16	15/6/11	21/6/11	24 TS /day	24 TS /day	constrained summer week
17	18/7/11	24/7/11	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.

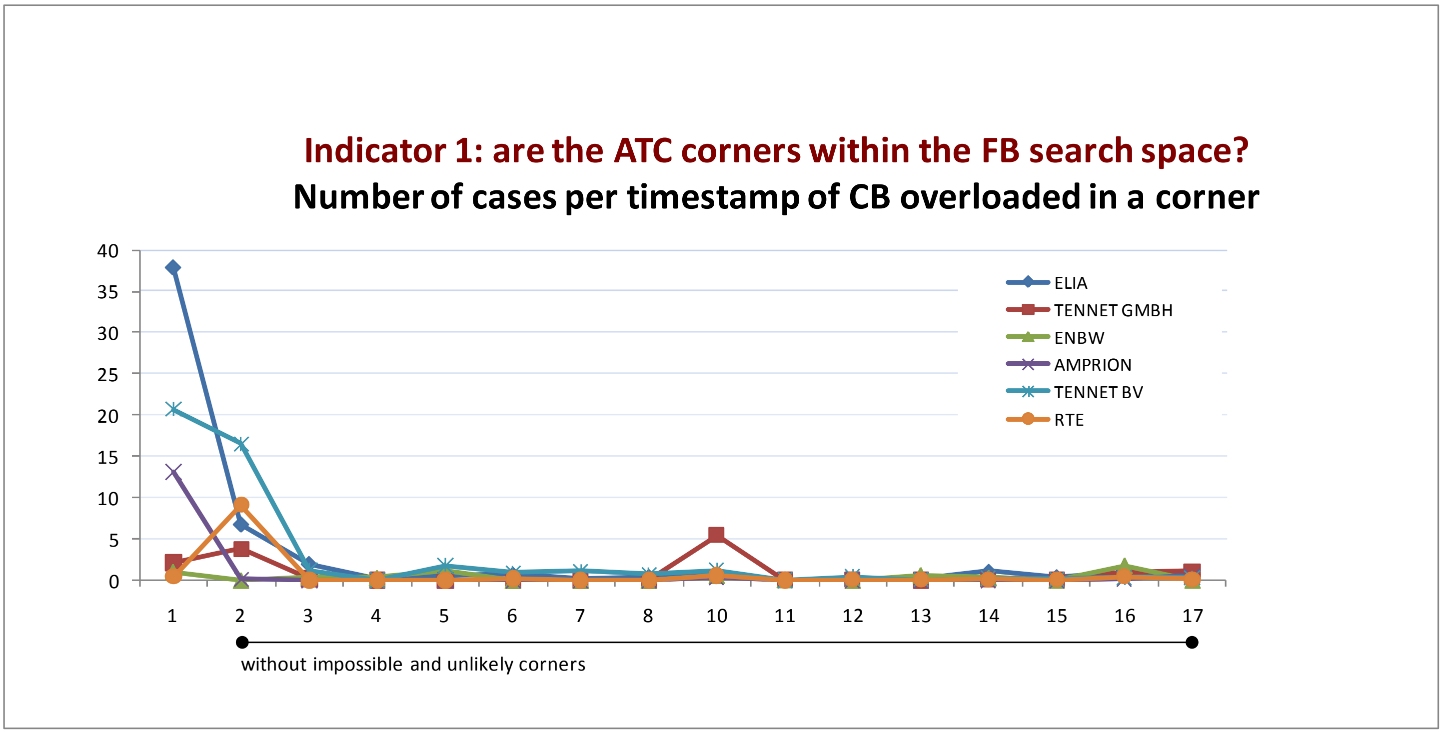
The methodological improvements leading to the proposed CWE enhanced FB were validated during the monthly meetings of the FB WG.

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 0.

2.3.3 Experimentation results

From December 2009 to July 2011, 17 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 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 3:30 and 10:30, 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 kinds 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.

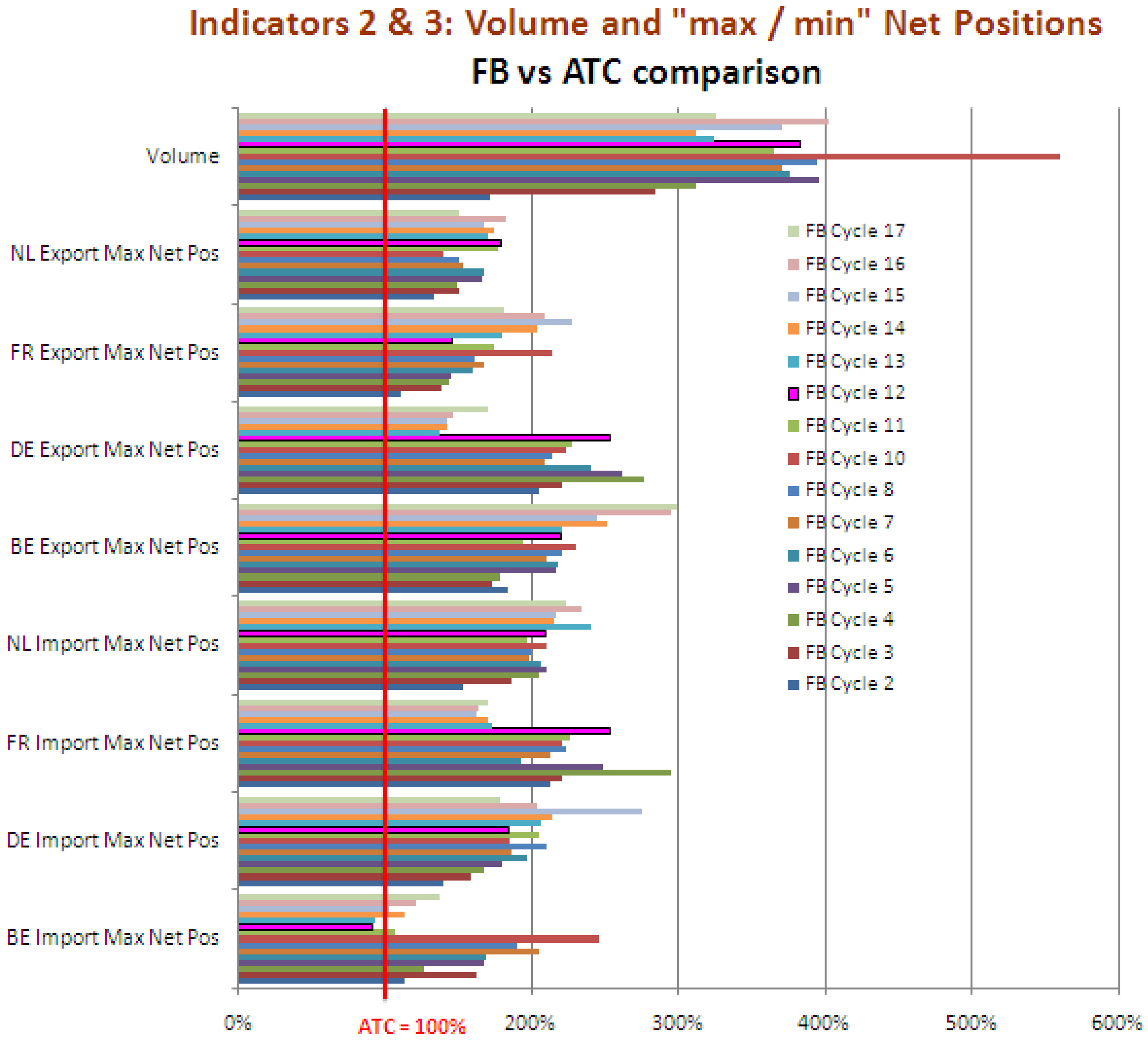
Note 4: for the indicators 2 & 3 the concepts of impossible and unlikely corners were not used. The volume and Net Position values compare the full NTC search space with the full FB one.

Note 5: from November 2010 up to and including July 2011, the produced FB parameters have been used for the “Price/Market impact analysis” performed jointly by PXs/TSOs that is presented in chapter 3.

Note 6: in this updated report, indicators from cycles 13 to 17 (March 2011 to July 2011) are in line with figures computed along previous cycles and enable to confirm the conclusions above: overloaded CBs remains extremely rare in proportion, and in any case observed in unrealistic situations, which confirms the fact that the FB methodology enables TSO to guarantee SoS with regard to current standards.

Note 7: a close look on the figure above enables to note a relative increase in the overloads proportion on the 2 last cycles, 16 and 17. This can be explained since 2011 summer was quite constrained, but does not change the conclusions above: as a matter of fact the observed overloads do not show up in relevant corners.

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 8: 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.

Note 9 : updated indicators, from cycles 13 to 17 (March 2011 to July 2011), are in line with figures computed along previous cycles and enable to confirm the conclusions above, that is significant increase in the search space volume and in the non-simultaneous max Import/Export capabilities.

2.4 Improvement of the security of supply and cooperation between TSOs

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

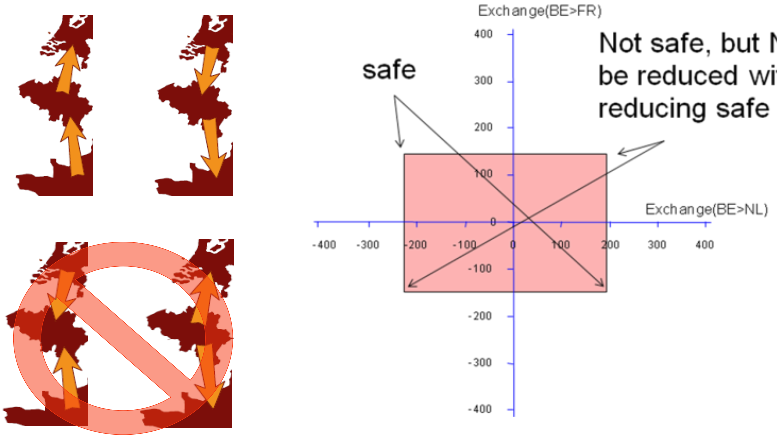
The FB description is closer to the reality of the grid, which induces a natural need for increased cooperation and information exchange between the CWE TSOs in the FB operational process. Furthermore an increase in the level of coordination between the TSOs is facilitated. Then the FB method has more physical meaning and is more transparent than the NTC method.

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

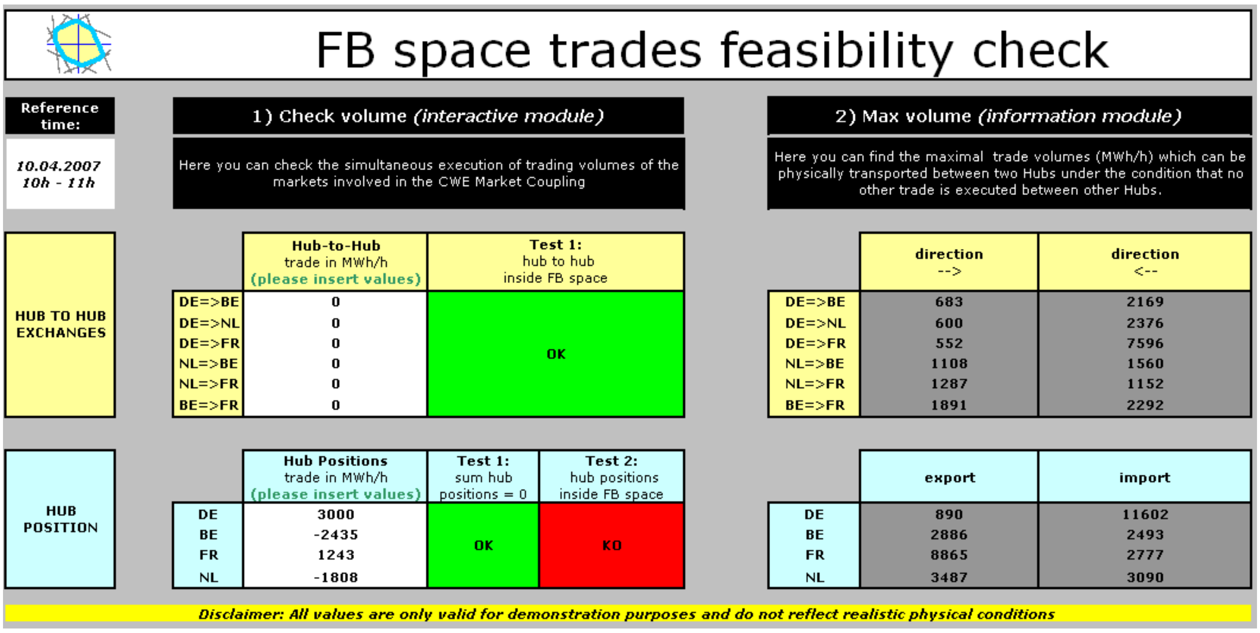
Elia chooses to provide maximum capacities to the market, but if one day the market behaves differently than foreseen, and reaches one of the unlikely corners, Elia will have to use exceptional D-1 and real-time measures to guarantee grid security. FB simply removes this issue.

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[13] 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.

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.

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[14])

ELIA

Belgium has no electrical borders outside CWE.

[13] 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

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

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.

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.

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

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

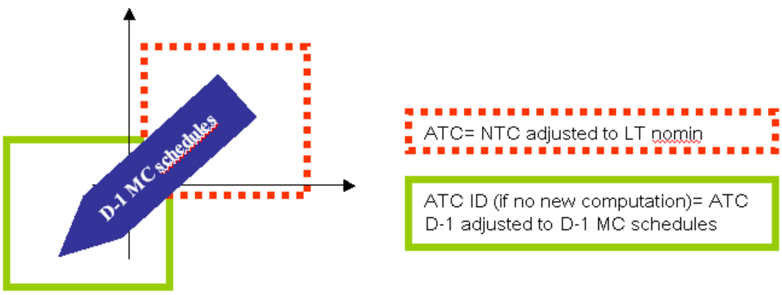
Note: As a consequence of this statement, CWE TSOs will require from future NWE intraday processes, a full compliancy with the FB modelling (this will affect in particular the so-called capacity management module).

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.

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.

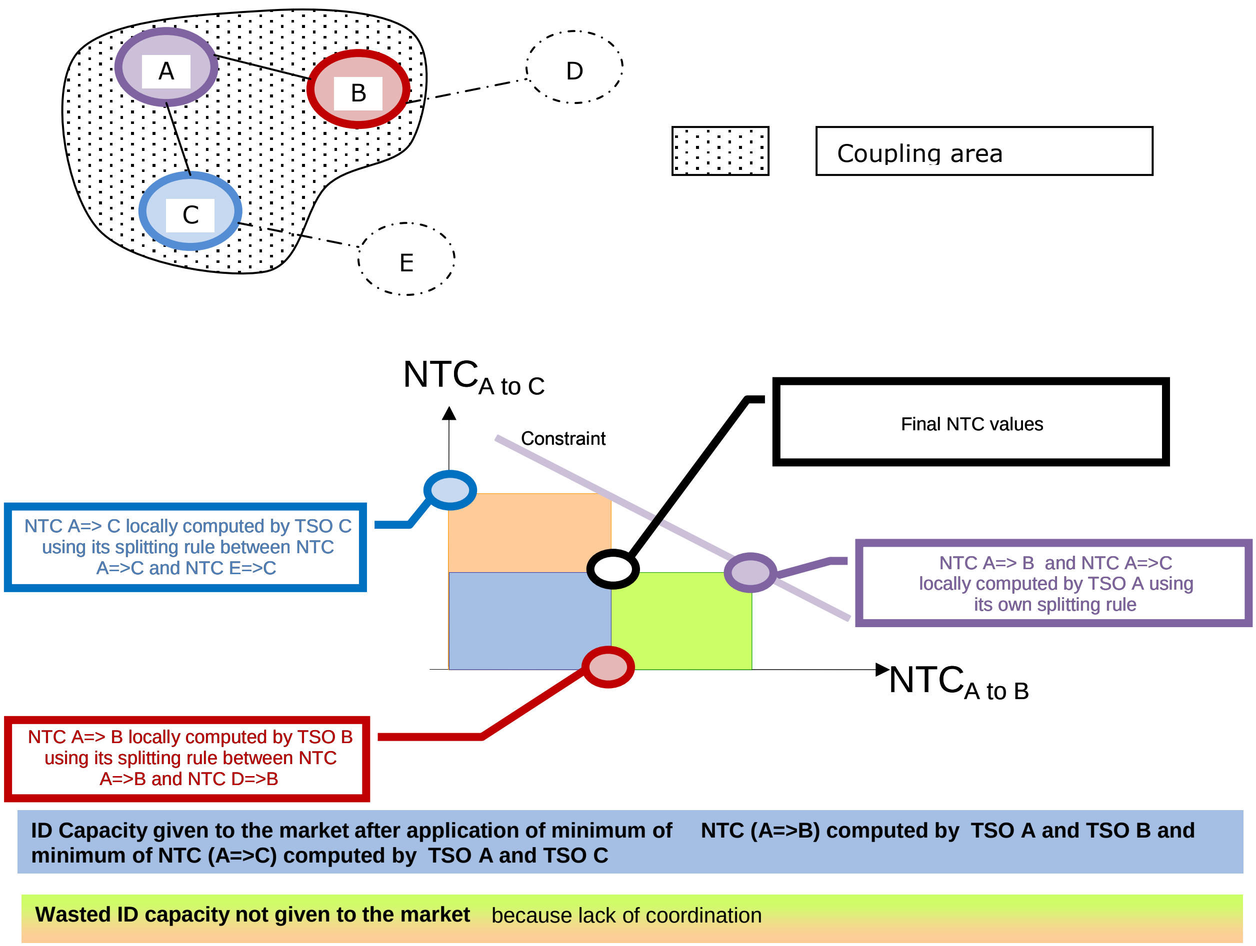


- The CWE TSOs that have implemented a local ID NTC computation have the opportunity to adjust bilaterally their D-1 NTC/ATC values.

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.

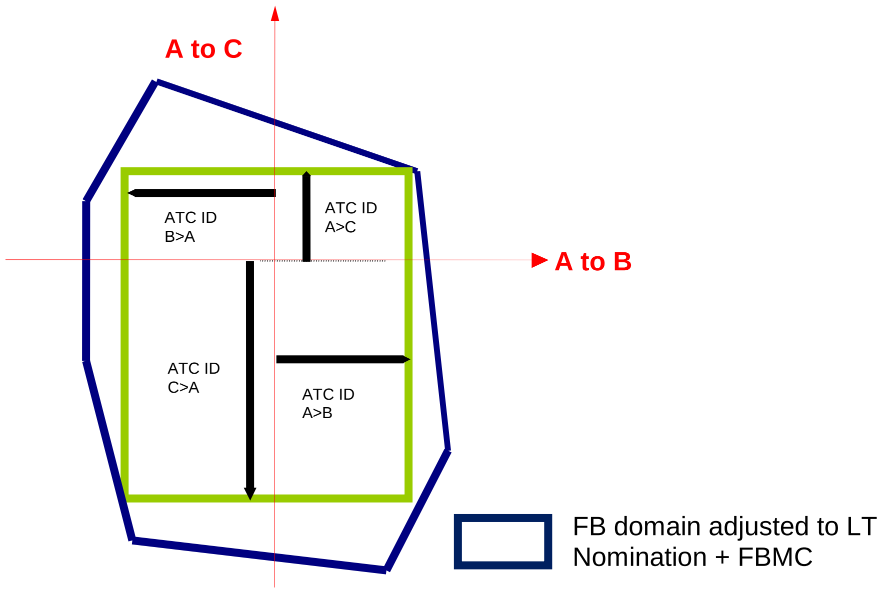
Interim situation: ID ATC computation with FBMC in D-1

<u>Preliminary remarks:</u>

- 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.

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 <u>ATCs</u> are computed and not ID <u>NTCs</u> as explained in section 5.8.

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

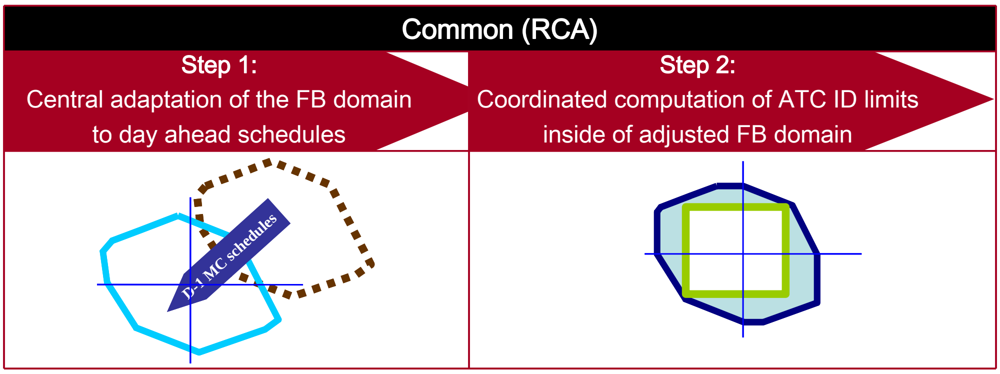
The coordinated ID ATC calculation process computes the 8 CWE ID ATCs directly from the adapted FB domain:

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 have been proposed and developed during the FB experimentation to prove the feasibility of the coordinated splitting approach and to come up with initial ID ATC values that are computed from the FB domain.

Remark*: the final algorithm selected is described later in this section. 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***

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

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 ID ATC computation

Context

AHAG defined in 2011[15] three different levels of capacity calculation:

- Level 0: no ID capacity calculation. ID capacities are just leftovers from DA capacities after DA allocation
- Level 1: ID capacity calculation based on DACF
- Level 2: ID capacity updates based on IDCF

[15] In the report "AHAG Capacity calculation project, Synthetic document and main achievements", published in March 2011.

CWE TSOs intend to head for level 1 as soon as possible. However the method proposed in the following paragraph is just a level 0 method. As explained in the previous chapter, putting in place such a method was a prerequisite for FBMC, since it should be possible to compute easily ID ATC after FBMC.

Main idea

The coordinated ID ATC calculation process computes the 8 CWE ID ATCs directly from the adapted FB domain. There is no recomputation of FB parameters in D-1 based on DACF. The main idea of the algorithm described hereafter is to divide the remaining available margins after FBMC equally to the 4 CWE borders, and then translate these margins into ID ATC with PTDF.

This algorithm has been chosen over the others (not described in this report) based on the following criteria

- Need to have capacities in all direction for ID if possible (no zero) since ID is considered as an adjustment market
- Fairness between borders
- Transparent and easy to explain
- Linked with physics of the grid
- Capacity maximisation while respecting security

Algorithm description

The FB market coupling net positions are used to adjust the margins of the critical branches:
[vector with margins after the FBMC] = [vector with RAMs] – [PTDF matrix]*[vector with market coupling net positions]
By doing this, the new margins represent the margins on the critical branches after the net positions of the FBMC have been taken into account. From this updated FB domain, the ID ATC domain is determined in the following way.

From the presolved PTDF matrix, which is a zone-to-hub PTDF matrix, a zone-to-zone PTDF matrix is computed, in which only the positive numbers are stored.

Zone-to-hub PTDF matrix

BE	DE	FR	NL
-0.03994109	0.05431623	0.0633787	0.03374869
0.03985412	-0.05419794	-0.06324065	-0.03367519
0.06273492	0.2651218	0.3659828	0.2211313
0.04247724	0.3739356	0.2178424	0.4641062
0.004729872	0.1670373	0.08955165	-0.01145841
0.0487344	-0.1879473	-0.07615791	-0.2570781
0.008705636	0.2488978	0.1549257	-0.04966162
0.001697983	0.0837971	0.03401952	-0.1253377
-0.00101835	-0.06637765	-0.02220839	0.1499735
-0.00808217	-0.09222963	-0.1996102	-0.06960133
0.01001291	-0.1497662	0.001483622	-0.1328685
0.007830005	-0.1362592	0.03977019	-0.1290404
-1	0	0	0

zone-to-zone PTDF matrix (with only positive numbers)

BE>FR	BE>NL	DE>FR	DE>NL	FR>BE	FR>DE	NL>BE	NL>DE
0	0	0	0.02056754	0.10331979	0.00906247	0.07368978	0
0.10309477	0.07352931	0.00904271	0	0	0	0	0.02052275
0	0	0	0.0439905	0.30324788	0.100861	0.15839638	0
0	0	0.1560932	0	0.17536516	0	0.42162896	0.0901706
0	0.01618828	0.07748565	0.17849571	0.08482178	0	0	0
0.12489231	0.3058125	0	0.0691308	0	0.11178939	0	0
0	0.05836726	0.0939721	0.29855942	0.14622006	0	0	0
0	0.12703568	0.04977758	0.2091348	0.03232154	0	0	0
0.02119004	0	0	0	0	0.04416926	0.15099185	0.21635115
0.19152804	0.06151917	0.10738057	0	0	0	0	0.0226283
0.00852929	0.14288141	0	0	0	0.15124982	0	0.0168977
0	0.13687041	0	0	0.03194019	0.17602939	0	0.0072188
0	0	0	0	1	0	1	0

The method applied to compute the ID ATCs in short comes down to the following approach:

- For each critical branch, share the remaining margin between the four borders that are positively influenced with equal shares (1/4 in our case).
- From those shares of margin, maximum bilateral exchange are computed by dividing each share by the positive zone-to-zone PTDF
- The maximum bilateral exchanges are set to the minimum values obtained over all CBs
- Iterate until the maximum bilateral exchange cannot be increased any more
- The 8 ID ATCs get the values that have been determined for the 8 maximum bilateral exchanges

Example

This approach is illustrated in the example below.

Imagine that we have a critical branch CBx with a margin of 100 MW left after the FBMC. This margin is given to the ID market, equally shared among the four oriented borders (among the 8) that load the line (25 MW of margin each):

CBx

Direction	margin	PTDF_z2z	incremental max. bilateral exchange	max. bilateral exchange
FR>BE	100/4 = 25	0.15	margin/PTDF = 25/0.15 = 166.7 MW	0 + 166.7 = 166.7 MW
DE>FR	100/4 = 25	0.15	margin/PTDF = 25/0.15 = 166.7 MW	0 + 166.7 = 166.7 MW
NL>BE	100/4 = 25	0.4	margin/PTDF = 25/0.4 = 62.5 MW	0 + 62.5 = 62.5 MW
NL>DE	100/4 = 25	0.1	margin/PTDF = 25/0.1 = 250 MW	0 + 250 = 250 MW

There are two other CBs in this very simple example: CBy and CBz (with very artificial numbers).

CBy

Direction	margin	PTDF_z2z	incremental max. bilateral exchange	max. bilateral exchange
BE>FR	40/4 = 10	0.1	margin/PTDF = 10/0.1 = 100 MW	0 + 100 = 100 MW
FR>DE	40/4 = 10	0.1	margin/PTDF = 10/0.1 = 100 MW	0 + 100 = 100 MW
NL>BE	40/4 = 10	0.1	margin/PTDF = 10/0.1 = 100 MW	0 + 100 = 100 MW
NL>DE	40/4 = 10	0.1	margin/PTDF = 10/0.1 = 100 MW	0 + 100 = 100 MW

CBz

Direction	margin	PTDF_z2z	incremental max. bilateral exchange	max. bilateral exchange
BE>FR	200/4 = 50	0.1	margin/PTDF = 50/0.1 = 500 MW	0 + 500 = 500 MW
FR>DE	200/4 = 50	0.1	margin/PTDF = 50/0.1 = 500 MW	0 + 500 = 500 MW
BE>NL	200/4 = 50	0.1	margin/PTDF = 50/0.1 = 500 MW	0 + 500 = 500 MW
DE>NL	200/4 = 50	0.1	margin/PTDF = 50/0.1 = 500 MW	0 + 500 = 500 MW

This exercise is performed for every critical branch in the FB parameter file (in this example 3 CBs). As it is the first step (step 1) of the iterative computation, the initial value of the maximum bilateral exchange equals zero at this stage.

Despite the fact that for CBx a maximum bilateral exchange is computed for NL>DE of 250 MW, for CBy this value is only 100 MW, and the lowest value (on all CB) must hold in order to prevent possible overloads. So, after the maximum bilateral exchanges for all critical branches are computed, the minimum value (on all CB) for each bilateral exchange is stored. In our example:

Direction	max. bilateral exchange	Direction	max. bilateral exchange
FR>BE	166.7	BE>FR	100
DE>FR	166.7	FR>DE	100
NL>BE	62.5	BE>NL	500
NL>DE	100	DE>NL	500

The impact of this set of bilateral exchanges is now taken into account by updating the margins of the critical branches. In the case of CBx, if the bilateral exchange NL>DE is set to 100 MW, this bilateral exchange would only use PTDF*bilateral exchange = 0.1*100 = 10 MW instead of 25 MW. This means that 15 MW can be shared again. In other words, at each iteration "n" we have the following formula for the margin of CB "x":

$$Margin_n^x = Margin_{n-1}^x - \sum_{i=1}^{4} BE_{i;n-1}^x * PTDF_i^x$$

Where:
i = 1..4 represent the four oriented borders which load positively CBx
$BE_{i;n-1}^x$ *is the minimum bilateral exchange in direction i computed at step n-1*
$PTDF_i^x$ *is the sensitivity of CBx towards a bilateral exchange in direction i.*

CBx

old margin	new margin
100	100 – 166.7*0.15 – 166.7*0.15 – 62.5*0.4 – 100*0.1 = 15

CBy

old margin	new margin
40	40 – 100*0.1 – 100*0.1 – 62.5*0.1 – 100*0.1 = 3.75

CBz

old margin	new margin
200	200 – 100*0.1 – 100*0.1 – 500*0.1 – 500*0.1 = 80

Starting step2: the new margin is shared again, in the same way as before. Note that the initial max. bilateral exchange is not equal to zero now.

CBx

Direction	margin	PTDF_z2z	incremental max. bilateral exchange	max. bilateral exchange
FR>BE	15/4 = 3.75	0.15	margin/PTDF = 3.75/0.15 = 25 MW	166.7 + 25 = 191.7 MW
DE>FR	15/4 = 3.75	0.15	margin/PTDF = 3.75/0.15 = 25 MW	166.7 + 25 = 191.7 MW
NL>BE	15/4 = 3.75	0.4	margin/PTDF = 3.75/0.4 = 9.4 MW	62.5 + 9.4 = 71.9 MW
NL>DE	15/4 = 3.75	0.1	margin/PTDF = 3.75/0.1 = 37.5 MW	100 + 37.5 = 137.5 MW

CBy

Direction	margin	PTDF_z2z	incremental max. bilateral exchange	max. bilateral exchange
BE>FR	3.75/4 = 0.94	0.1	margin/PTDF = 0.94/0.1 = 9.4 MW	100 + 9.4 = 109.4 MW
FR>DE	3.75/4 = 0.94	0.1	margin/PTDF = 0.94/0.1 = 9.4 MW	100 + 9.4 = 109.4 MW
NL>BE	3.75/4 = 0.94	0.1	margin/PTDF = 0.94/0.1 = 9.4 MW	62.5 + 9.4 = 71.9 MW
NL>DE	3.75/4 = 0.94	0.1	margin/PTDF = 0.94/0.1 = 9.4 MW	100 + 9.4 = 109.4 MW

CBz

Direction	margin	PTDF_z2z	incremental max. bilateral exchange	max. bilateral exchange
BE>FR	80/4 = 20	0.1	margin/PTDF = 20/0.1 = 200 MW	100 + 200 = 300 MW
FR>DE	80/4 = 20	0.1	margin/PTDF = 20/0.1 = 200 MW	100 + 200 = 300 MW
BE>NL	80/4 = 20	0.1	margin/PTDF = 20/0.1 = 200 MW	500 + 200 = 700 MW
DE>NL	80/4 = 20	0.1	margin/PTDF = 20/0.1 = 200 MW	500 + 200 = 700 MW

The minimum value for each bilateral exchange is stored again (step 2). In our example:

Direction	max. bilateral exchange	Direction	max. bilateral exchange
FR>BE	191.7	BE>FR	109.4
DE>FR	191.7	FR>DE	109.4
NL>BE	71.9	BE>NL	700
NL>DE	109.4	DE>NL	700

This computation continues until the maximum value over all critical branches of the absolute difference between the margin of computational step i+1 and step i is smaller than a stop criterion. In our example the difference equals:

Direction	Difference	Direction	Difference
FR>BE	191.7 - 166.7 = 25	BE>FR	109.4 – 100 = 9.4
DE>FR	191.7 - 166.7 = 25	FR>DE	109.4 – 100 = 9.4
NL>BE	71.9 – 62.5 = 9.4	BE>NL	700 – 500 = 200
NL>DE	109.4 – 100 = 9.4	DE>NL	700 – 500 = 200

As the maximum value of the difference (200 MW in this case) is larger than the stop criterion (e.g. 1.e-3), the computation continues.

When the stop criterion is met, the 8 ID ATCs get the values that have been determined for the 8 maximum bilateral exchanges.

The ATC values are then rounded down to an integer value.

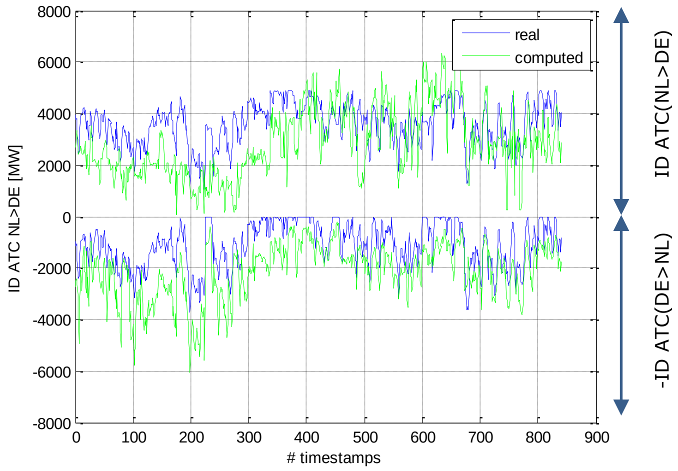
After algorithm execution, there are some critical branches with no remaining available margin left. These are the limiting elements of the ID ATC computation.

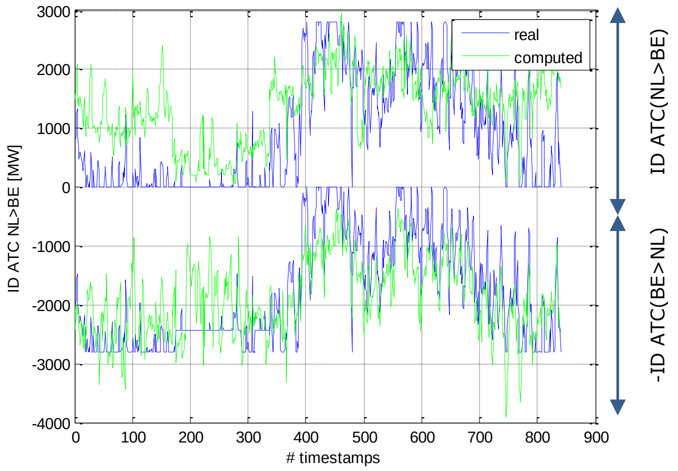
Initial ID ATC computation: experimental results

The coordinated ID ATC calculation process as presented in the previous section has been tested on the data of the cycles 11, 12, and 13 (in total: 840 timestamps during 2010-2011 winter).

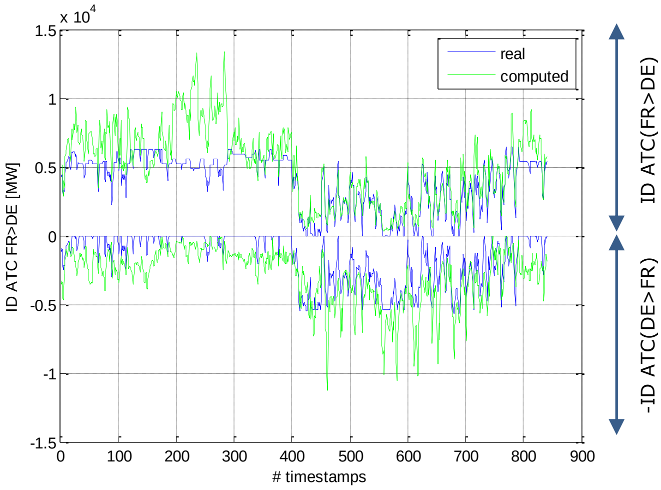
With FBMC in operation, the FB domain would be adjusted in accordance to the net positions resulting from the FBMC, followed by the ID ATC computation.
The experiments and the experimental results that we want to show in this section serve however a slightly different purpose, and so is the approach that we needed to follow. We want to compare the ID ATCs that are computed from the FB domain, with the ones that we had in real time, following the ATCMC. To make this comparison meaningful, the net positions established under the ATCMC are now used to adjust the FB domain, followed by the ID ATC computation. In this way, both the real ID ATCs, as well as the ones computed from the FB domain, reflect the capacity that is left for the ID market after the ATCMC: the capacity left in the ATC model versus the capacity left under the FB model.

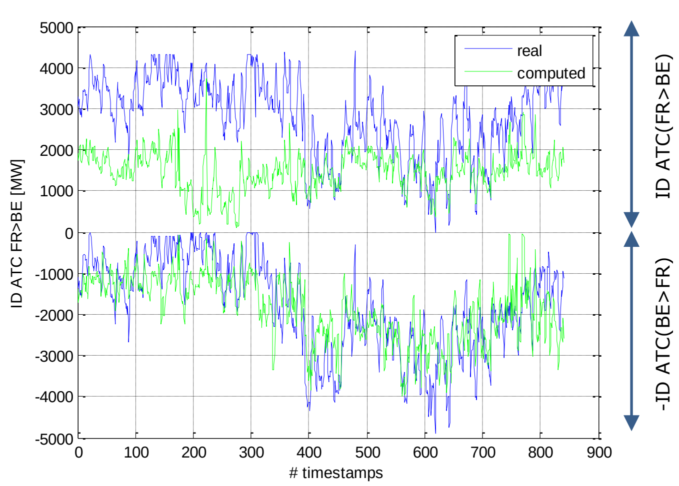
The detailed results of the ID ATCs on the 840 timestamps analyzed are shown in the four graphs hereunder. Note that these capacity values are ATC and not NTC[16]



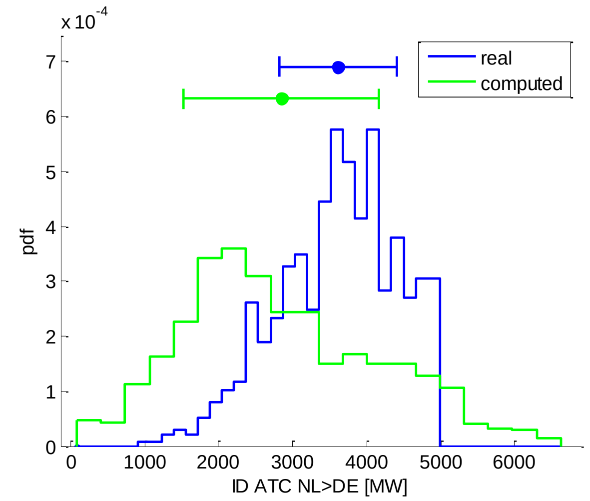


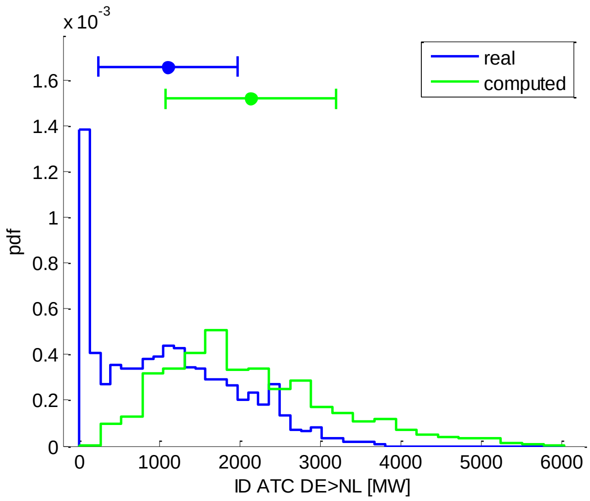
[16] See annex 5.x for an explanation of this distinction between ATC & NTC.

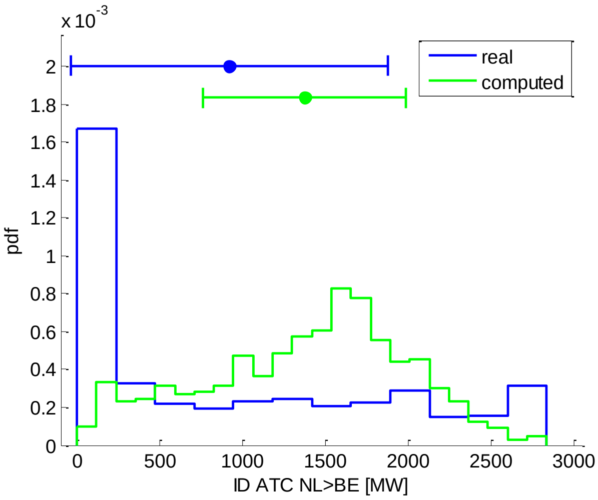


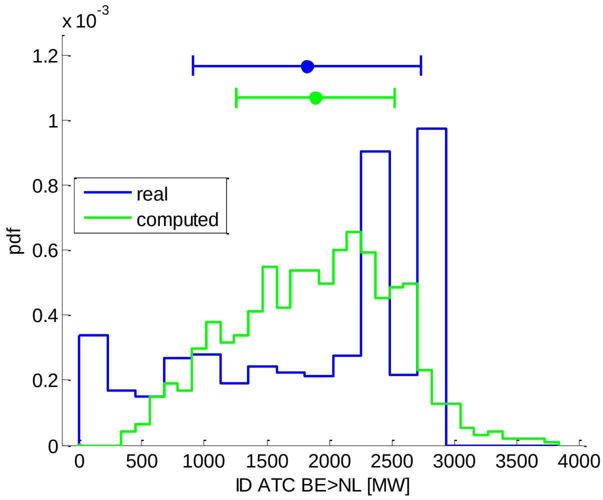


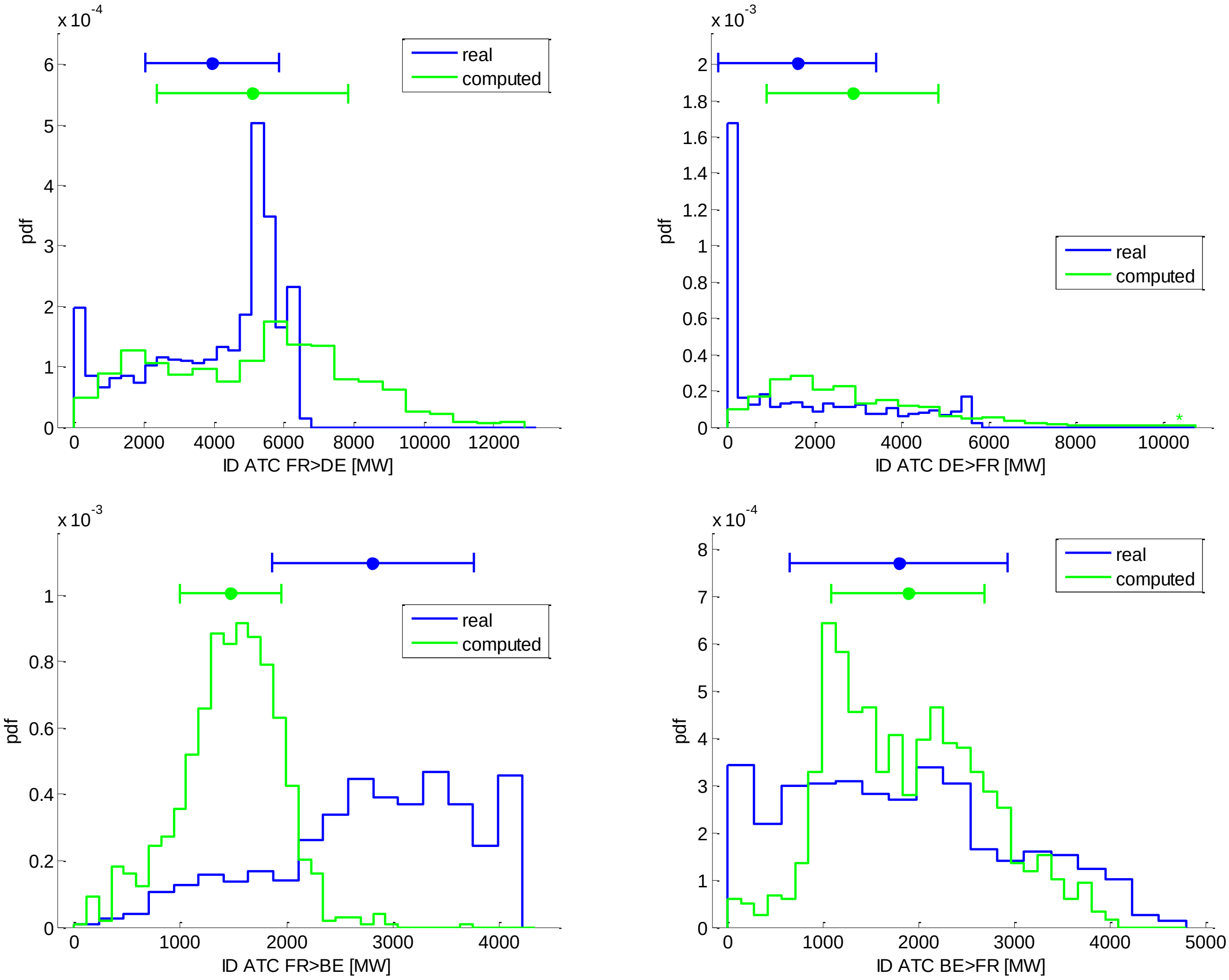
The detailed results and overall statistics come together in the following histograms, where one will find the comparative probabilities of finding a given ID ATC, for each oriented border :











General conclusion on ID ATC

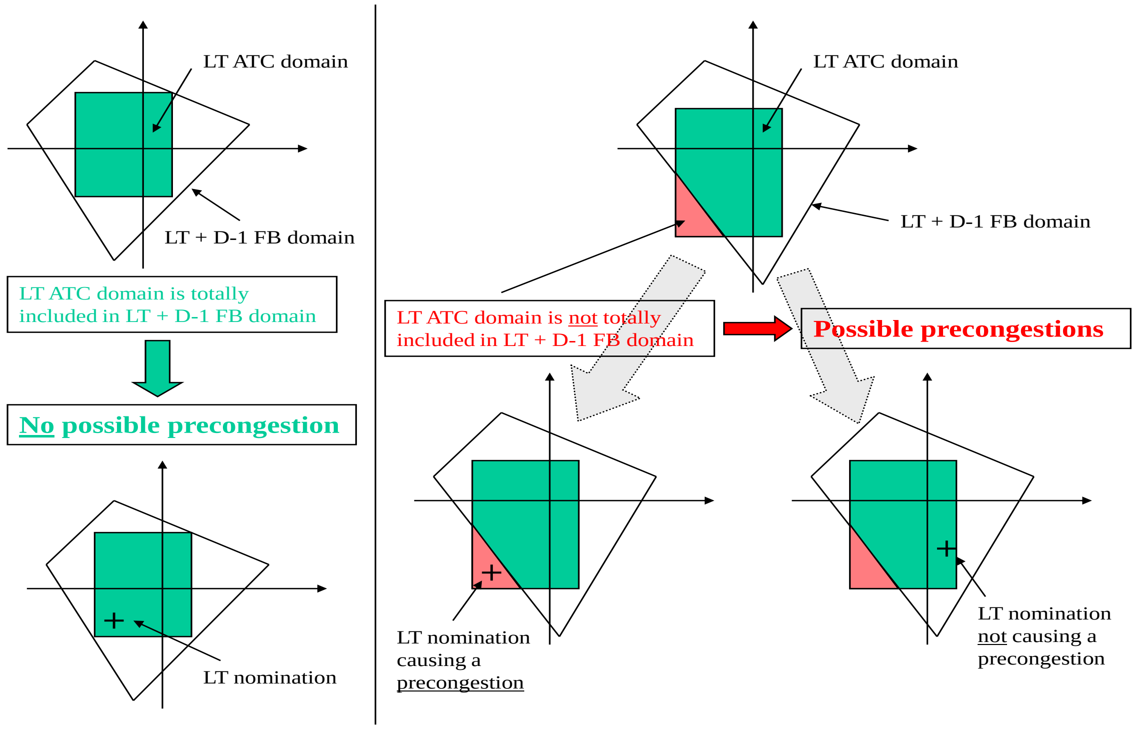
For a matter of compatibility with ATC-based ID processes, CWE TSOs propose in this section a coordinated method of capacity splitting which enables to deduce from the Day Ahead FB domain the capacity still available after market coupling. CWE TSOs consider the proposed method to be fair, transparent and straightforward. Although it is true that this method is only capacity splitting corresponding to a "level 0" calculation in the AHAG framework, CWE TSOs have observed on a 900 timestamp simulation that this method has, globally, a positive effect on ID ATC by comparison to current procedures. Moreover, as detailed in the table in section 2.6.2.3, this method can be seen as an intermediary step leading to a more advanced way of computing ID ATCs.
Finally, CWE TSOs wish to stress that this method, being based on a D-1 FB domain, itself defined from a D-2 basecase, may possibly lead to ID ATC which eventually differ significantly from the actual grid capacities in real time. This is an obvious consequence of deducing ID ATC from a D-1 security domain. As a matter of fact, some situations were observed in the above simulations where the defined ATC were significantly lower than historical ones. For this reason, and in order to avoid sending as soon as D-1[17] misleading signals to the market, CWE TSOs will investigate the possibility to incorporate some tolerance margins in this process. In any case, Security of Supply would not be jeopardized since ID ATCs would undergo a process of coordinated verification and adjustment up to their allocation in real time.

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 LTA 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.

[17] Because ID ATC will be processed as soon as the results of day ahead market coupling are available.



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 LTA 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.

TSO will continue to work on solutions ensuring the adequacy between the LT ATC domain and the FB domain.

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

During the 2010-2011 CWE TSO FB experimentation it was proven that the Enhanced FB capacity calculation:

- is feasible from an operational point of view (except for the verification step which has still to be tested by most TSOs)
- 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 and 2011 CWE FB experimentation. As the current results are based on practical assumptions of an adequate FRM level, the CWE TSOs will finalize the FRM methodology and assessment as well as the operational application of the verification method in the upcoming months in order to confirm the above.

From a SoS point of view, CWE TSOs recommend a close monitoring of FB results during the parallel run.

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[18], 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 FB constraints data representing 9 weeks of data sampled between December 2010 and July 2011. They allow a better comparison of ATCMC and FBMC (cf. Section 3.2).

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

3.2 Data

3.2.1 Data used

The data used will be the following:

For December 2010 and January 2011, 2 weeks each month (cycles 11 and 12) and from March to July 2011, one week each month (cycle 13 to 17), 24 hours each day, for FR, BE, NE, DE:

- PXs' input data: Historical order books posterior to the coordinated ATC MC launch on November 9th.
- TSOs' 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:

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

Three of these four limitations are addressed in the performed simulation, the only remaining one being that the order books are based on the knowledge of the ATC MC system.

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

On the other side, some new limitations appear:

- 9 weeks of data between December 2010 and July 2011, instead of 318 days equally distributed among the year. However, even if it is not possible to extrapolate indicators to a yearly period, winter, mid season and summer are represented in the sample, thus giving an idea of the overall behaviour of FB MC.
- 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.
- The results presented in this Market Impact Analysis are obtained with a Flow-based domain subject to some assumptions that still need to be validated by TSOs. With a systematic verification step and with different FRM values, the Flow-based domain would change (decrease or increase) and the related market results would be impacted.

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.

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

Several approaches are being discussed by the PXs and 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:

Example

Let us 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 double the welfare compared to an export from B to C in order to use the resource.

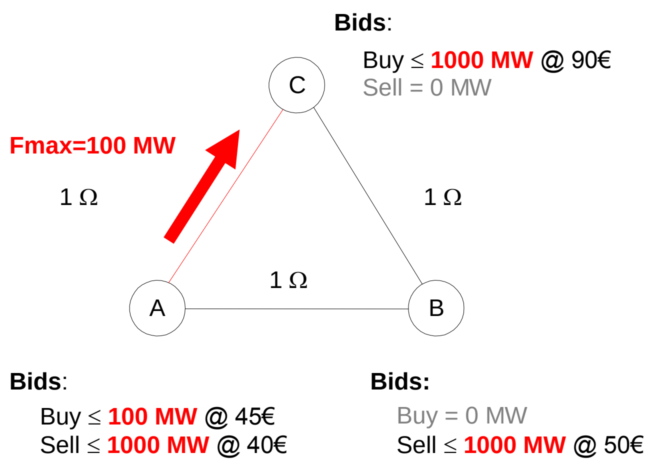


Figure 1: Three-node non-intuitive example (inputs)

The optimal situation is given below:

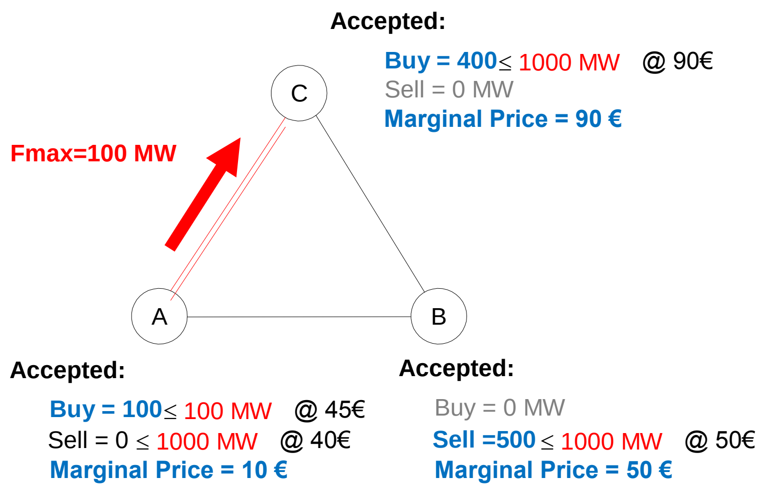


Figure 2: Three-node non-intuitive example (results)

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 non-intuitive, because the cheapest area (area A) imports. The 100 MW commercial exchange between B and A "destroys" welfare because it is from a high price to a low price area. In other words, if it was the only exchange to take place, the welfare would be negative. It takes place because it relieves the congestion and thus allows an exchange between B and C that "creates" more welfare than the "destroyed" welfare.

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

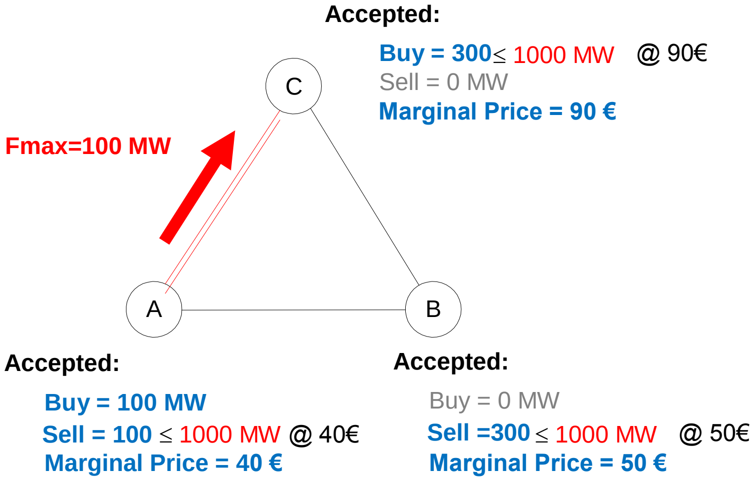


Figure 3: Three-node intuitive example (results)

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 bidding areas are exporting (except if the kth and the k+1th areas have the same prices).

Corollary 1: There exist at least one set of positive ATCs linking each pair of bidding areas that would give the same clearing.

Corollary 2: The net exchange positions can be decomposed in at least one set of intuitive bilateral exchanges i.e. from cheap bidding areas to expensive bidding areas. In other words, at least one set exists in which no exchange is allowed from an expensive area to a cheap one, while they are allowed between any other pair of areas irrespective of the existence of an electrical boundary.

This intuitiveness definition can be enforced in COSMOS through a heuristic. This algorithm is used to compute the FBIMC results presented in this report. The equations of the corresponding model are given in the annex 5.11.4.

3.3.2 "Bilateral Intuitiveness" considering existence of interconnections

We define direct bilateral (commercial) exchange as an exchange between two electrically-connected bidding areas. For example, no direct bilateral exchange is possible between France and Netherlands or between Belgium and Germany because there is no interconnector interlinking the two countries. Note that this is currently the case with ATCMC because the ATCs are non-null only on existing electrical boundaries.

Definition 2: We define a situation as being "bilateral intuitive" if there exists at least one decomposition of the net exchange positions into a set of intuitive direct bilateral exchanges (from the cheapest bidding area to the most expensive, across existing electrical boundaries only).

Corollary 3: 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 will be called "source-to-sink non-intuitive" and those not compliant with definition 2 will be called "bilateral non-intuitive" solutions. All "bilateral non-intuitive" situations are also "source-to-sink non-intuitive".

3.3.3 Differences between both intuitiveness definitions

According to the source-to-sink definition, the following situations are both intuitive:

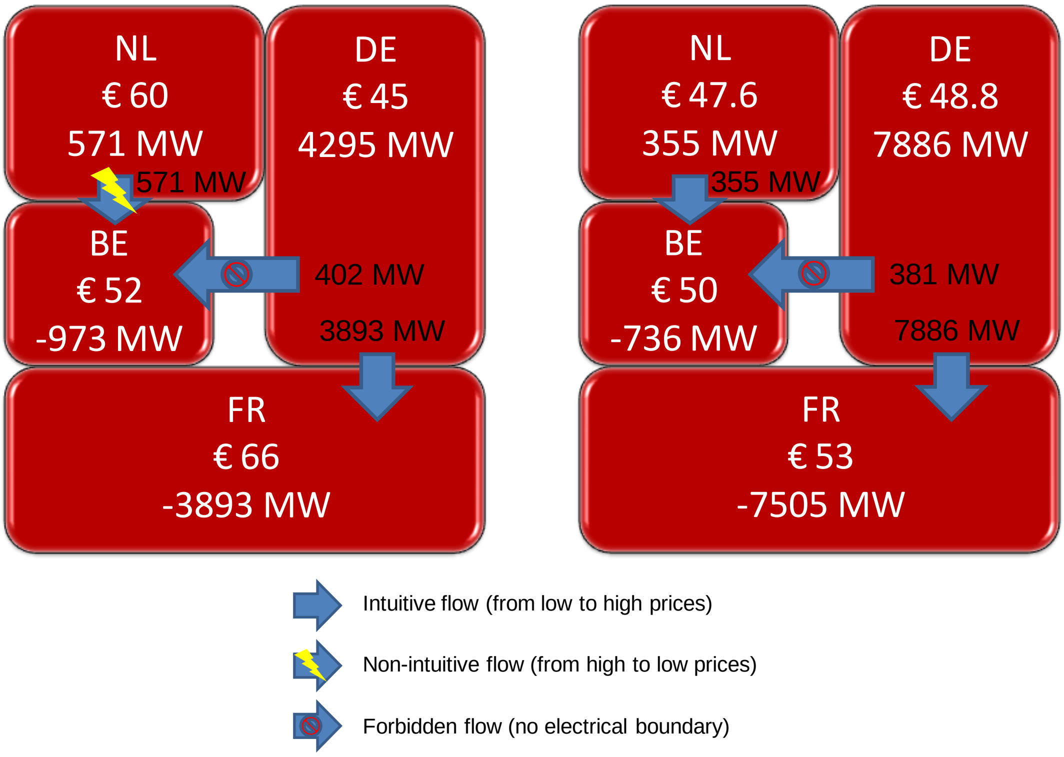


Figure 4: source-to-sink intuitive and bilateral non-intuitive situation

On the left side of the figure, NL is exporting while its two adjacent bidding areas (BE and DE) are cheaper. Therefore it is bilateral non-intuitive, because NL cannot export to a neighbouring higher-priced bidding area. The 2 most expensive markets are NL and FR. They are globally importing (so that it is source-to-sink intuitive), but there is no interconnection between FR and NL which is one cause of the bilateral non-intuitive situation, because it forbids NL to export to the only bidding area with a higher price: FR. The other cause of bilateral non-intuitiveness is the impossibility for DE to export to BE (the part of its production that cannot be imported in France) because there is no electrical boundary between DE and BE.

On the right side of the figure:

- Let us try to build a intuitive exchange decomposition:
  - An export of 355 MW from NL to BE is intuitive;
  - An export of 7505 MW from DE to FR is intuitive;
  - The only possibility left to close the decomposition that follows the electrical boundaries is a 381 MW export from DE to BE.

  However this last exchange is bilateral non-intuitive because there is no electrical boundary between BE and DE. Thus the situation is bilateral non-intuitive.

- It is source-to-sink intuitive as the DE-BE path is allowed with this definition of intuitiveness. It can be also verified through the condition that the k most expensive market are importing with k from 1 to 3.

FBMC may be extended to even more distant non-adjacent bidding areas. For example, a situation could be source-to-sink intuitive but bilateral non-intuitive because source-to-sink intuitiveness allows bilateral exchanges between Belgium and Greece.

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 market coupling *(ATCMC)* mode
- FB with intuitive market coupling *(FBIMC)* mode
- FB with market coupling *(FBMC)* mode
- Infinite capacity market coupling mode

The implementation of FBIMC is a heuristic which finds source-to-sink intuitive solutions but does not guarantee their optimality (cf. Section 5.11.4 for details).

No ramping constraint on the net position has been activated, i.e. no limitation of the net position change from one hour to the next has been set.

The comparison of ATCMC, FBIMC and FBMC is 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 (DAMW) 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[19]. It is called day ahead market welfare to make clear that it does not represent all the welfare associated with the clearing process.

Figure 5 illustrates the overall DAMW change in FBMC and FBIMC compared to ATCMC (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 generally 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 more than 87% of the maximum possible increase reached by using infinite capacities (87% for FBIMC and 88% for FBMC). The congestion rent shows a decrease of 78% in FBMC and 77% in FBIMC compared to ATCMC.

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

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

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

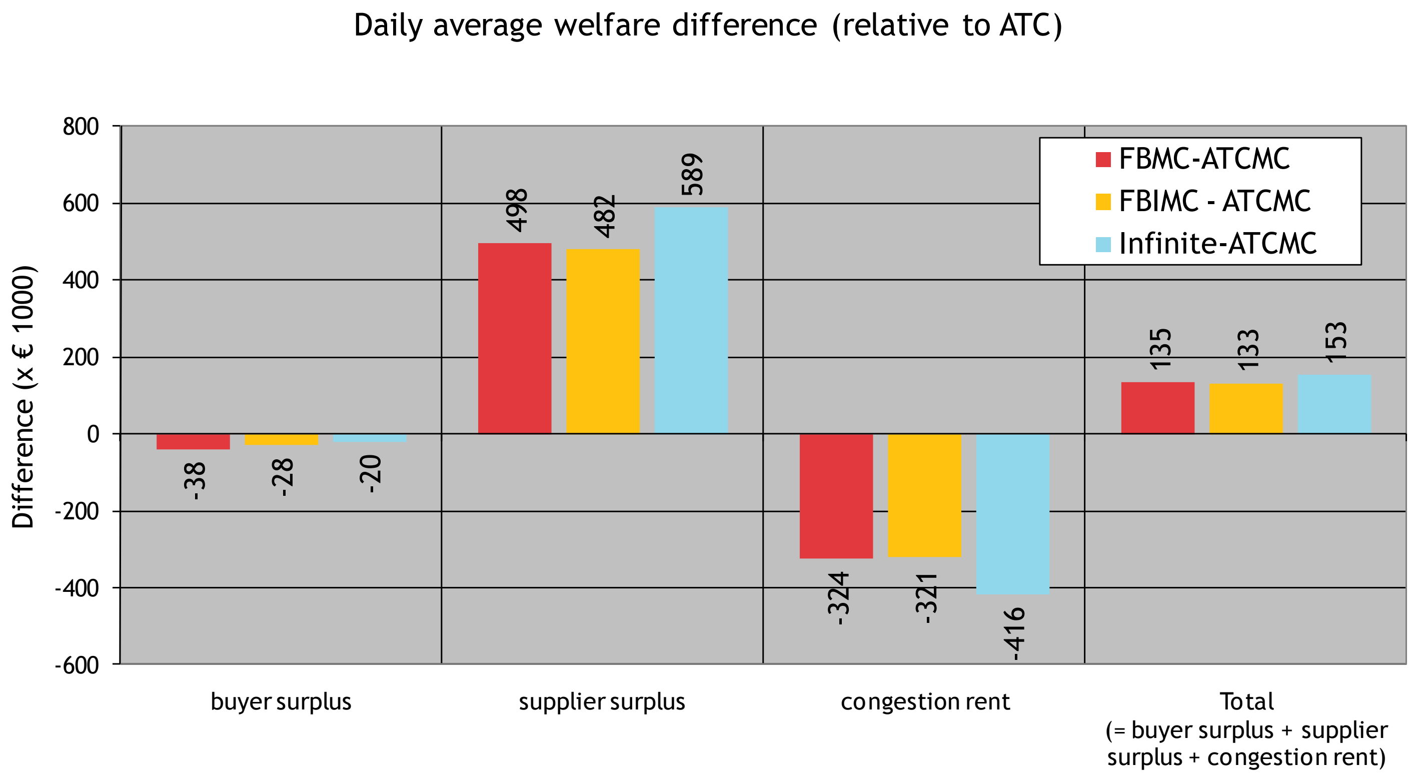


Figure 5: Daily average welfare difference relative to ATCMC split by actor in k€/day

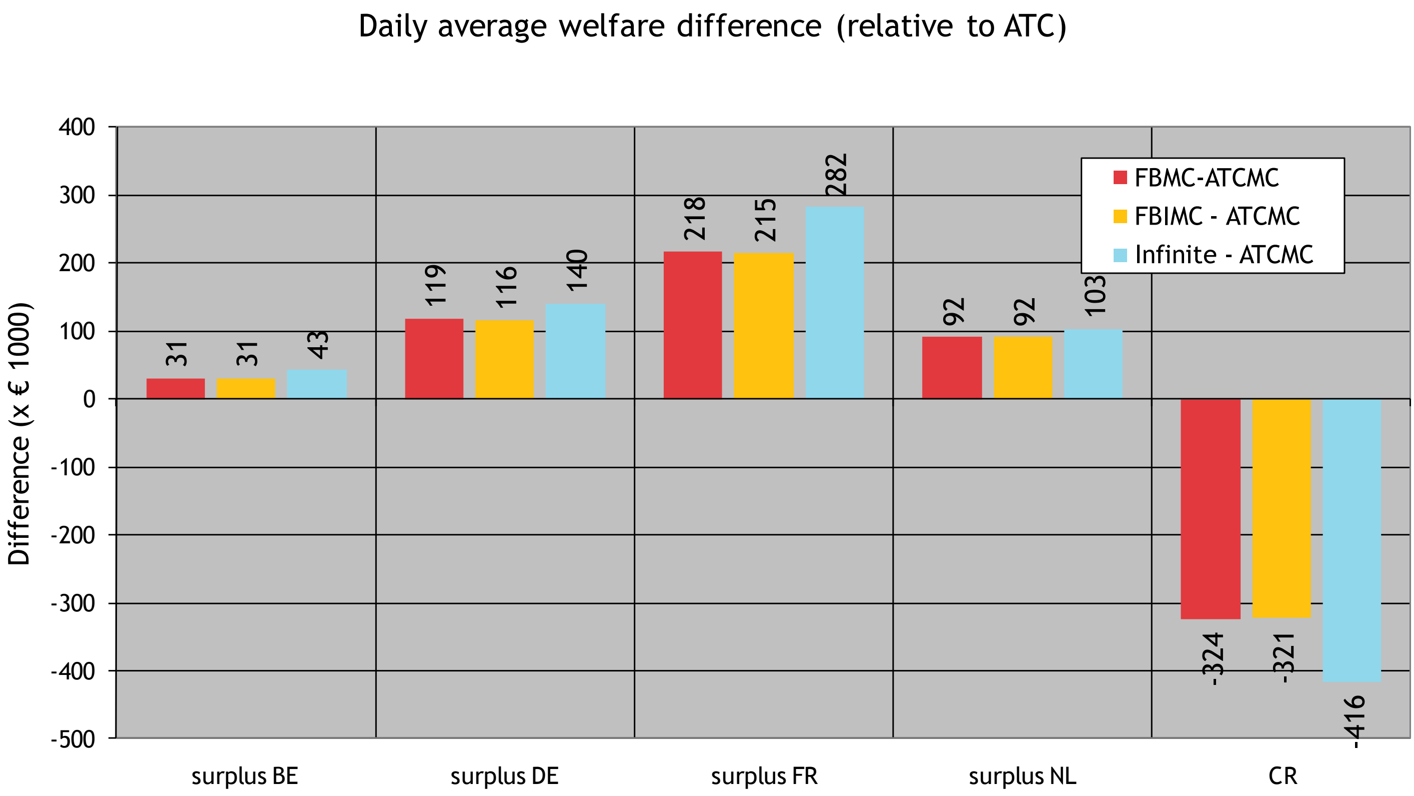


Figure 6: Daily average welfare difference relative to ATCMC split by area in k€/day

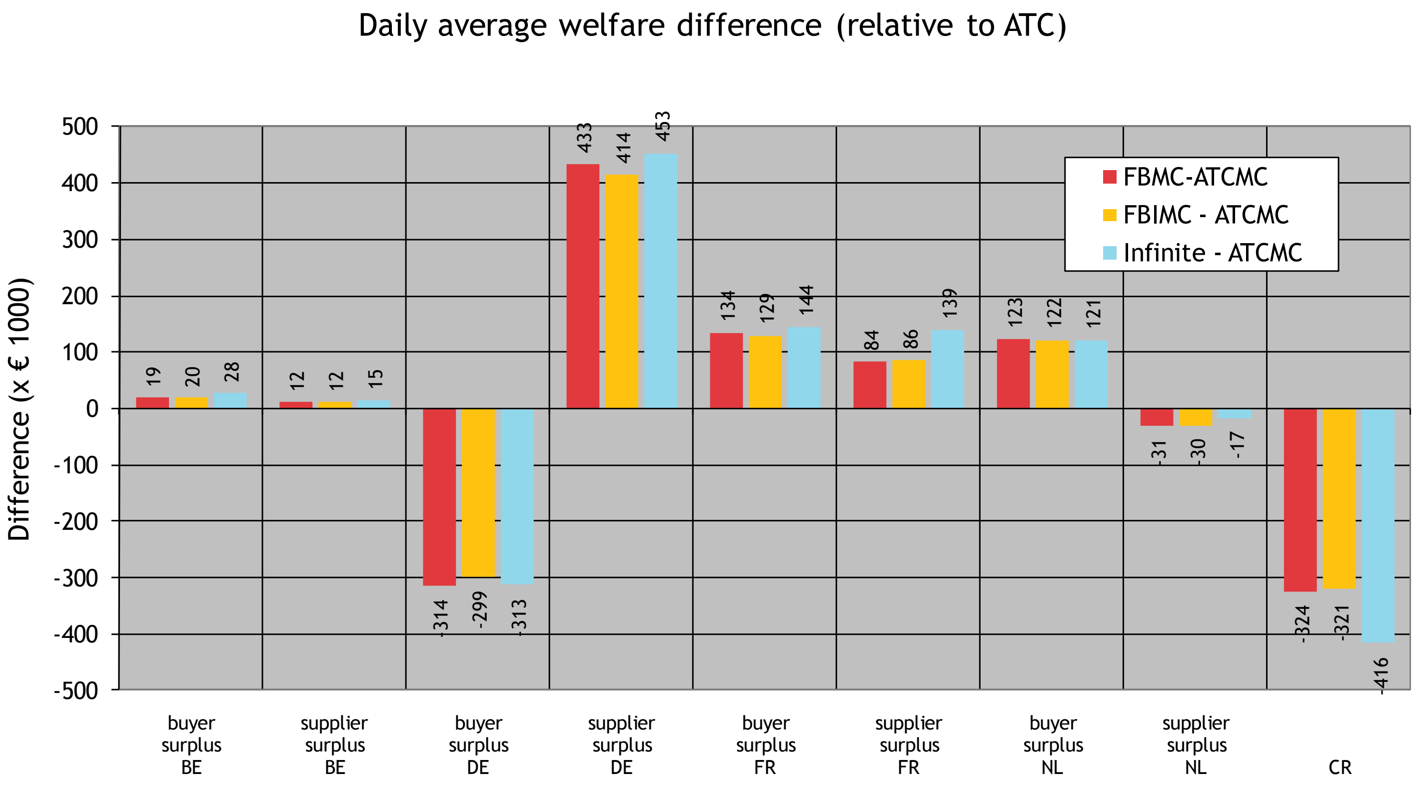


Figure 7: Daily average welfare difference relative to ATCMC split by area and by actor in k€/day

3.4.5 Market clearing volumes

Here are the definitions of the 4 clearing volume indicators used:

- Supply Clearing Volume (SCV): the sum over the whole period of the supply volume in a bidding area (volume of accepted supply bids);
- Demand Clearing Volume (DCV): the sum over the whole period of the demand volume in a bidding area (volume of accepted demand bids);
- Market Clearing Volume (MCV): the sum over the whole period of the maximum per hour of the Demand and Supply Clearing Volumes. It is this indicator that is usually reported by the PXs. Note that the MCV of a set of bidding areas considered as one area is not equal to the sum of the MCV of the bidding areas because the exchanges are counted twice: once in the MCV of the exporting area and once in the MCV of the importing area.
- Total Clearing Volume (TCV): the sum over the whole period of the Demand Clearing Volume and of the Supply Clearing Volume. The sum over several areas of the TCV is the TCV of the set of these areas.

Figure 8 and Figure 9 show the change in clearing volumes per bidding area in FBMC relative to ATCMC (DCV, SCV and TCV on Figure 8 and MCV on Figure 9). FBIMC results are similar and thus not shown. Three observations can be made:

- The main change is the increased export from Germany to France, but this is linked with the specific sample, especially as it covers 2 weeks in December 2010 with cold weather in France.
- The TCV over all bidding areas increases: Overall, the increase of demand in areas in which the prices decreased is larger than the decrease of demand in areas in which the prices increased. However, no definitive conclusion can be made. Indeed, a detailled analysis (not shown here) showed that the TCV variation is negative on some cycles.
- All areas see an increase of the MCV. The high increase of the sum of MCV over all bidding areas is linked to the fact that exchange are counted twice: once in the exporting area, once in the importing area, therefore, as FBMC globally increases the exchanges, the total MCV significantly increases contrary to the total TCV that remains almost unchanged.

Figure 10 shows the detail of MCV per day and per area. It illustrates that FBMC and FBIMC most of the time lead to the same market clearing volume. The most prominent difference between FBMC and FBIMC can be seen on

December 1st, 2010 in France. Significant differences with ATCMC occur, for example during the first cycle (up to December 5th, 2010) in France.

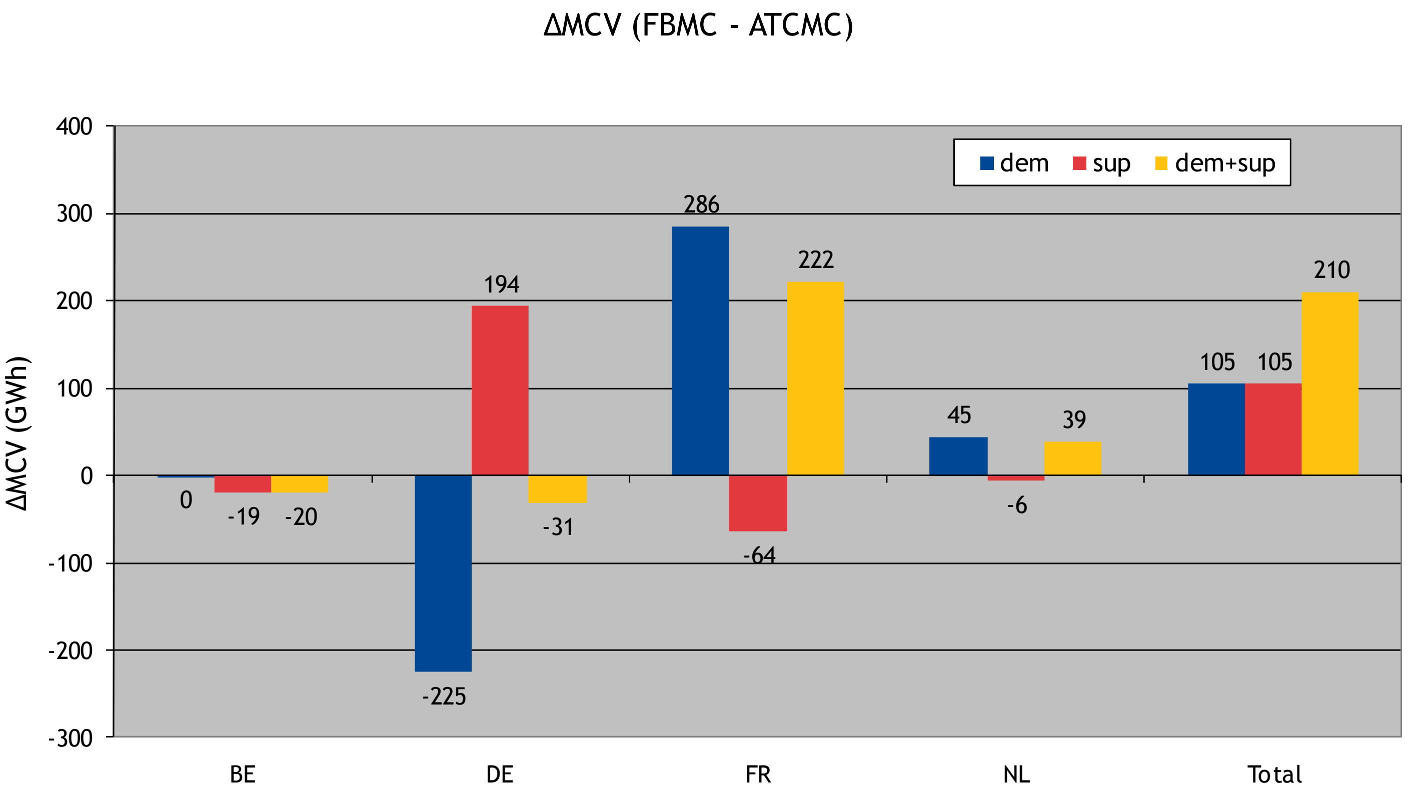


Figure 8: Sum of Demand, Supply and Total Clearing Volumes by area over all the simulation period

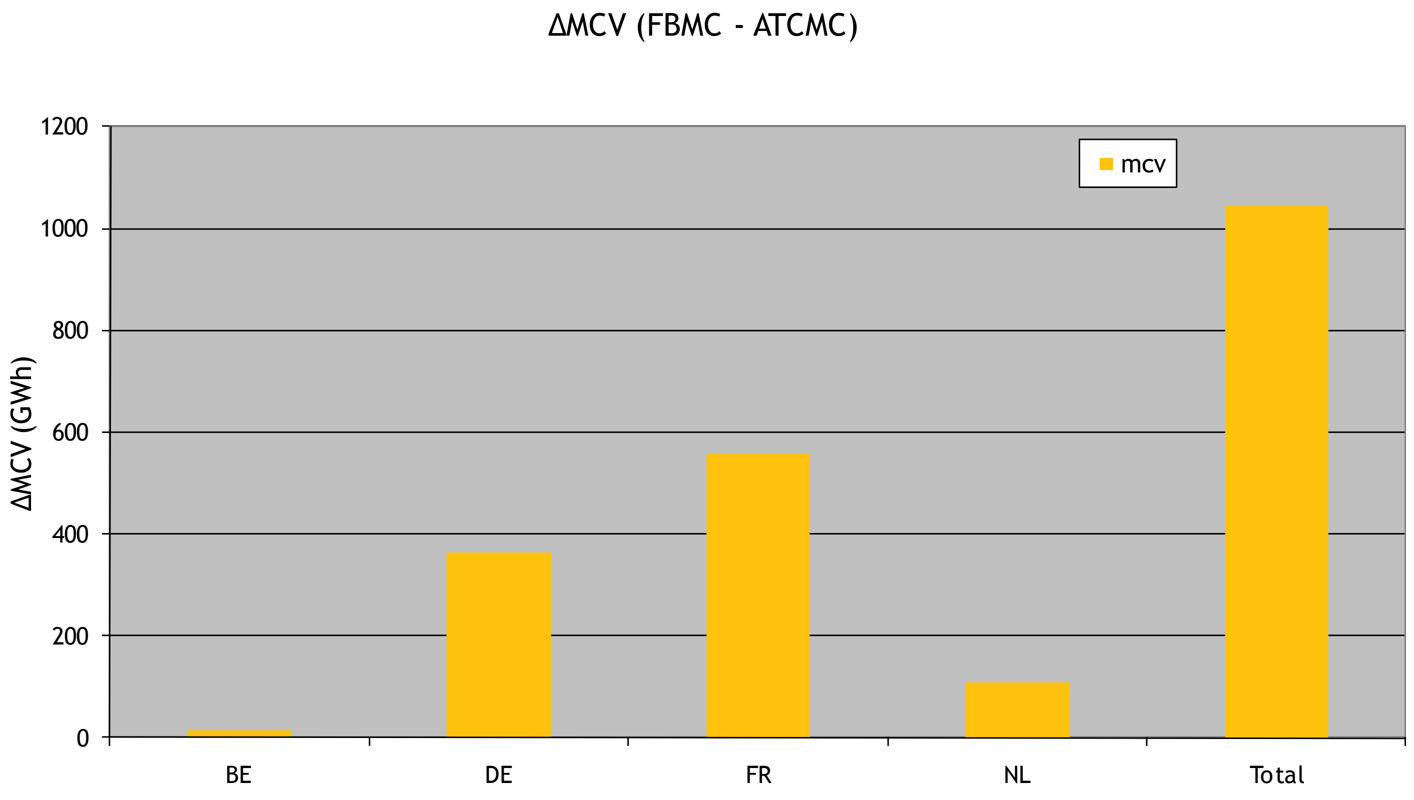
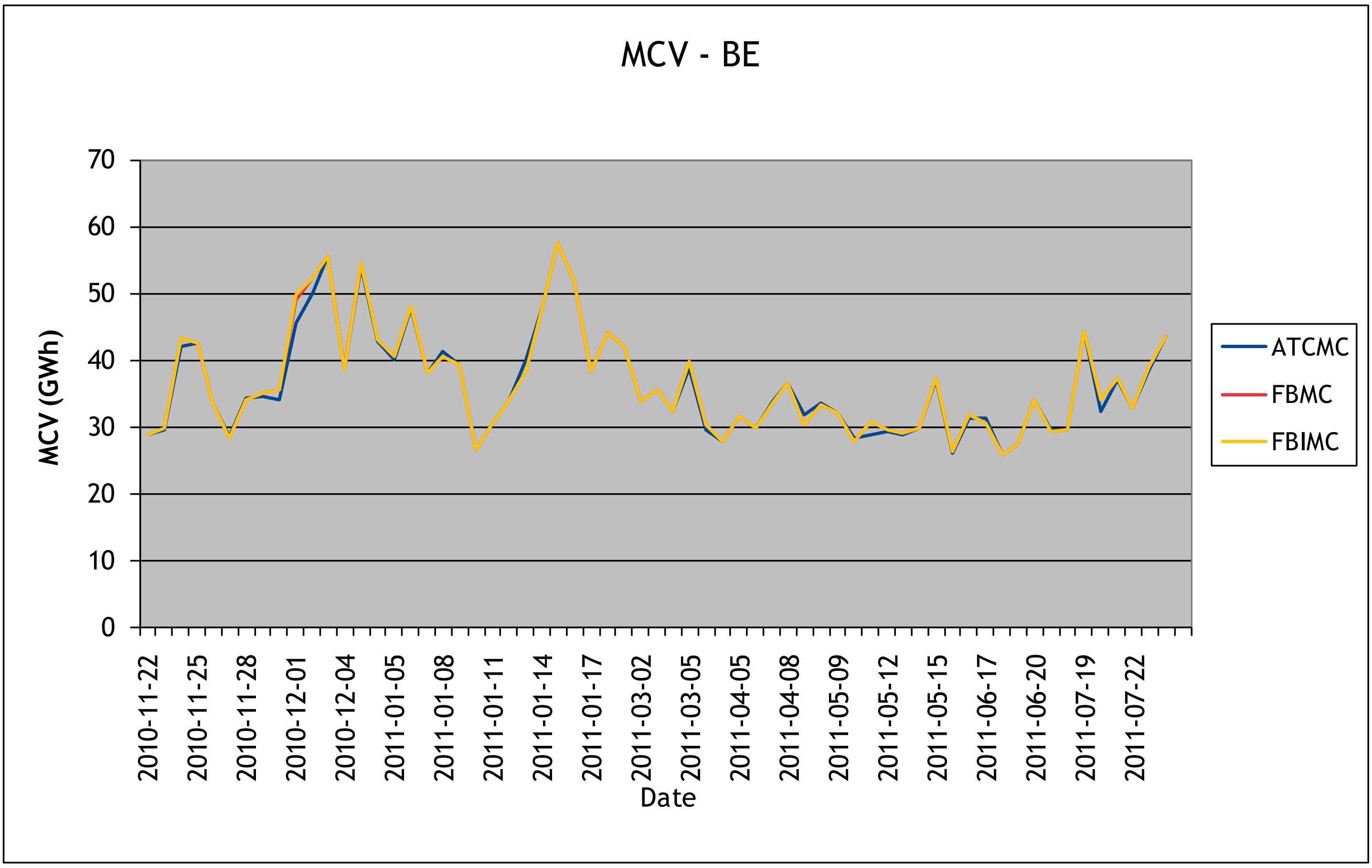
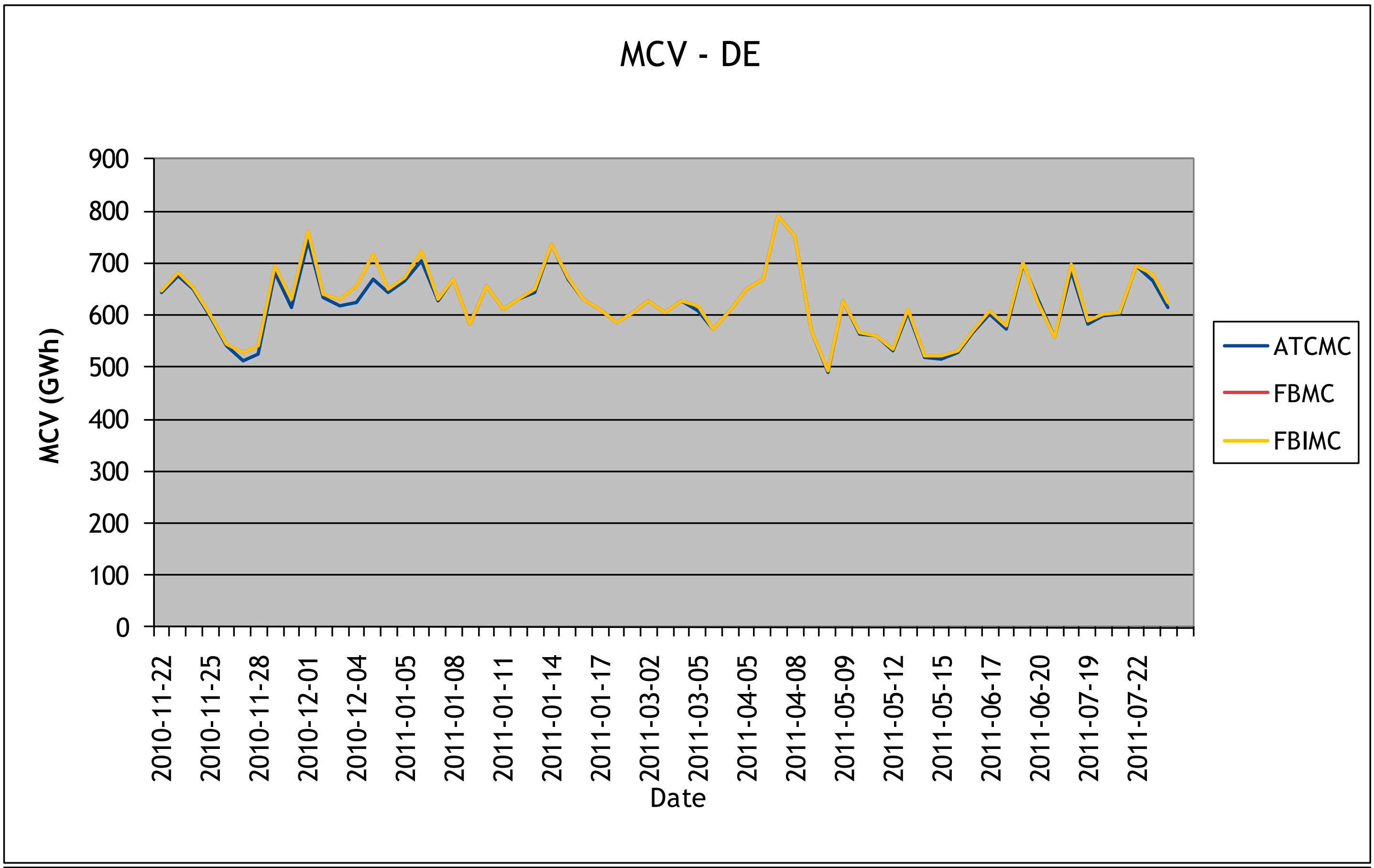


Figure 9: Sum of Market Clearing Volume by area over all the simulation period




MCV - DE
MCV (GWh)
900
800
700
600
500
400
300
200
100
0
2010-11-22
2010-11-25
2010-11-28
2010-12-01
2010-12-04
2011-01-05
2011-01-08
2011-01-11
2011-01-14
2011-01-17
2011-03-02
2011-03-05
2011-04-05
2011-04-08
2011-05-09
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2011-06-17
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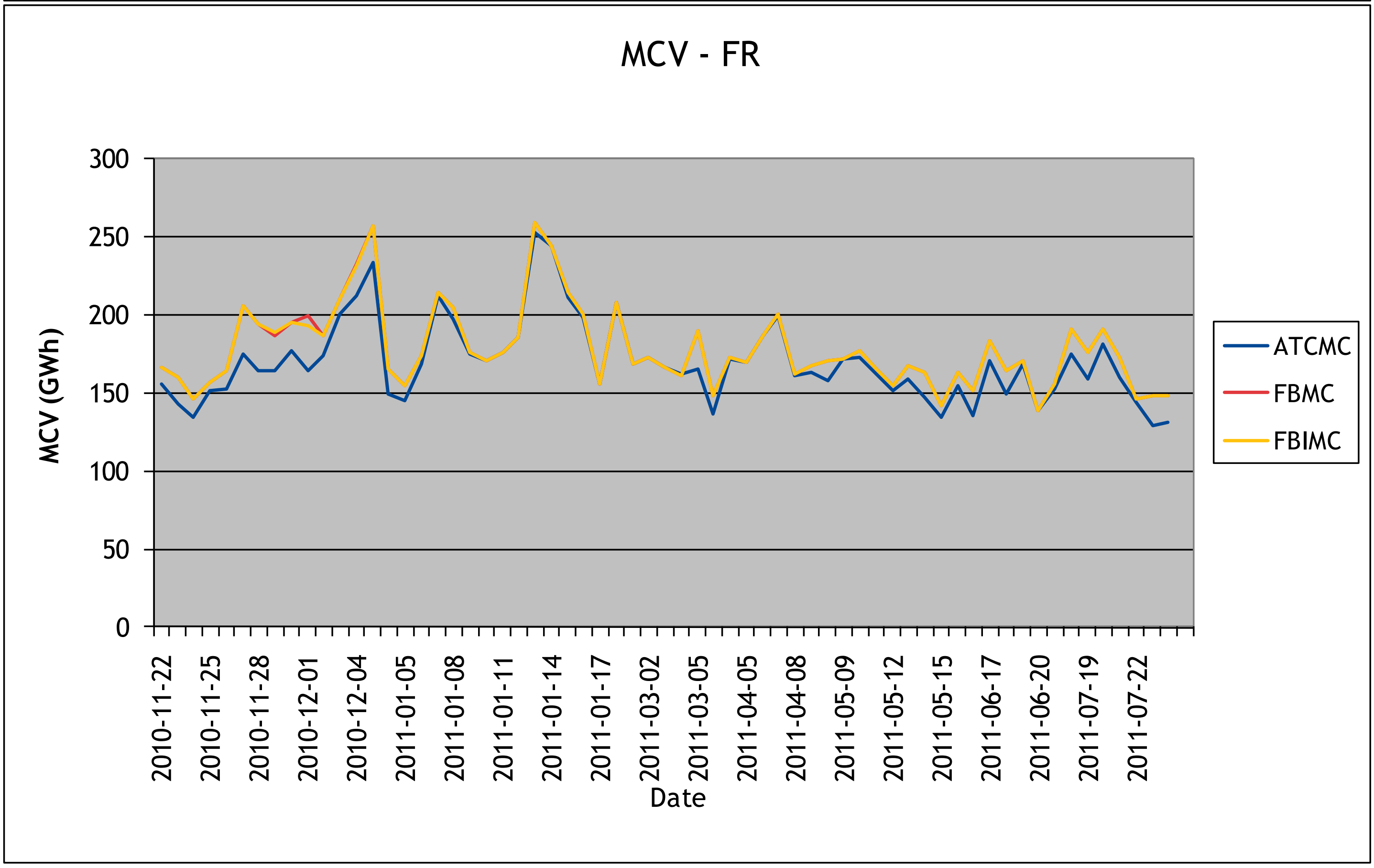
2011-07-19
2011-07-22
Date
ATCMC
FBMC
FBIMC


MCV - FR
MCV (GWh)
300
250
200
150
100
50
0
2010-11-22
2010-11-25
2010-11-28
2010-12-01
2010-12-04
2011-01-05
2011-01-08
2011-01-11
2011-01-14
2011-01-17
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Date
ATCMC
FBMC
FBIMC

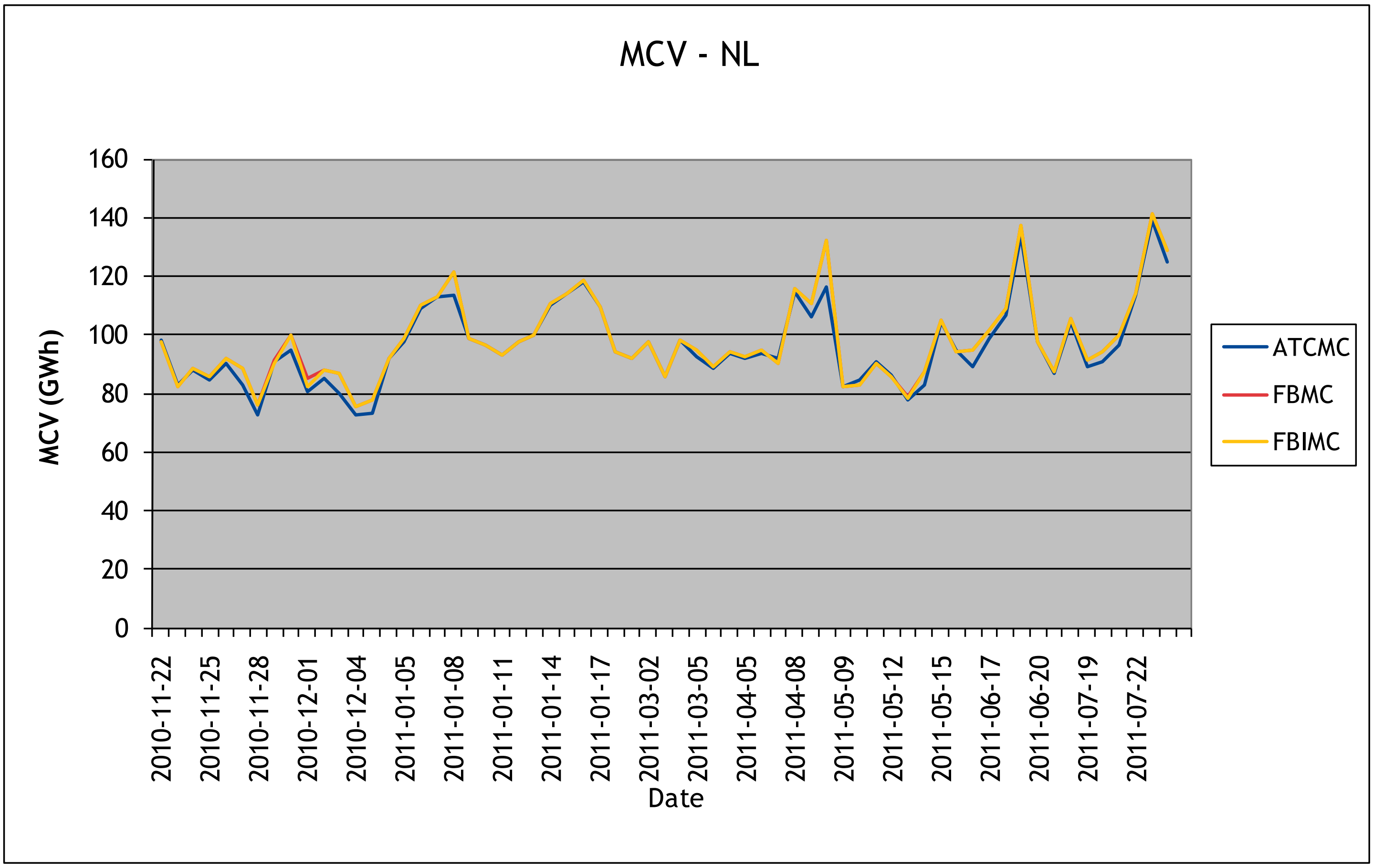


Figure 10: Daily MCV per area

Finally, to give an idea of the changes in flow patterns, some clearings are presented below. They are selected among those with the largest changes between ATCMC and FBMC.

Figure 11 and Figure 12 show 2 situations in which the exchanges (measured as the sum of exports) are significantly increased. In the first case, DE is exporting 4200 MW more. In the second, FR is exporting 2350 MW more.

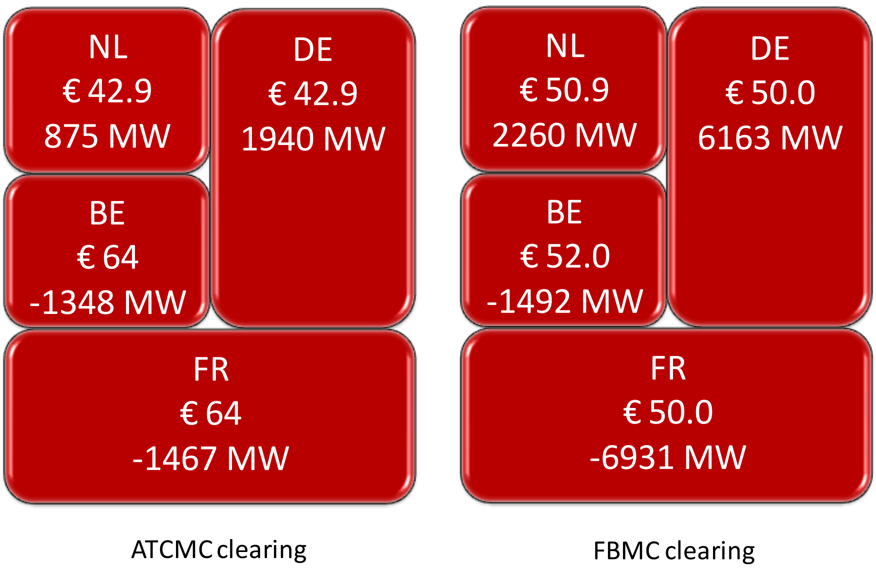


Figure 11: December 1th, 2010, 24:00 clearings

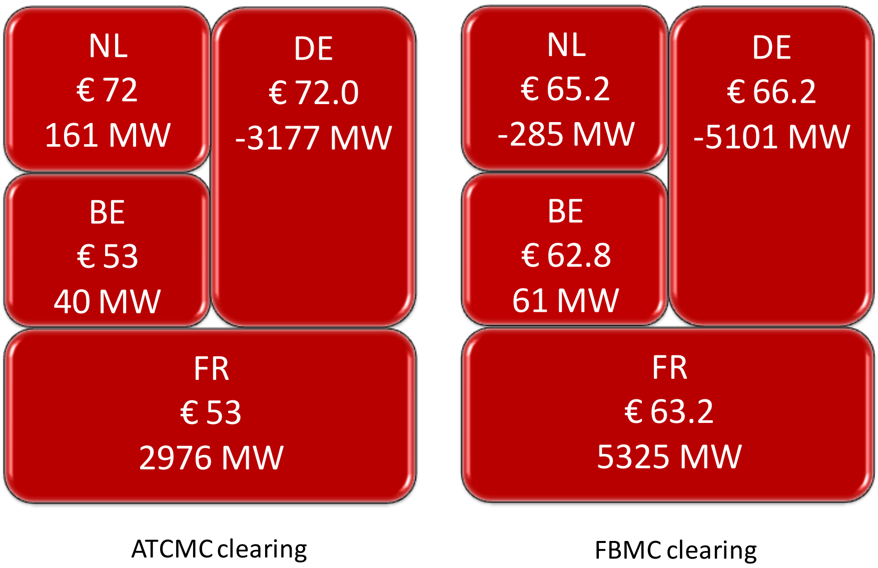


Figure 12: May 13th, 2011, 21:00 clearings

Figure 13 and Figure 14 show the situations where the maximum net export over the simulated period is reached respectively for FR and DE. For DE, the situation is non-intuitive because NL imports with the lowest price. In FBIMC, DE exports are reduced to 9284 MW. For FR, full convergence is reached whereas a divergence of 16 €/MWh existed in ATCMC.

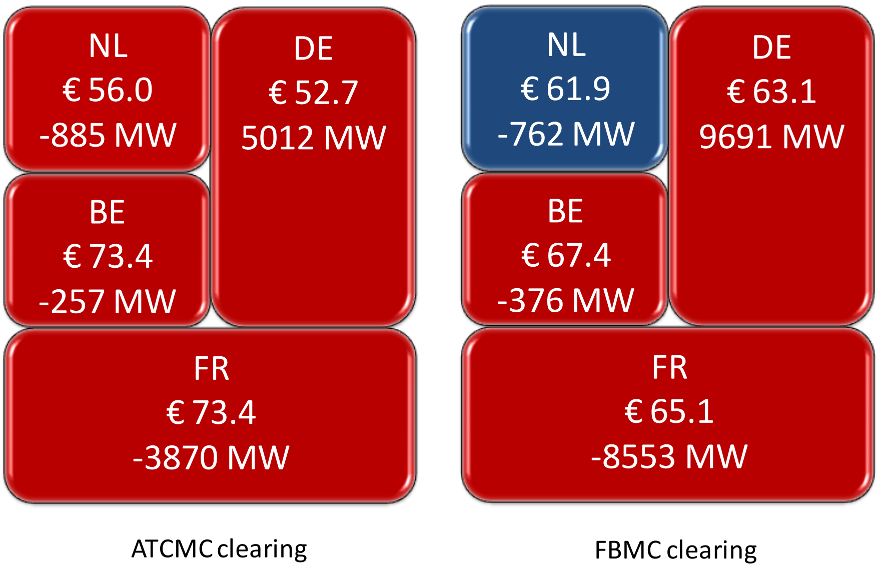


Figure 13: December 4th, 2010, 20:00 clearings: maximum DE export in FBMC

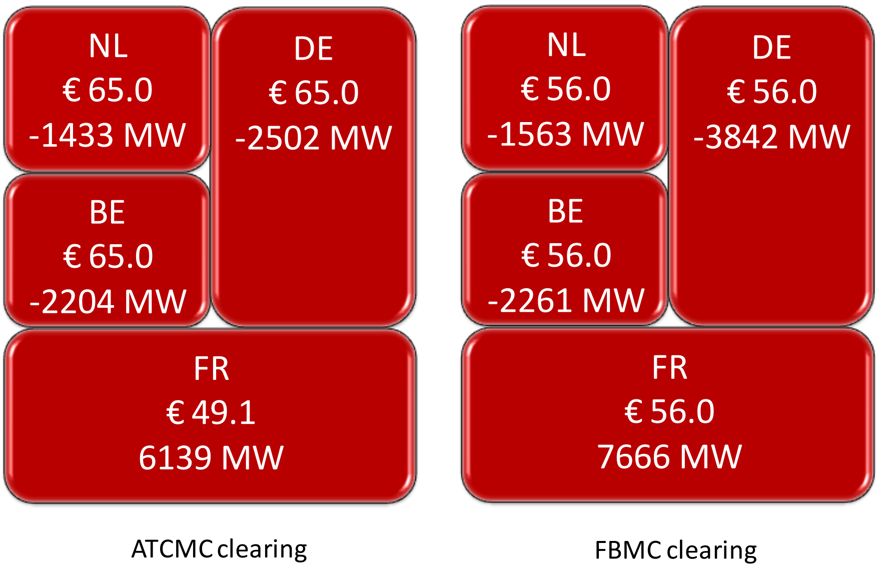


Figure 14: January 15th, 2011, 18:00 clearings: maximum FR export in FBMC

Figure 15 and Figure 16 show the situations where NL respectively imports the maximum and exports the maximum over all situations. In both cases, FBMC clearing created full convergence. Similar figures are not shown for Belgium because the maximum export and the maximum import do not change significantly with the switch to FBMC.

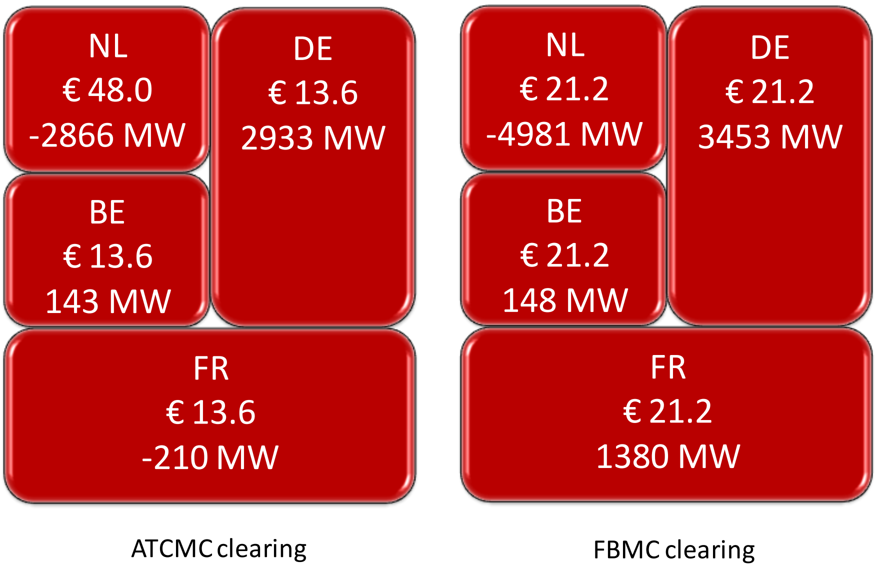


Figure 15: April 10th, 2011, 15:00 clearings: maximum NL import in FBMC

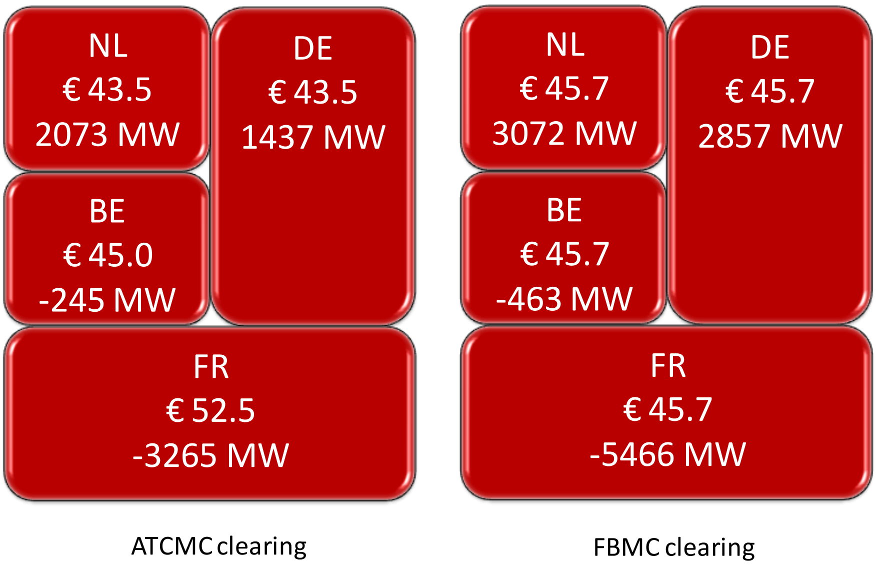


Figure 16: November 30th, 2010, 06:00 clearings: maximum NL export in FBMC

3.4.6 Price convergence

Full price convergence ("Copper plate") is achieved when the price in all areas is approximately equal (tolerance: 0.005 €/MWh on rounded prices[20]). Partial convergence is reached when at least 2 areas have approximately the same price. Full divergence means that all areas have prices that differ more than the tolerance.

Figure 17 illustrates the convergence reached with each method. The first column "numHours" gives the number of hours on which the simulation was reached (24x7x9 = 1512 h). The next ones ("fullConv", "partialConv", "fullDivergence") are respectively the number of hours of full convergence, partial convergence and full divergence. Figure 18 represents the same results but in proportion of the number of situations rather than in number of hours.

As, most of the time, the ATC domain is included in the FB domain, an 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 (cf annex 5.11.3 for details). The small increase of partial convergence in FBIMC compared to FBMC is directly linked with the intuitiveness constraints on prices[21]. Note that a full divergence is not necessarily worse than a partial convergence. For example, let's consider a partial convergence of 2 areas with 40 €/MWh and 2 zones with 80 €/MWh, and a full divergence in FB with prices equal to 40.1 €/MWh - 40.2 €/MWh – 40.30 €/MWh – 40.4 €/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, FB allowed full convergence on 90% of hours instead of 58% in ATC.

[20] Prices are rounded to 0.01 €/MWh in BE, DE and NL and to 0.001 €/MWh in FR. Therefore, the lowest meaningful tolerance on rounded prices is 0.005 €/MWh.

[21] Indeed, when intuitiveness is enforced, it generally results in limiting the non-intuitive exchange between areas up to the point where these areas have the same clearing price so that the remaining exchange between them is allowed. Then, the exchange between these areas becomes compatible with the prices so that the situation becomes intuitive. See Section 3.4.9 for more details.

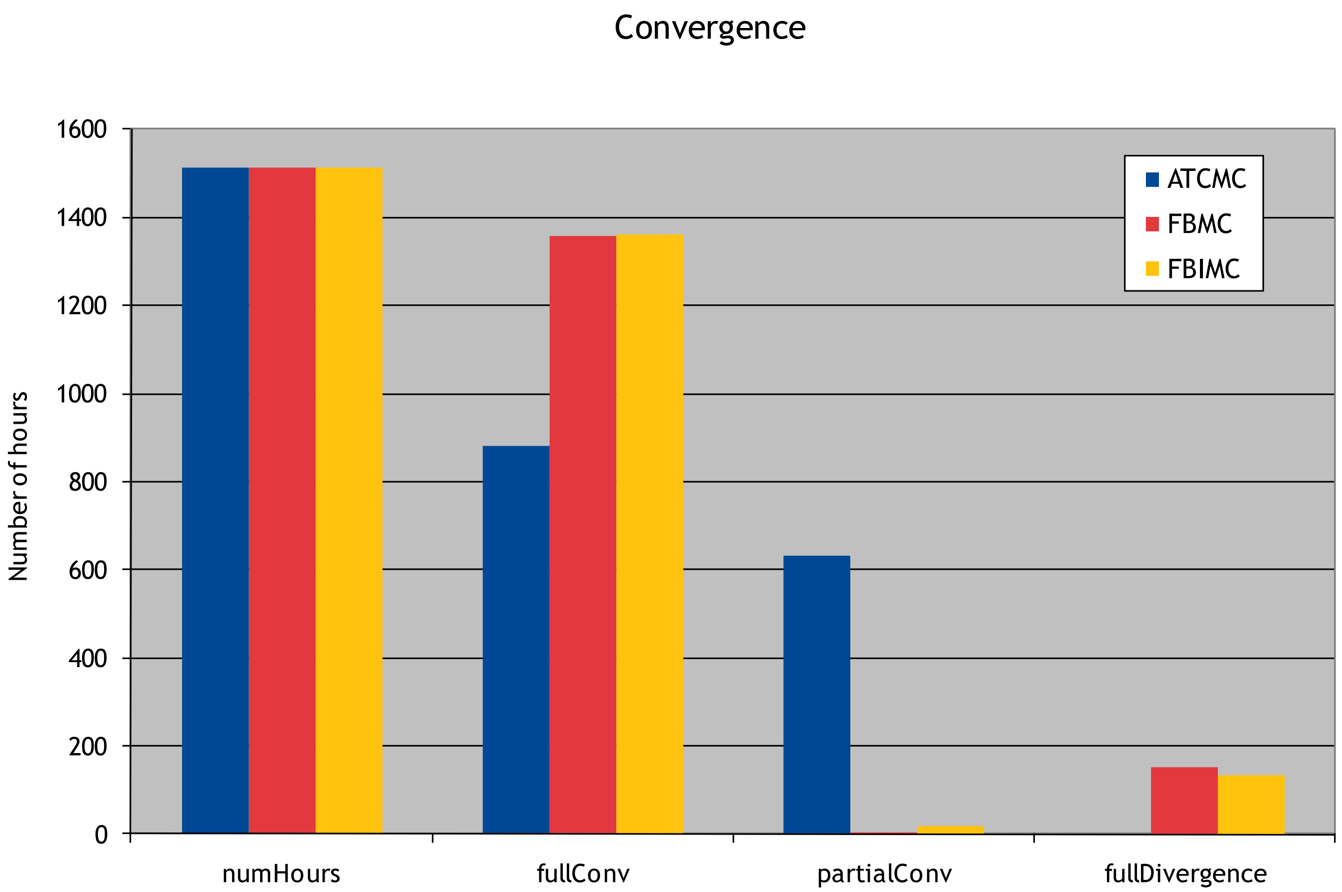


Figure 17: Convergence of prices over areas in hours (tolerance: 0.005 €/MWh)

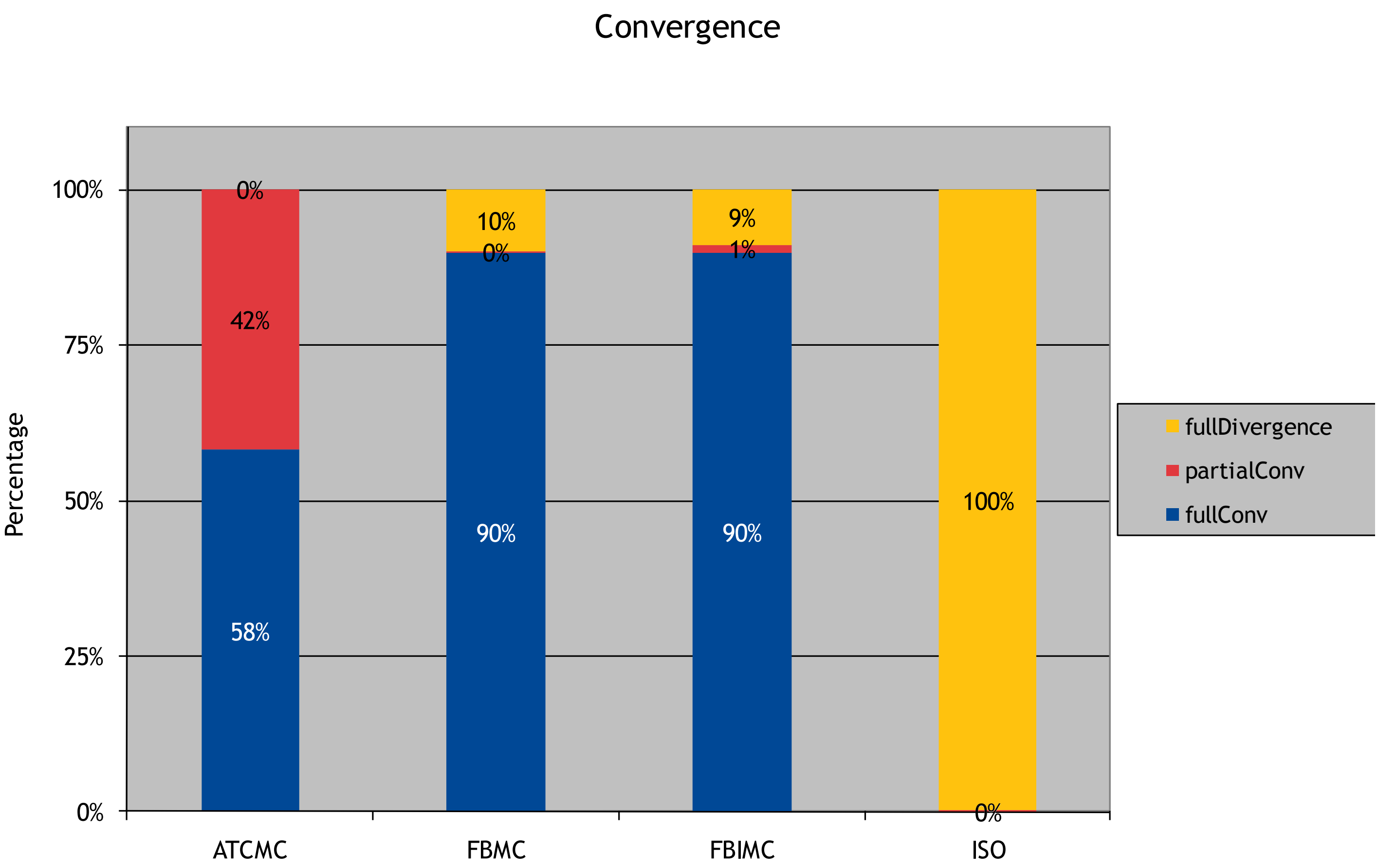


Figure 18: Convergence of price difference between areas in proportion of the number of situations (tolerance: 0.005 €/MWh)

As the FB domain usually includes the ATC domain, it is expected that FBMC results in full convergence when ATCMC results in full convergence. It is the case to the exception of 2 situations (March 4th, 2011, hour 1 and 3 –cf Figure 19) for which FBMC results does not result in full convergence while ATCMC does. For these two marginal situations, the ATCMC clearing point is out of the FB domain, yet causing overloads of a few megawatts only on the limiting CBs. In these 2 timestamps, the borders of the ATC and FB domains were tangent, and the amount of overloads in FB is of the same order of magnitude as the accuracy of the calculation. This explains why these marginal situations do not raise any concern and do not compromise the general rule of inclusion of the ATC domain within the FB one for realistic corners.

These observations are summed up in the table below:

(In number of hours)	FBMC / FBIMC not full convergence	FBMC / FBIMC full convergence	Total
ATCMC not full convergence	10.0%	31.8%	41.8%
ATCMC full convergence	0.1%	58.1%	58.2%
Total	10.1%	89.9%	100.0%

Full convergence results are similar with FBIMC to the exception of one situation (May 13th, 20:00) where full convergence is reached in FBIMC and a small price divergence of 0.02 €/MWh is observed in FBMC. It has been checked that this unexpected effect is linked to block orders. Indeed, without such block order effects, enforcing intuitiveness cannot remove a congestion.

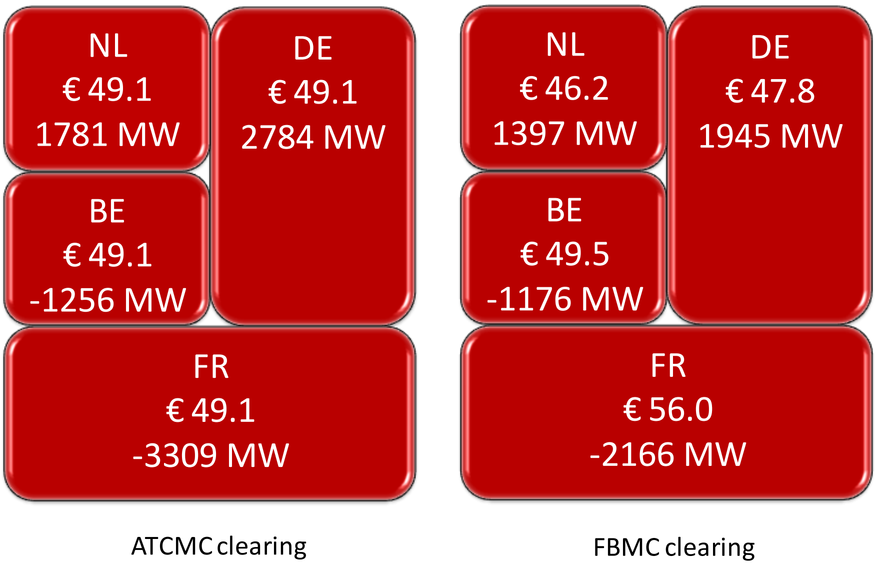


Figure 19: March 4th, 2011, 03:00 clearings: full convergence in ATCMC and no convergence in FBMC

Occasionnally, due the interaction of block orders and capacity parameters over several hours, the convergence is reached in both cases but with a significantly different clearing, as on June 17th, 2011, 12:00.

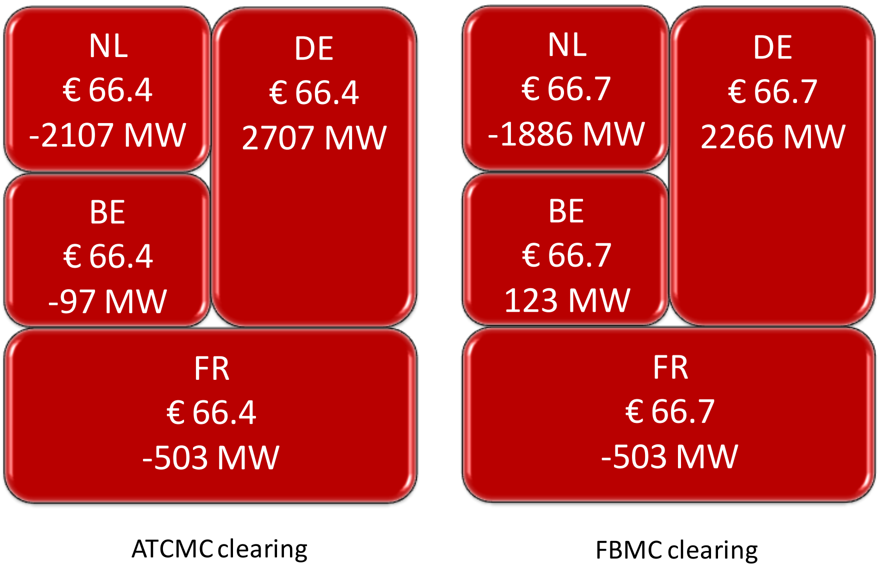


Figure 20: June 17th, 2011, 12:00 clearings

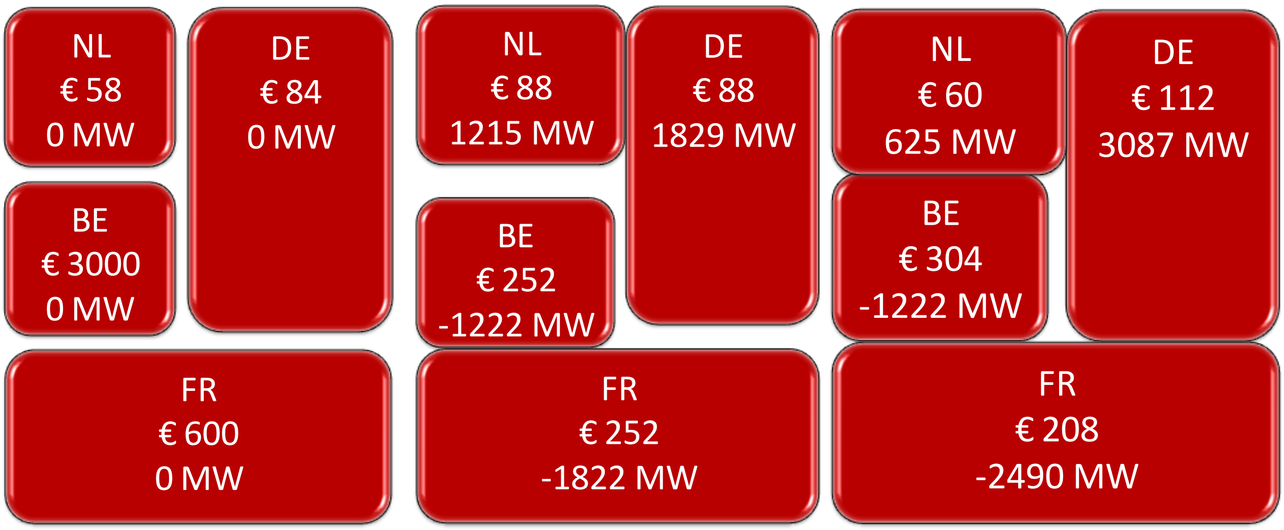
3.4.7 Price divergence

The graphs (Figure 21 and Figure 22) show the hourly difference between the highest and the lowest price among all areas, 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 all hours except the first one. The FBIMC is very close to FBMC (less than 2 €/MWh to the exception of 3 situations where it is 2.3, 3.8 and 20 €/MWh respectively). However, the zoom on the first hours (Figure 22) shows that there is at least 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. No such similar situation has been found since this date. Note that the fact that a price divergence distribution is below another one does not mean that the price divergence is always lower. For example, there are 19 hours where the divergence is larger in FBMC than in ATCMC (versus 615 where the divergence is larger in ATCMC than in FBMC, table not shown). December 2nd, 2010, 19:00 is one of them.

<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 / FBIMC</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 clearing point 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 to 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 areas. 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. In 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[22]. 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[23]) :

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

[22] Possible bilateral exchanges (BEx): BEx(DE⇒FR) = 3399 MW, BEx(FR⇒BE) = 910 MW, BEx(NL⇒BE) = 313 MW, BEx(NL⇒DE) = 312 MW

[23] 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).

- The isolated price of Belgium is 3000 €/MWh, which indicates a low market resilience. The isolated price in France is 600 €/MWh 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.

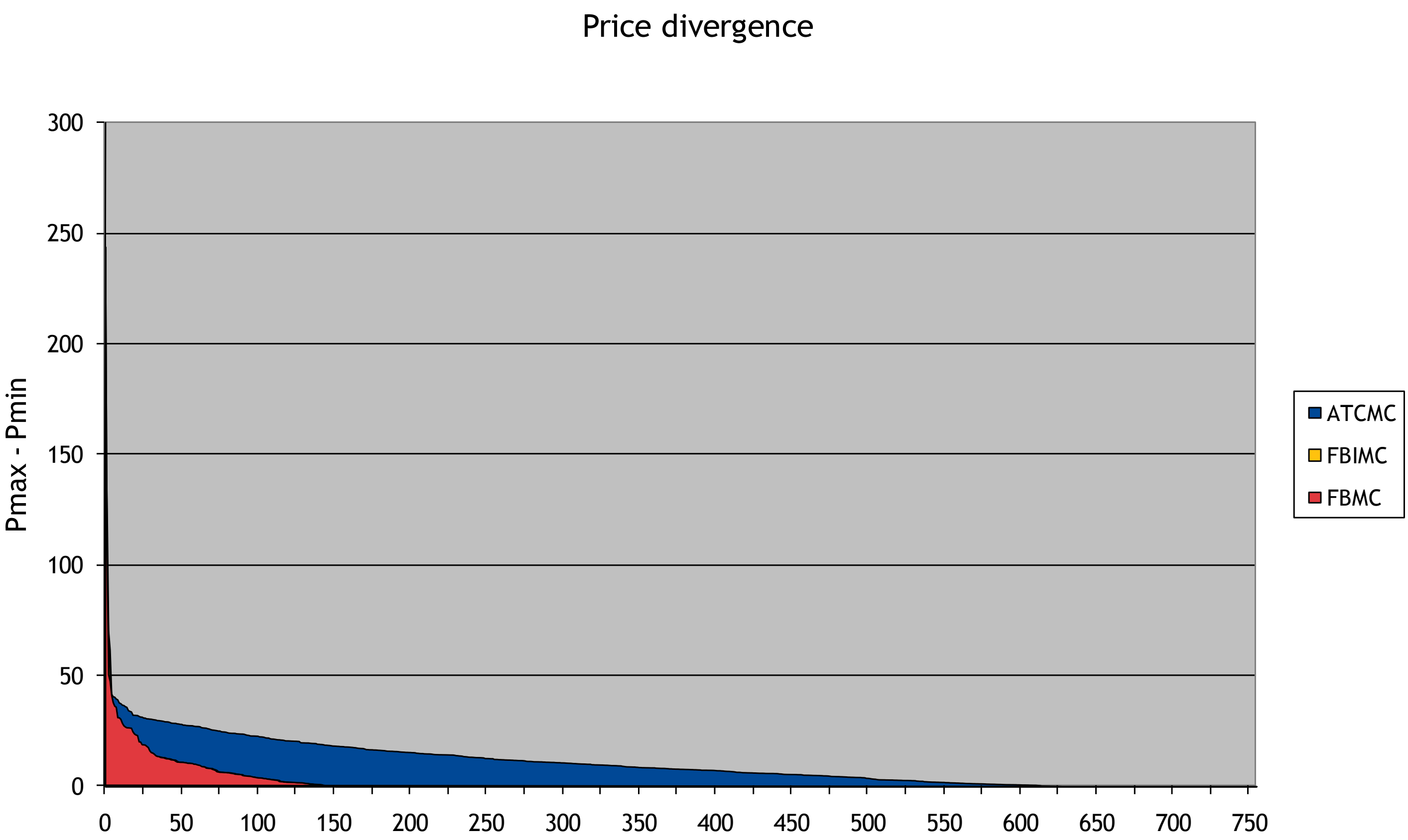


Figure 21: Maximum price difference distributions

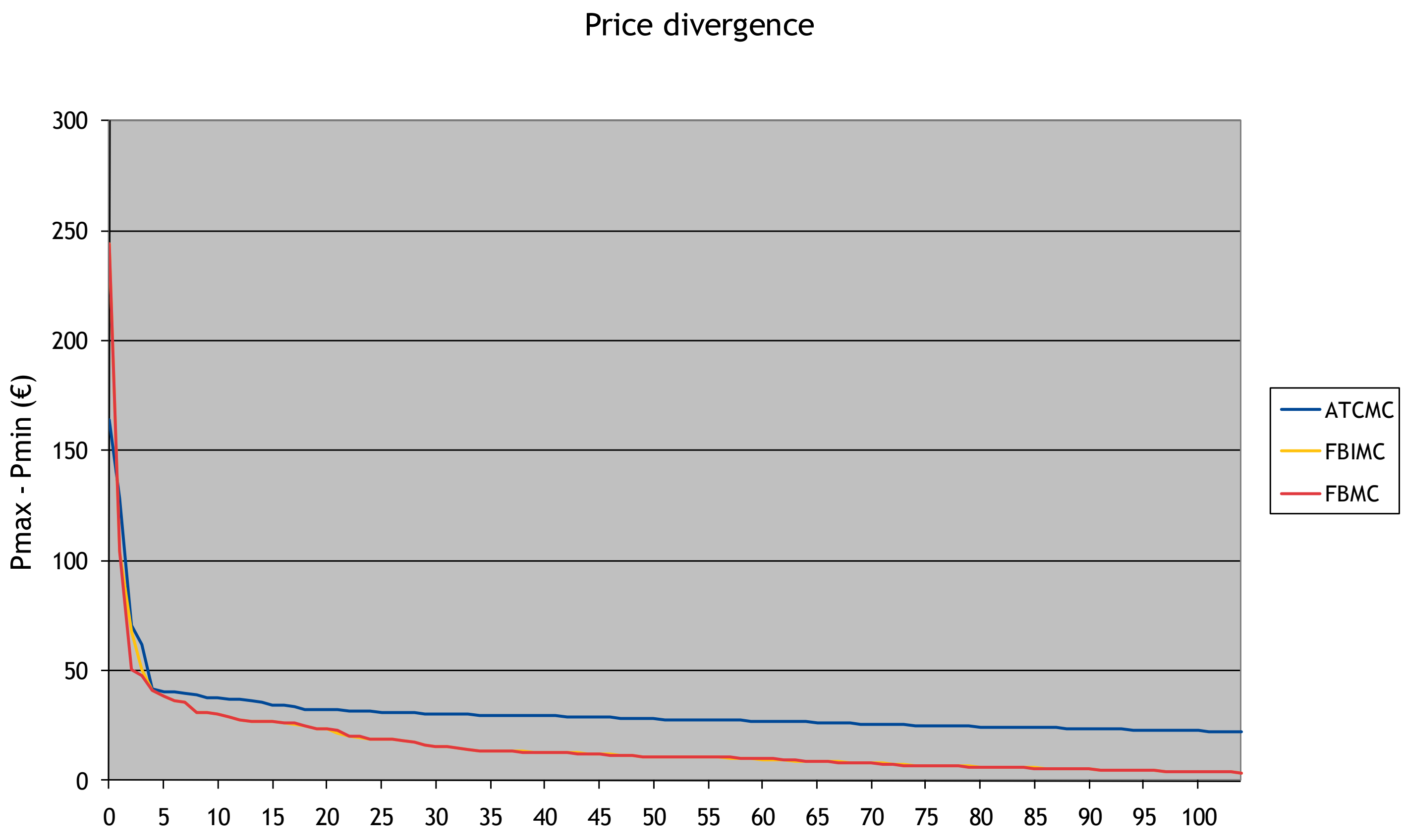


Figure 22: Maximum price difference distributions (zoom)

Finally, in order to give a feeling of the changes from ATCMC to FBMC, the 3 next figures are the 3 situations with the maximum price divergence in ATCMC while no congestion occurs in FBMC (and, as expected, in FBIMC). In the top one, more exports from DE to NL allow full convergence. In the middle one, more exports from NL-DE to BE-FR creates the convergence. In the bottom one, increased import capacities in NL allows the price to converge.

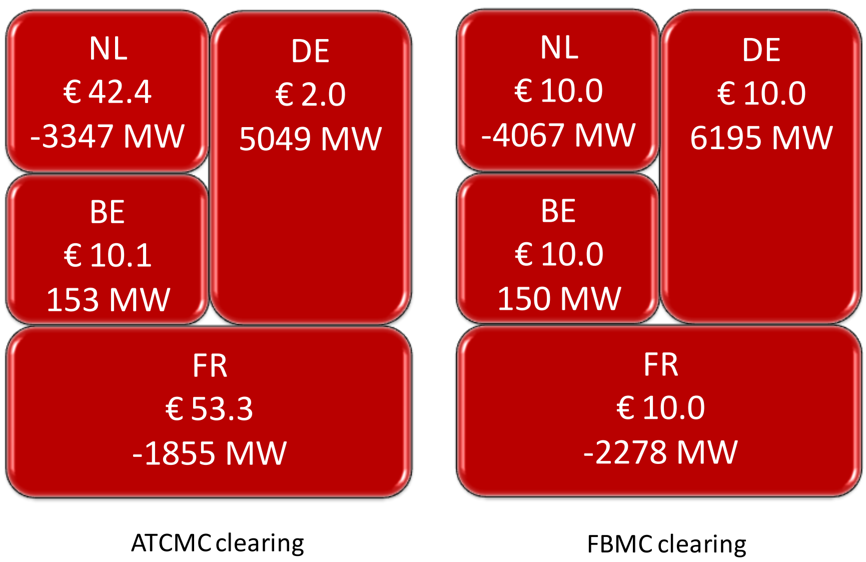


Figure 23: June 6th, 2011, 15:00 clearings

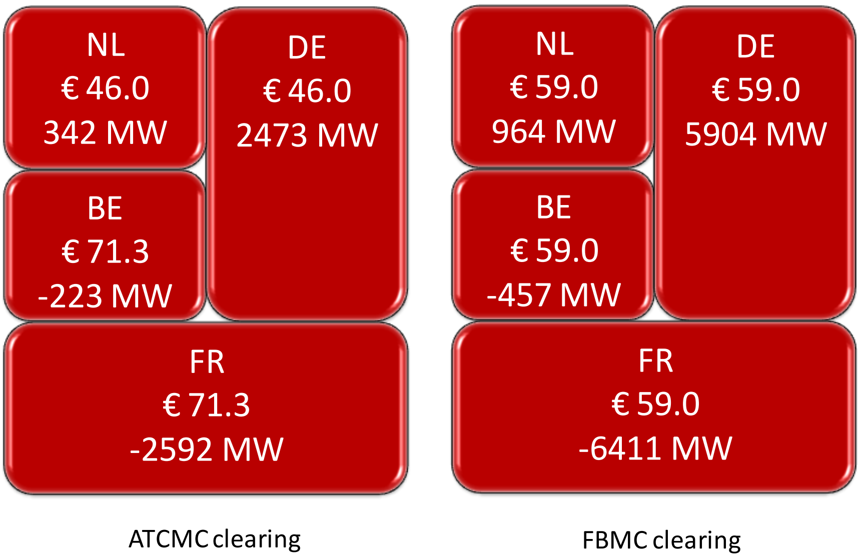


Figure 24: December 1st, 2010, 22:00 clearings

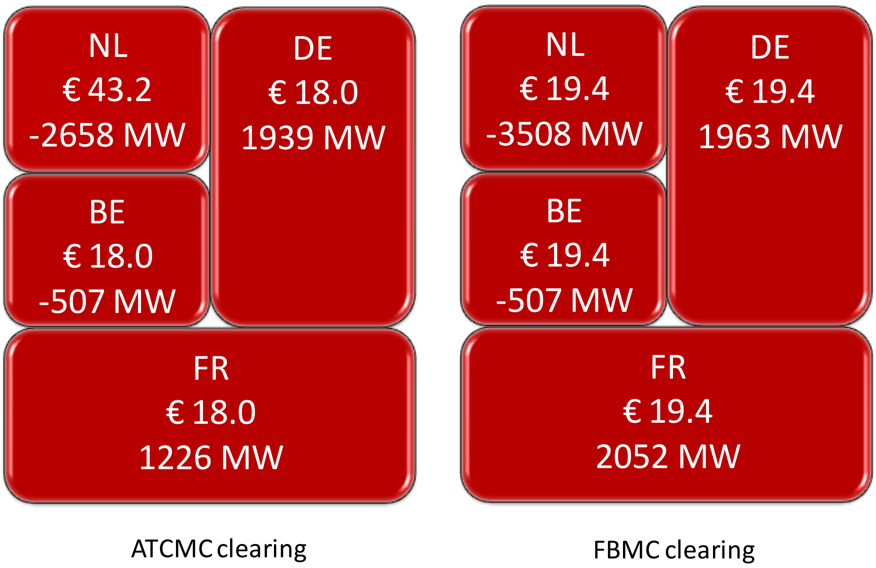


Figure 25: April 9th, 2011, 04:00

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 26 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 the plotted interval is 68%.

Globally, the price increases in areas exporting more and decreases in areas 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. For the Netherlands, the standard deviation is higher in FBMC, indicating a slightly higher volatility of the base price, probably linked to the fact that the partial convergence between NL and DE that anchored the NL price to DE during this period in ATCMC disappears in FB[24].

[24] For example, see slide 11 of the presentation shown at CWE Market Coupling Flow-Based Forum on June 1st, 2011. http://clients.rte-france.com/htm/fr/offre/telecharge/CWE_Flow_Based_Forum_1st_June_2011_presentation.pdf

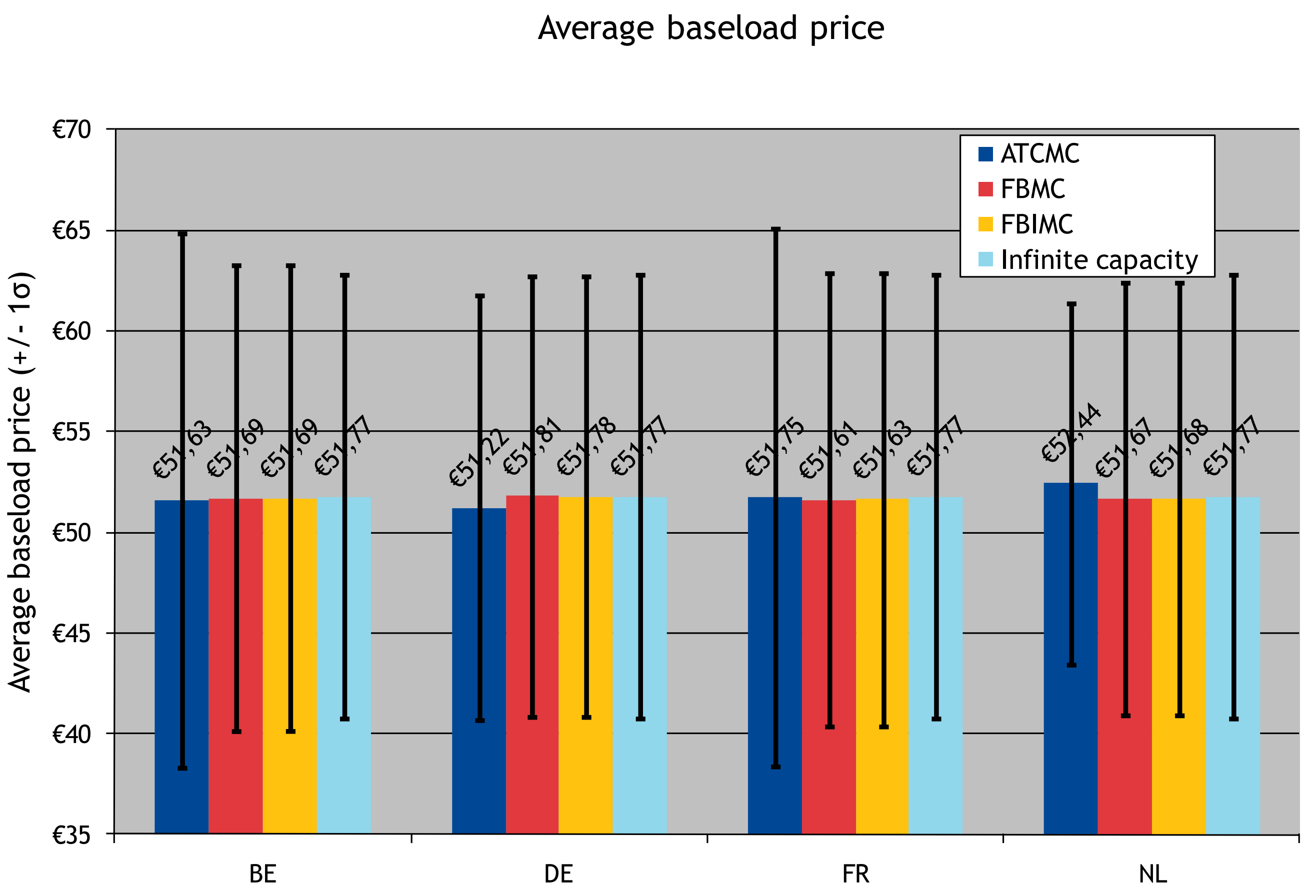


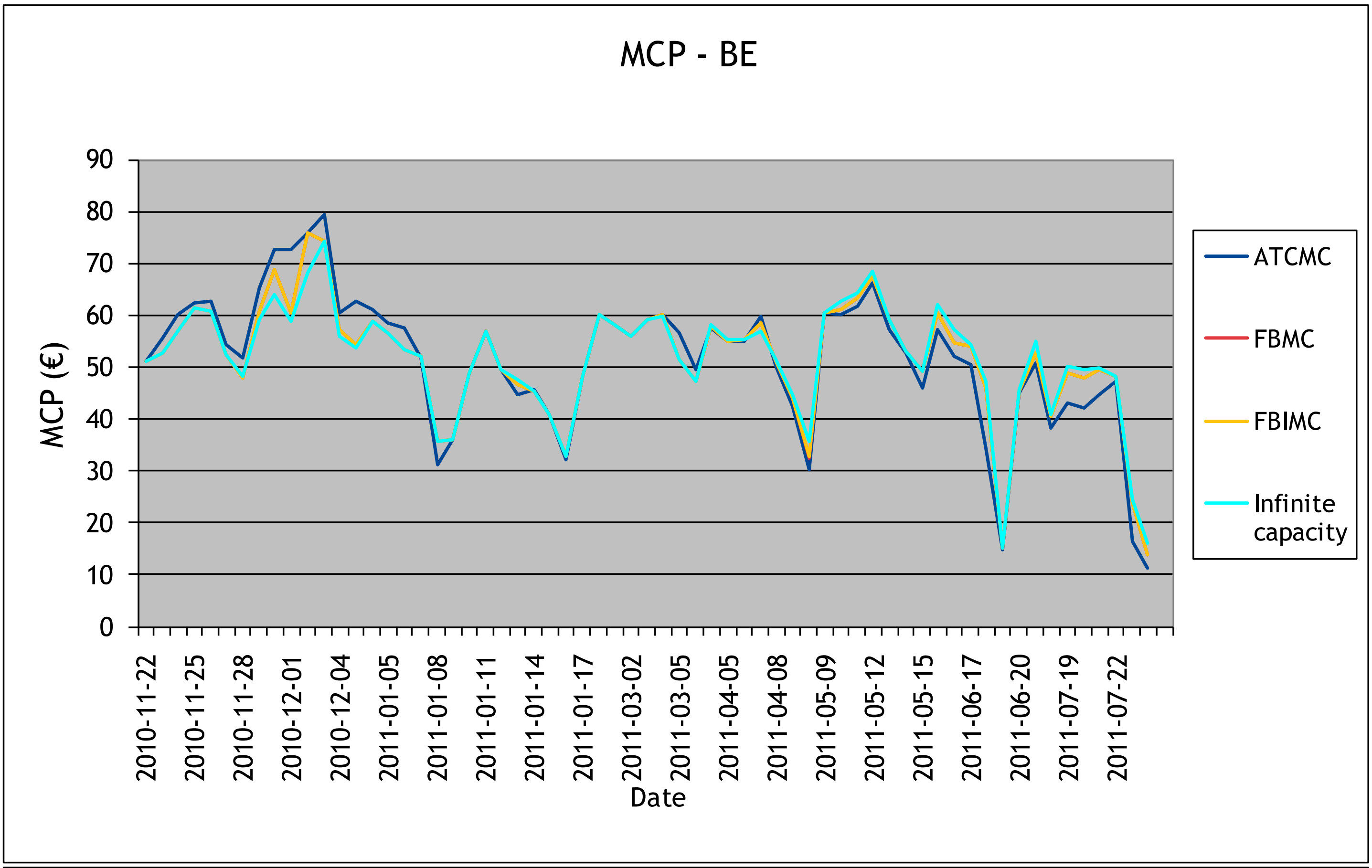
Figure 26: Average baseload price in €/MWh

The simulation period is short enough to plot the daily baseload price per area in Figure 27. Figure 28 represents the hourly clearing price per areas. 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 first periods of 2 weeks was significantly different: it was rather tensed with many congestions, while the following mid-season months are rather flat with full convergence during most hours. The last cycles (June and July) are clearly more tensed.

On April 9th and 10th, the daily baseload price is significantly lower in FBMC and FBIMC than in ATCMC in the Netherlands, corresponding to a significant increase of the imported volume (cf. Figure 10). This is an example of the benefit of FB methodology.

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
2010-11-25
2010-11-28
2010-12-01
2010-12-04
2011-01-05
2011-01-08
2011-01-11
2011-01-14
2011-01-17
2011-03-02
2011-03-05
2011-04-05
2011-04-08
2011-05-09
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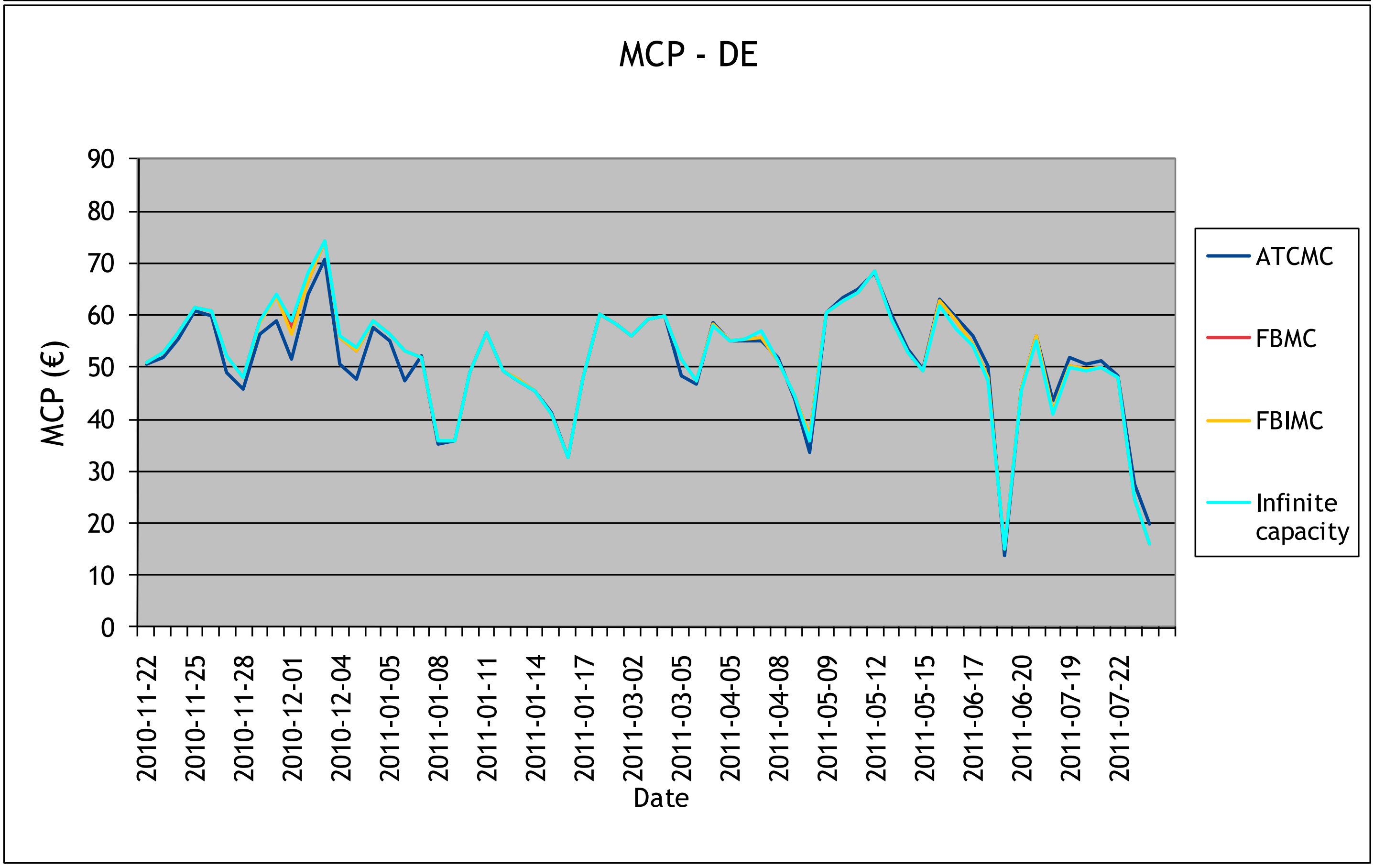
2011-07-19
2011-07-22
Date
ATCMC
FBMC
FBIMC
Infinite capacity


MCP - DE
MCP (€)
90
80
70
60
50
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30
20
10
0
2010-11-22
2010-11-25
2010-11-28
2010-12-01
2010-12-04
2011-01-05
2011-01-08
2011-01-11
2011-01-14
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2011-03-05
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2011-04-08
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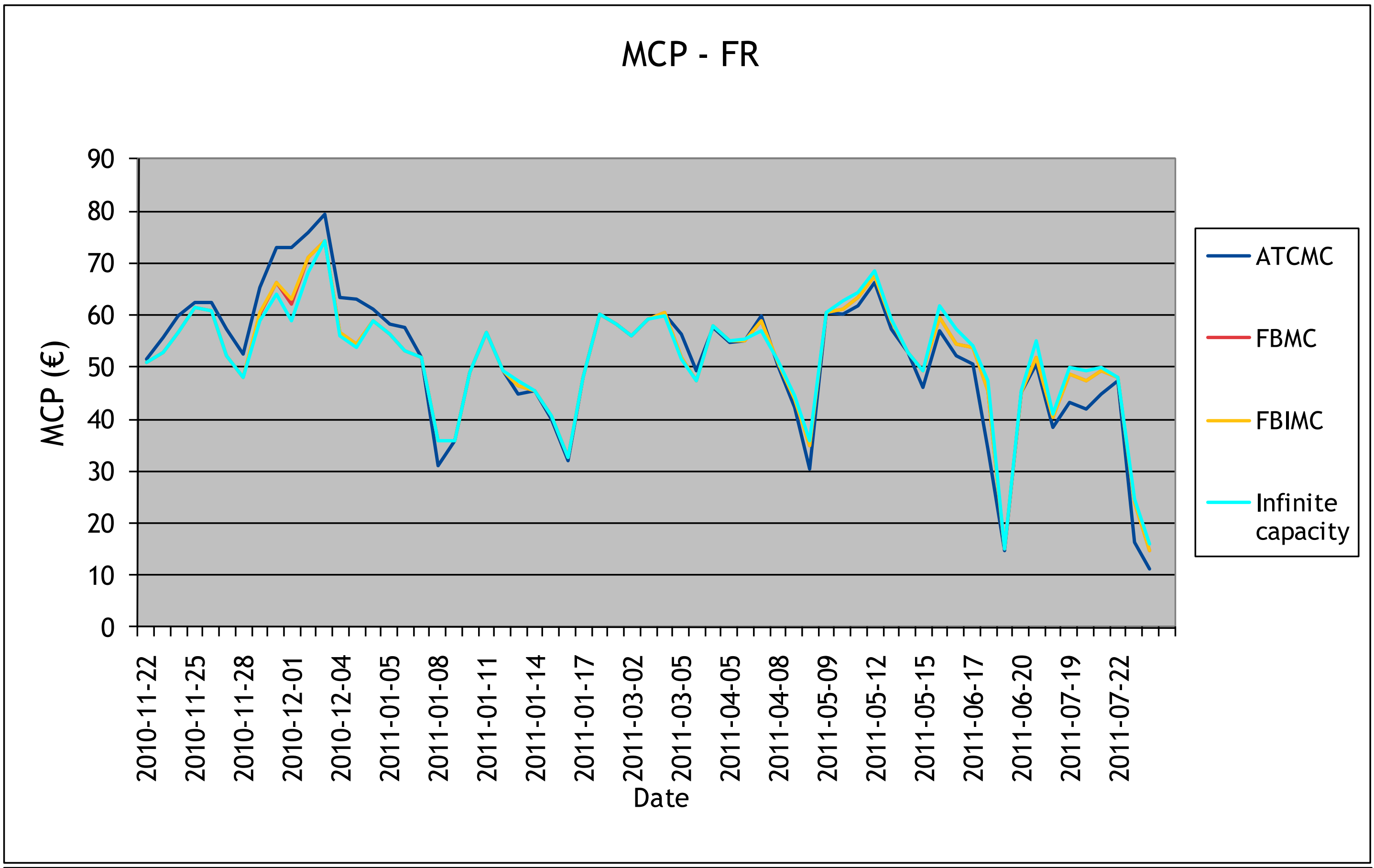
Date
ATCMC
FBMC
FBIMC
Infinite capacity



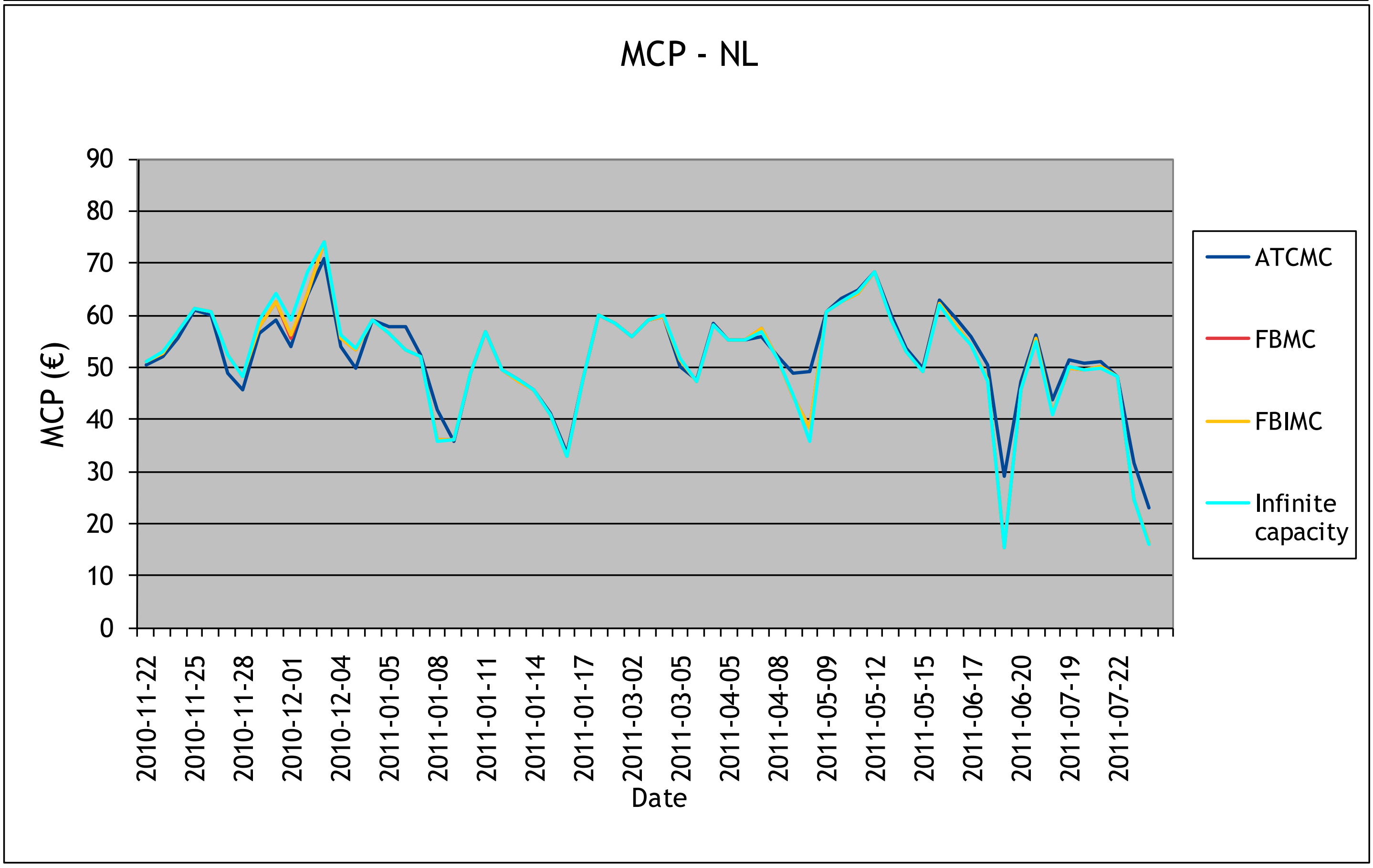
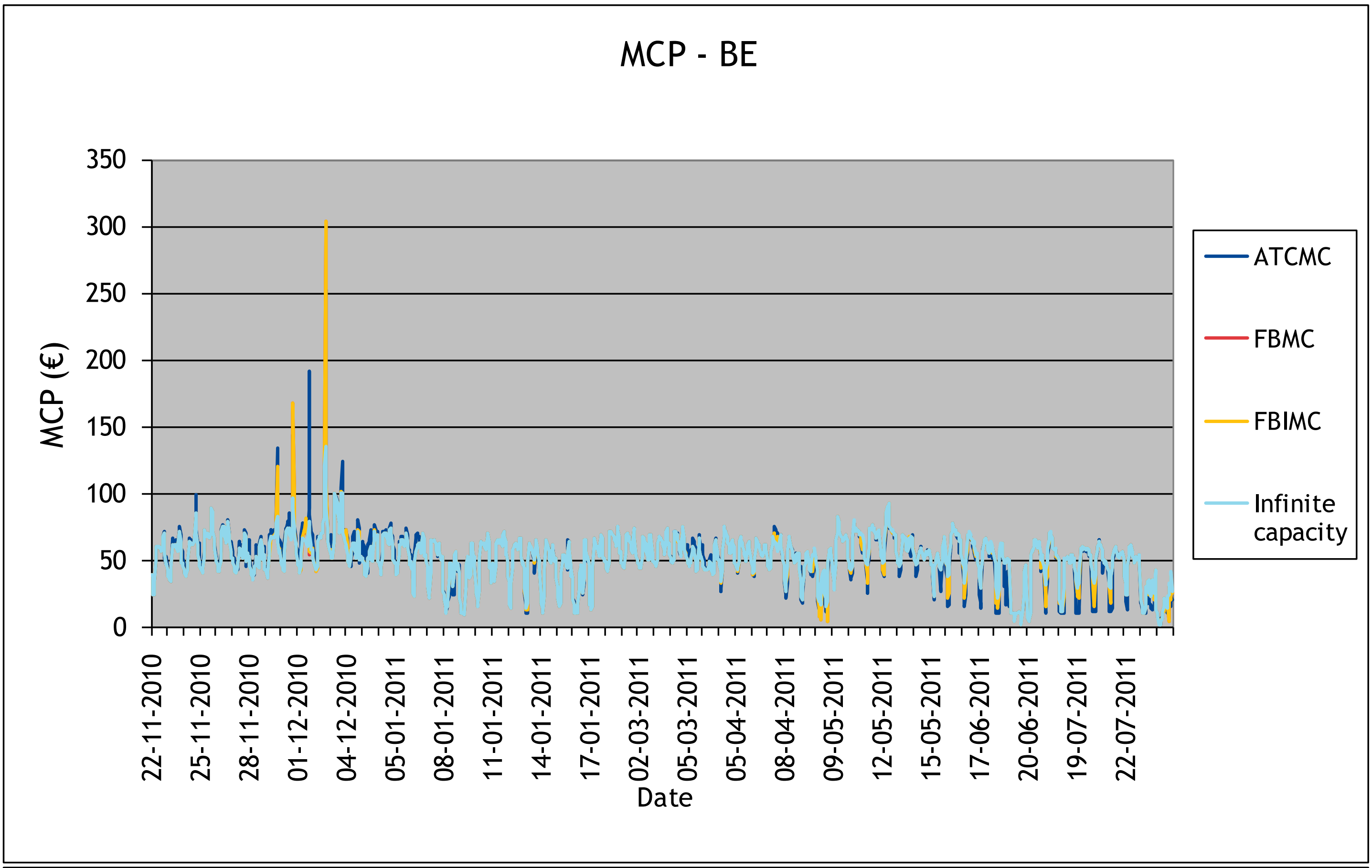
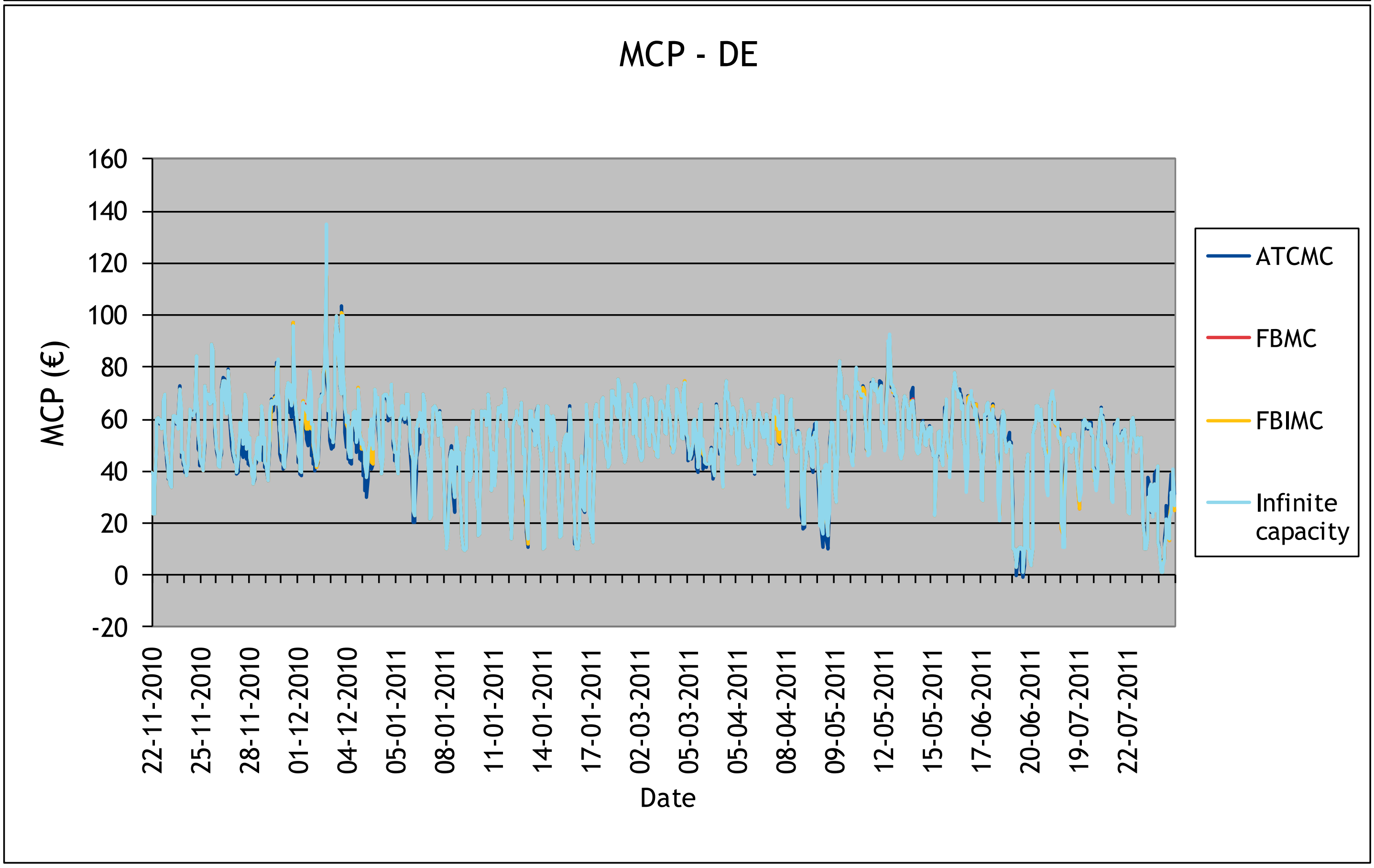
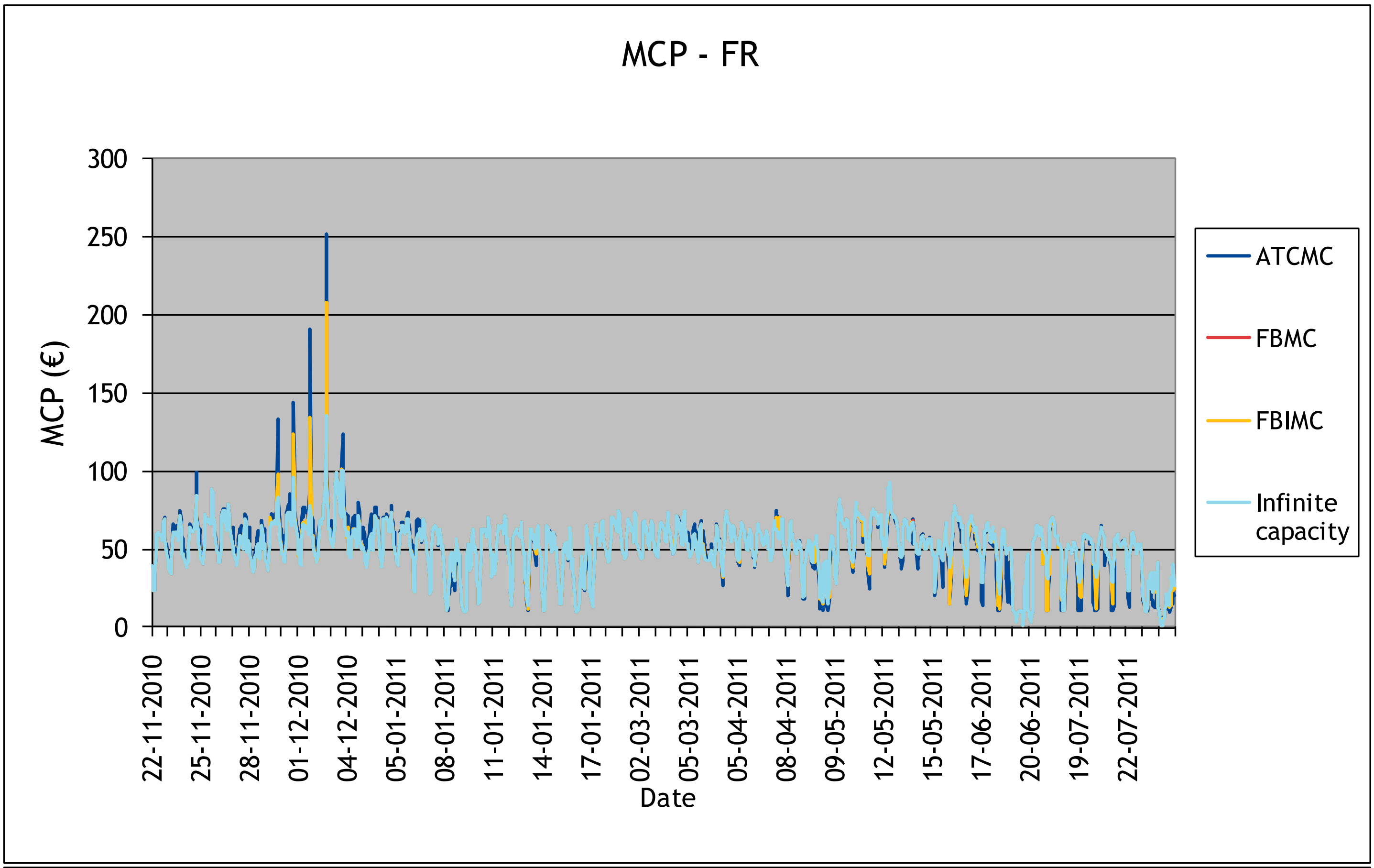


Figure 27: Daily baseload price per area


MCP - BE
MCP (€)
350
300
250
200
150
100
50
0
22-11-2010
25-11-2010
28-11-2010
01-12-2010
04-12-2010
05-01-2011
08-01-2011
11-01-2011
14-01-2011
17-01-2011
02-03-2011
05-03-2011
05-04-2011
08-04-2011
09-05-2011
12-05-2011
15-05-2011
17-06-2011
20-06-2011
19-07-2011
22-07-2011
Date
ATCMC
FBMC
FBIMC
Infinite capacity


MCP - DE
MCP (€)
160
140
120
100
80
60
40
20
0
-20
22-11-2010
25-11-2010
28-11-2010
01-12-2010
04-12-2010
05-01-2011
08-01-2011
11-01-2011
14-01-2011
17-01-2011
02-03-2011
05-03-2011
05-04-2011
08-04-2011
09-05-2011
12-05-2011
15-05-2011
17-06-2011
20-06-2011
19-07-2011
22-07-2011
Date
ATCMC
FBMC
FBIMC
Infinite capacity



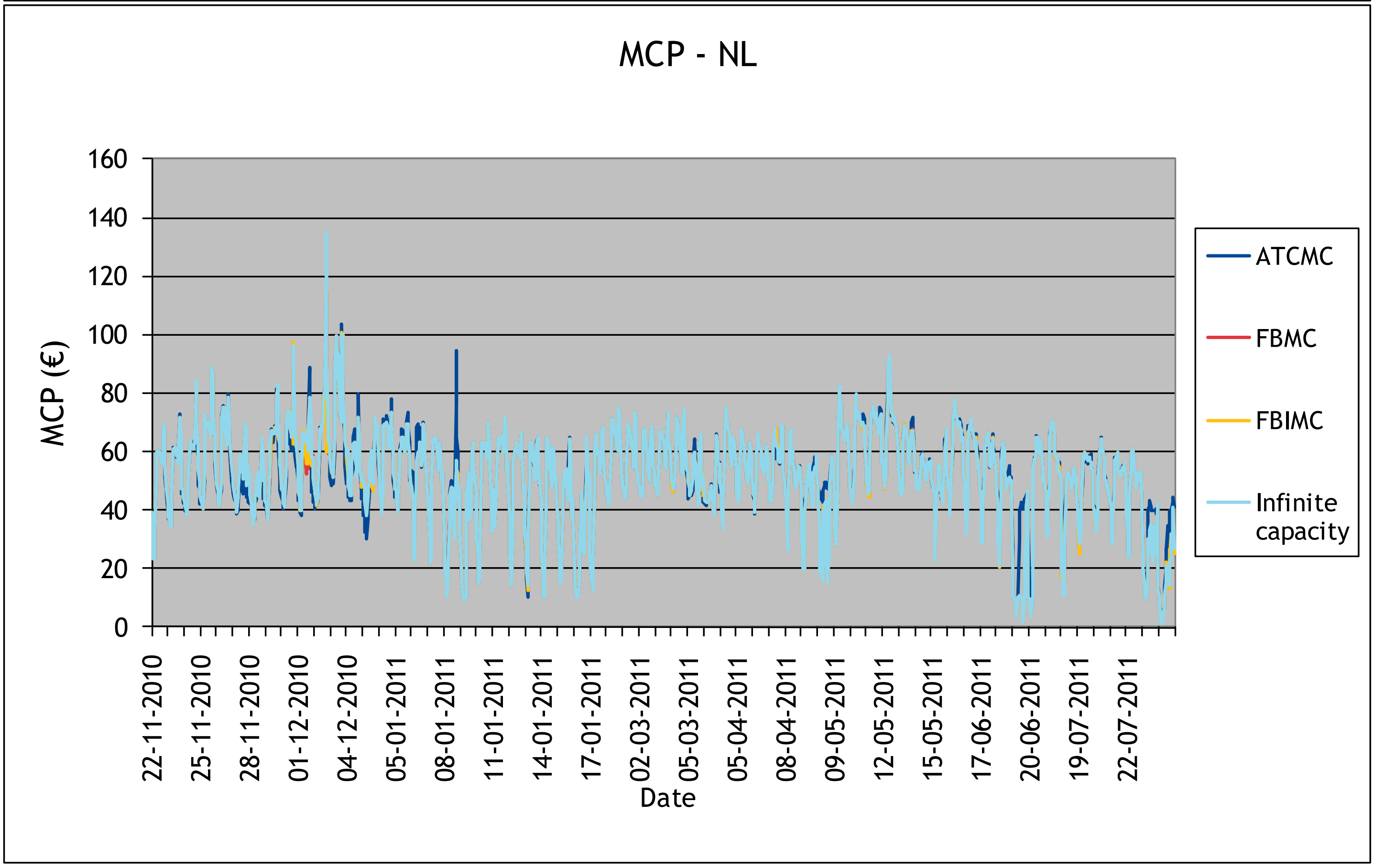


Figure 28: Hourly clearing price per area

3.4.9 Frequency of non-intuitive situations

- According to the "source-to-sink intuitiveness"

Source-to-sink intuitiveness (or intuitiveness) is defined in Section 3.3.1. A source-to-sink non-intuitive situation can be characterized by the fact that the N areas with the lowest clearing price are exporting, with N between 1 and the number of areas. The table below shows the number of hours in which such situations occurs.

Only 18 hourly situations out of 1512 are source-to-sink non-intuitive in FBMC. As expected, none are observed in FBIMC and ATCMC.

(tol. 0.005 €/MWh on rounded prices)	Number of hours where situations are source-to-sink non-intuitive	Proportion of hours where situations are source-to-sink non-intuitive	Proportion of hours where situations are source-to-sink non-intuitive among congested hours
ATCMC	0	0 %	0 %
FBMC	18	1.2 %	11.8 %
FBIMC	0	0 %	0 %
ISO	0	0 %	0 %

- According to the "bilateral intuitiveness"

In Section 3.3.2, we define a situation as being "bilateral intuitive" if it exists at least one set of intuitive direct bilateral exchanges (from the cheapest bidding area to the most expensive one).

(tol. 0.005 €/MWh on rounded prices)	Number of hours where situations are bilateral non-intuitive	Proportion of hours where situations are bilateral non-intuitive	Proportion of hours where situations are bilateral non-intuitive among congested hours
ATCMC	0	0 %	0 %
FBMC	22	1.5 %	14.4 %
FBIMC	6	0.4 %	3.9 %
ISO	0	0 %	0 %

Since bilateral intuitiveness 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: 4 source-to-sink intuitive situations are bilateral non-intuitive in FBMC. 2 additional FBMC source-to sink non-intuitive situations remain bilateral non-intuitive in FBIMC, while, for the other, solving the source-to-sink non-intuitiveness also solved the bilateral non-intuitiveness.

3.4.9.1 Description of source-to-sink non-intuitive situations

The source-to-sink non-intuitive situations occured during the days shown in the table below. The 'non-intuitiveness' corresponds to the minimum, over all sets of bilateral exchanges compatible with the clearing, of the maximum price difference along all the exchanges from high to low price areas found in a given set. The table below indicates the maximum non-intuitiveness observed among non-intuitive situations that occured during the day.

Day	Number of situations	Daily max. non-intuitiveness (€/MWh)
2010-11-28	1	0.24
2010-11-29	1	10.59
2010-12-01	11	15.05
2010-12-03	1	0.09
2010-12-04	1	1.19
2010-01-06	1	0.05
2010-03-05	1	1.57
2010-04-10	1	1.921

On December 1st, more than half of the non-intuitive situations occured. They are distributed during the day (from 7:00 to 21:00). The other non-intuitive situations happened either in the morning (8:00) or in the evening (20:00 and 24:00).

In all 18 situations, the bidding area with the lowest price imports. Among these situations, there are 2 situations where the 2 bidding areas with the lowest prices import. In 1 of these 2 situations, the second bidding area exports, but not enough to compensate the imports of the first bidding area. BE is importing with the lowest price in 6 situations and NL in the remaining 12 ones.

Schematically, non-intuitiveness is solved by the combination of 2 effects that occurs when increasing the NEX of the bidding areas with the lowest price:

- As imports decrease, price increases so that the area price is not the lowest anymore.
- Imports may decrease up to the point that the area exports, so that the fact that the area has the lowest price is not non-intuitive anymore.

Experimentally, both effects are observed and combined:

- In 16 situations out of 18, partial convergence is observed: in FBIMC, the prices of the 2 areas with the lowest prices are equal. Usually, it means that the BE price is aligned with the NL price (when the BE price is the lowest) or the NL price is aligned with the DE price (when the NL price is the lowest).
- In 4 situations, the NEX sign changes (in 2 situations, it occurs together with price convergence). It always concerns NL. In 2 situations, the new NL NEX is 0 MW. In 2 situations, the new NL NEX is strictly positive (154.5 MW –cf. Figure 30- and 358.9 MW –cf. Figure 31-: this effect is due to block orders which do not allow a continuous variation of NEX.

Below some typical source-to-sink non-intuitive situations are described and how FBIMC “solves” the non-intuitiveness. In the diagrams below, blue areas are in non intuitive situations. Green squares emphasize partial convergences or net export position sign change.

Figure 29 illustrates a timestamp in which NL was in a non-intuitive situation that was “solved” by creating partial convergence with DE. A block order effect is visible in BE where both the imports and the price increase from FBMC to FBIMC, whereas the price usually decreases when the imports increase.

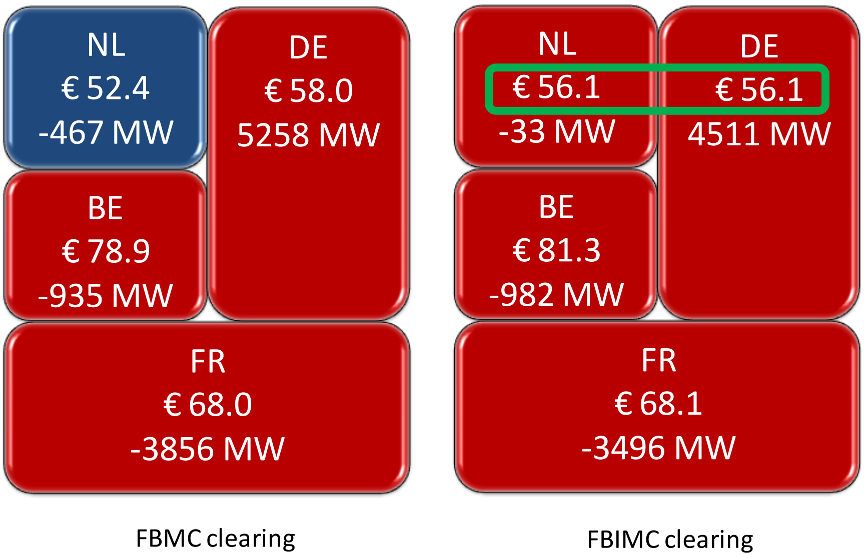


Figure 29: December 1st, 13:00 FBMC and FBIMC clearings

Figure 30 illustrates a timestamp in which BE was a non-intuitive situation that was “solved” by creating partial convergence with NL. A block order effect is visible because the price increase in BE that allowed the creation of partial convergence with NL is linked to an increase of imports, wherease the price usually decreases when the imports increase.

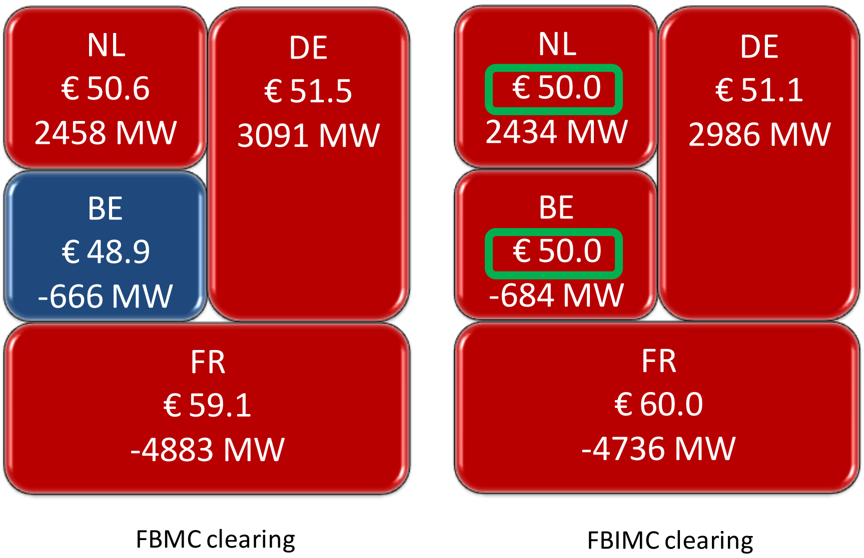


Figure 30: December 1st, 7:00 FBMC and FBIMC clearings

Figure 31 illustrates a timestamp where a non-intuitive situation in NL is "solved" by changing the sign of NL NEX.

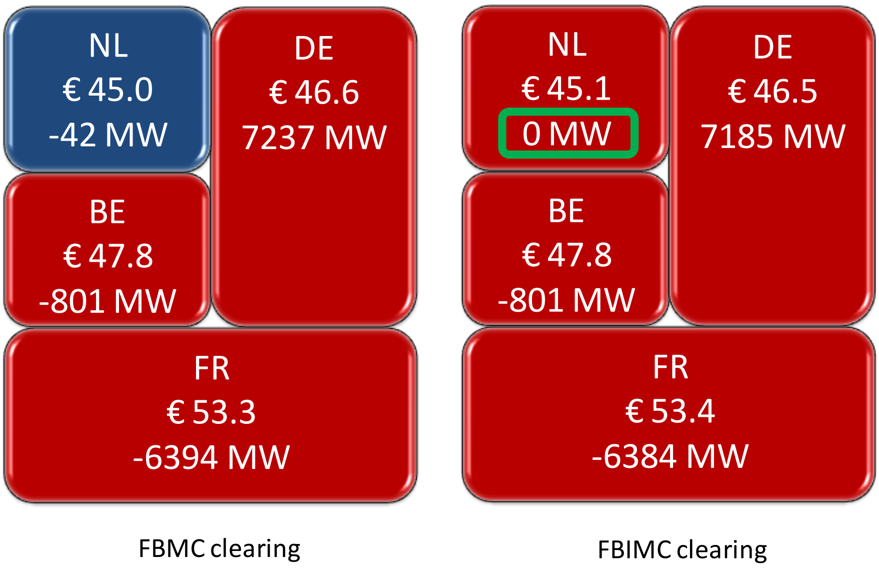


Figure 31: March 5th, 24:00 FBMC and FBIMC clearings

Figure 32 illustrates a timestamp in which a partial convergence between FR and BE is created to "solve" the non-intuitiveness in Belgium. Note that the Belgian net position does not change while the prices do. It is due to a price undeterminacy and to different rules in FBMC and FBIMC (in FBMC, the prices are directly linked to the PTDFs of congested branches while in FBIMC, partial convergence is created because counter-exchanges are not taken into account on congested lines – cf. Section 5.11.4). The fact that the FBIMC implementation of COSMOS is a heuristic is visible here: indeed, BE NEX did not change, but only its price. Therefore, it would have been possible to keep the NEX found in the FBMC clearing and to keep all price unchanged except the BE price that would have been set to 18.3 €/MWh (the value of the FR price).

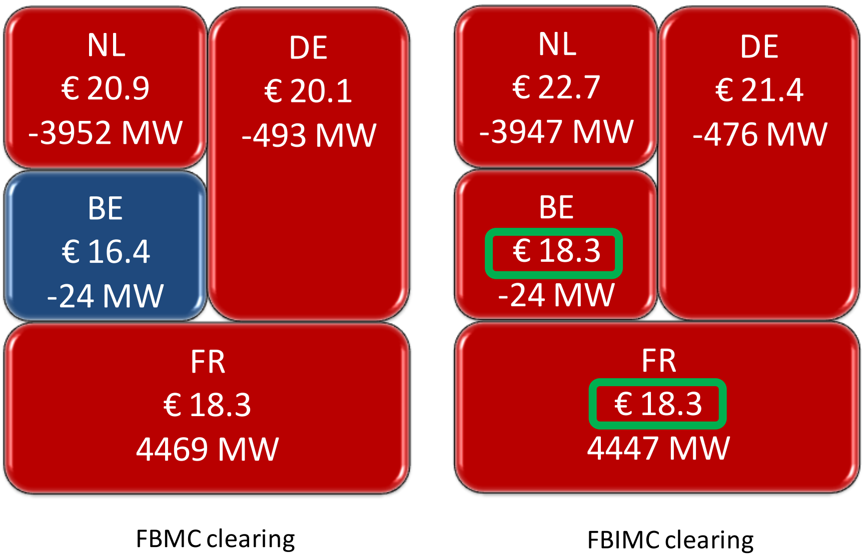


Figure 32: April 10th, 7:00 FBMC and FBIMC clearings

Figure 33 illustrates a complex situation with NL and BE being both non-intuitive (separately and together) "solved" by NEX sign change for NL and by creation of partial convergence with DE for BE. Note that the FBIMC situation is bilateral non intuitive because the export from DE to BE is impossible with this definition of intuitiveness.

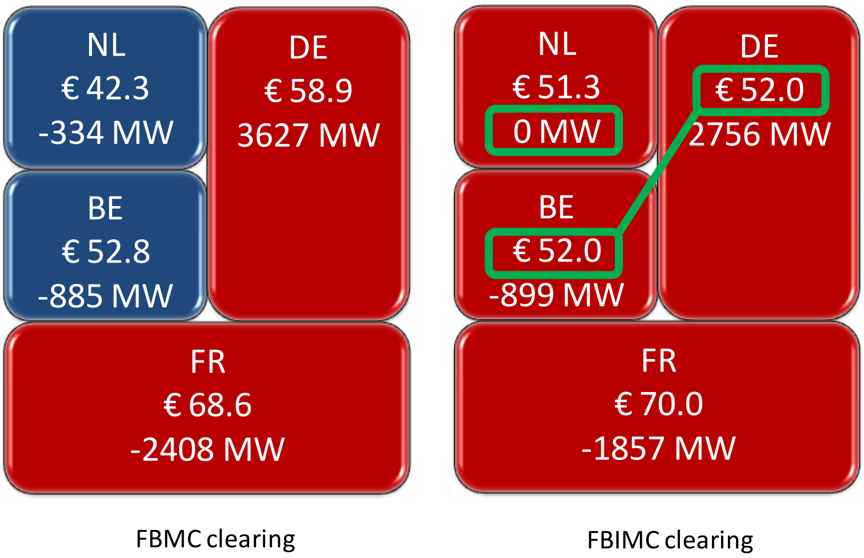


Figure 33: November 29th, 8:00 FBMC and FBIMC clearings

Figure 34 and Figure 35 illustrate timestamps where a non-intuitive situation in NL is "solved" by changing the sign of NL NEX. The fact that NL position becomes strictly positive, while 0 MW was enough, is due to the impossibility of a continuous variation of the NEX linked with block orders.

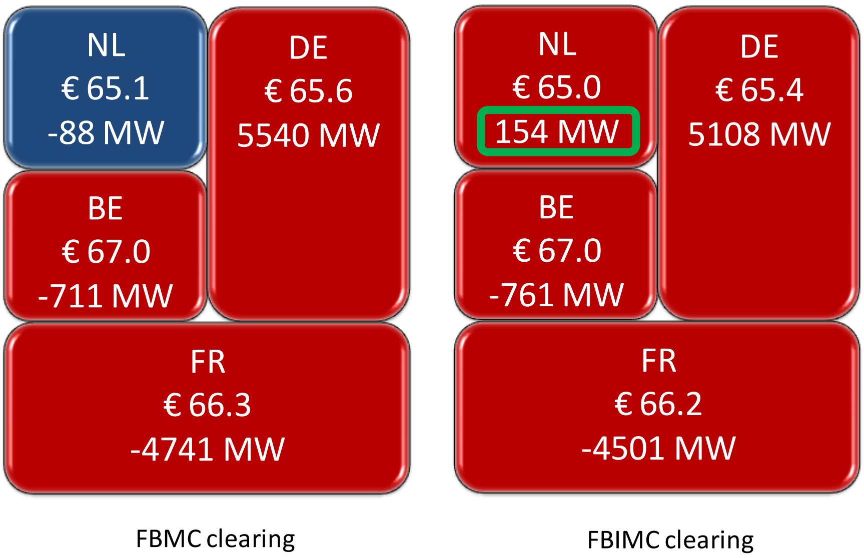


Figure 34: December 1st, 10:00 FBMC and FBIMC clearings

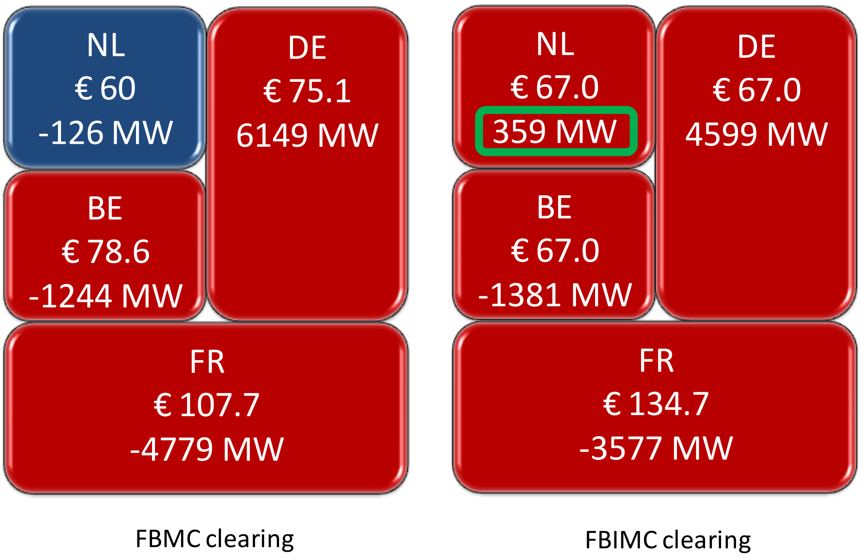


Figure 35: December 1st, 19:00 FBMC and FBIMC clearings

3.4.9.2 Description of bilateral non-intuitive situations

As already said, all FBMC source-to-sink non-intuitive situations are also bilateral non-intuitive while the corresponding FBIMC is source-to-sink intuitive. However, in 2 of these situations, the FBIMC clearing is bilateral non-intuitive:

Day	Number of situations	Daily max. non-intuitiveness (€/MWh)
2010-11-29	1	0.71
2011-03-05	1	1.37

The 2010-11-29 situation is already depicted in Figure 33. The bilateral non-intuitiveness arises from the forbidden export from DE to BE than can neither be decomposed into a DE->NL export followed by a NL->BE export nor into a DE->FR export followed by a FR->BE export due to the fact that the price is not constant along these paths. The second situation is similar.

In addition, in 4 situations, FBMC clearings are source-to-sink intuitive but bilateral non-intuitive. As they are source-to-sink intuitive, FBMC clearings are equal to FBIMC clearings. In the 3 first situations, an export from DE to BE is needed. In the fourth one, an export from FR to NL is needed. The first situation (December 4th, 2010, 24:00), which is the only one with a significant non-intuitiveness, is depicted on the right handside of Figure 4.

Day	Number of situations	Daily max. non-intuitiveness (€/MWh)
2010-12-04	1	1.23
2011-01-04	1	0.06
2011-03-03	1	0.33
2010-05-13	1	0.431

Note that, contrary to source-to-sink intuitiveness which is enforced in the current COSMOS FBIMC implementation, it is not possible to enforce bilateral intuitiveness in the current version of COSMOS so that it is currently impossible to present simulation results based on bilateral intuitiveness.

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. The table with the number of occurences of such situations is given below:

	# hours cheapest coupled market price < cheapest ISO market price	**# hours most expensive coupled market price > most expensive ISO market price**
ATCMC	1	2
FBMC	4	2
FBIMC	3	2

For higher price than in isolated mode, it does not happen more frequently in FBMC and FBIMC than in ATCMC. For the first situation (May 5th, 2011, 23:00), the price is 0.01 €/MWh higher in DE than in isolated mode. Full convergence is reached in ATCMC, FBMC and FBIMC. For the second situation (July 22nd, 2011, 19:00), the price is higher is all areas (between 1.02 and 1.51 €/MWh higher). Again, full convergence is reached. This effect is linked to block orders.

For lower prices than in isolated mode, it happens more often with FBMC and FBIMC than in ATCMC. In the 4 situations where it occurs in FBMC and FBIMC, the price discrepancy ranges between 0.1 €/MWh and 1.7 €/MWh. In ATCMC, the price discrepancy is 1.45 €/MWh. Therefore, even if the frequency of these events is higher in FBMC and FBIMC, the amplitude of discrepancies is similar.

3.4.11 Hour-to-hour net position volatility

For a given area, 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.

Figure 36 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.

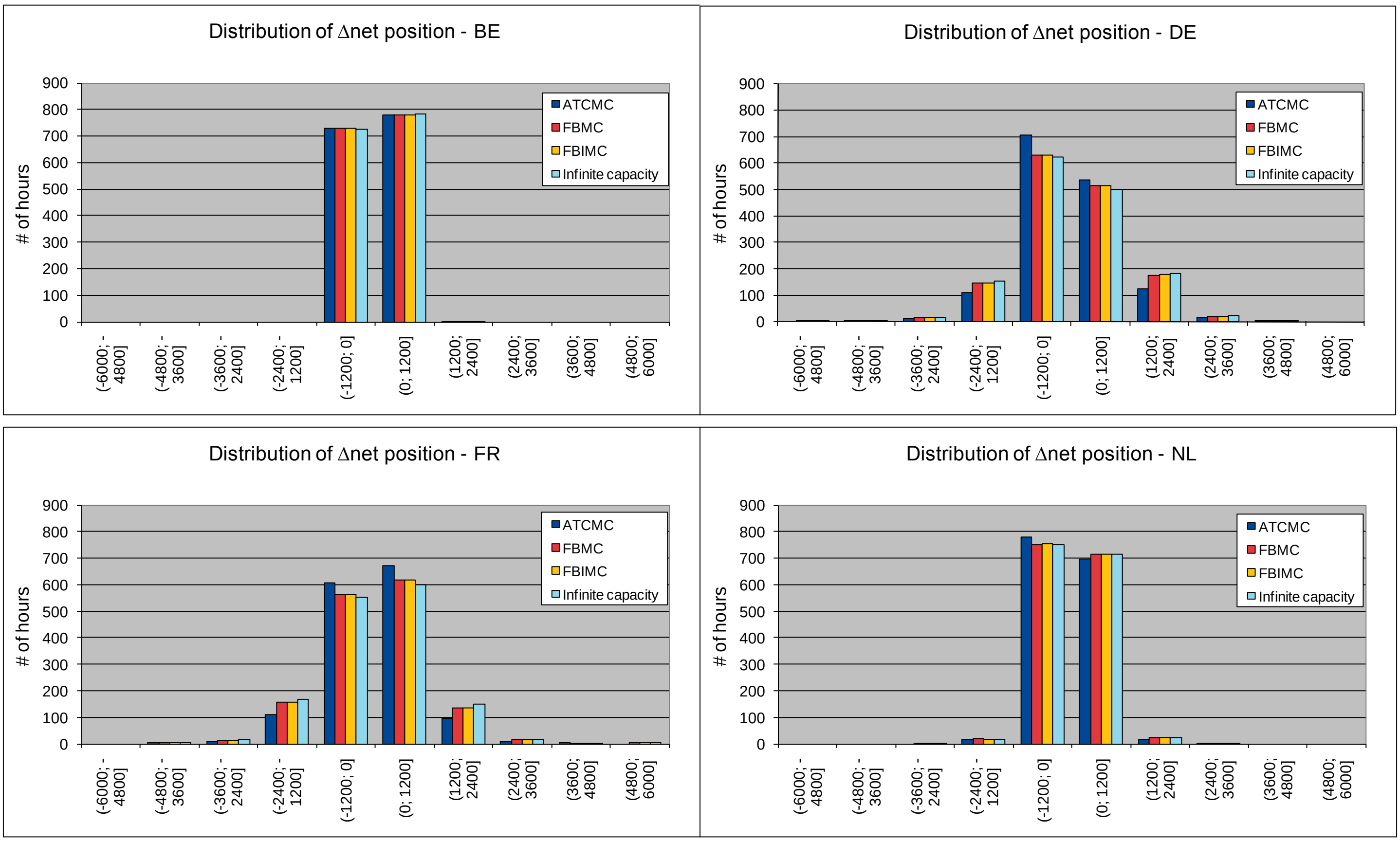


Figure 36: Net position volatility per area

3.4.12 Paradoxically rejected blocks

Paradoxically rejected blocks (PRB) are block orders that are rejected while they are "in the price" (below the price for sell bids and above it for buy bids). Overall, as shown in the table below, the number of rejected blocks and the associated welfare loss (for the owner of the bid) decrease when the capacity available and the convergence increase.

	Number of PRBs	PRB Welfare Loss
ATCMC	211	65,475 €
FBMC	157	31,027 €
FBIMC	162	34,712 €
Isolated	734	1,617,321 €
Infinite cap. MC	119	21,444 €

Therefore, the conclusion is that FBMC and FBIMC have a positive impact on the PRB issue because they increase the convergence compared to ATCMC.

3.4.13 Computation time

The computation time is an indicator of the complexity of the market clearing problem. The table below shows that the number of times that the algorithm reaches the time limit of 600s is not significantly larger in FBMC and FBIMC than in ATCMC and Infinite capacity MC.

	Number of runs reaching time limit (600 s)
ATCMC	3
FBMC	5
FBIMC	4
Isolated	46
Infinite cap. MC	4

Therefore, the conclusion is that the computation time for FBMC and FBIMC is not a problem.

3.4.14 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. This study has been done only on 2x2 weeks in December 2010 and January 2011.

To summarize the findings, the X^{th} centile of the price difference is computed[25]. For example, if the 90^{th} percentile of the price difference after the addition of a 1000 MW buy order is 6 €/MWh, it means that, in 90% of situations, the price difference is lower than 6€/MWh 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 €/MWh, it means that, in 90% of situations, the price difference is larger than -6 €/MWh (i.e. lower in absolute value).

Figure 37 and Figure 38 present the 90^{th} centile and the 97.5^{th} centile for each bidding area for ATCMC and FBMC:

- These 90^{th} and 97.5^{th} levels are somehow more stringent than the level used in usual market resilience analysis[26]. Indeed, the indicator ordinarily used is the average price difference over all situations. It explains why the price difference are higher in this report than in usual studies. The advantage of using indicators based on high centiles is that it focuses on the most sensitive situations only. Indeed, the resilience should be evaluated on highly tensed situations, whereas averaging over all situations damps the strong effect of highly congested situations with the mild effect of "copper-plate" situations.

- Overall, the resilience is better in FBMC than in ATCMC, which is consistent with the fact that the FB domain is usually larger than the ATC one. Results for FBIMC show a significant deterioration of the Belgium resilience while it is unchanged for other areas. The 1000 MW buy order resilience is not depicted for BE: indeed, it results in the so-called "double imports" which are deemed "unrealistic" (cf. Section 2.3.1.1). The ATCMC clearing point would lay outside of the FB domain, so that the comparison of ATCMC and FBMC would be impossible.

- Finally, it is important to note that resilience is computed from price differences, 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.

[25] 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.
[26] For example, http://www.belpex.be/uploads/Market_resilience_analysis.pdf

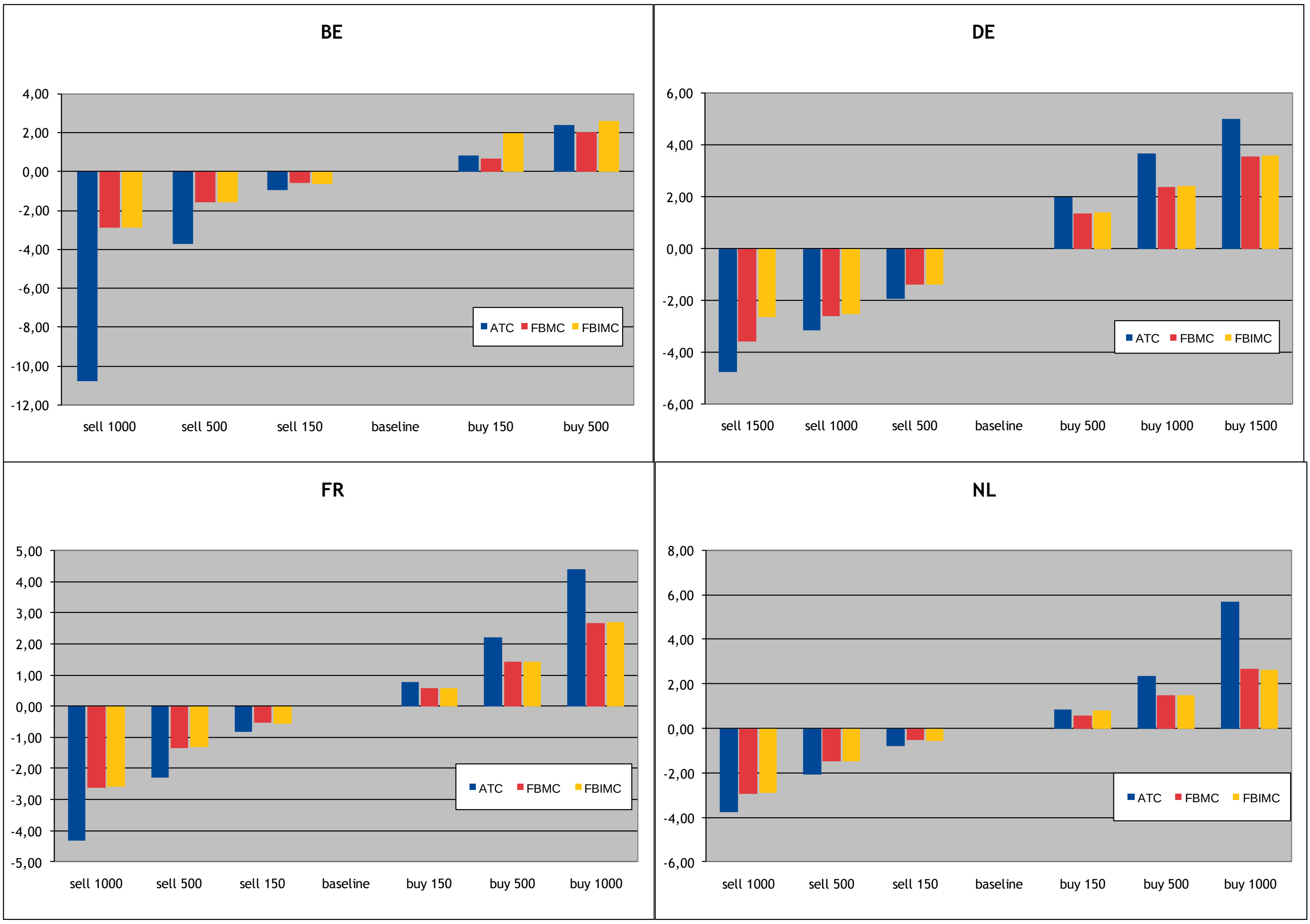


Figure 37: Resilience per bidding area at 90% in €/MWh

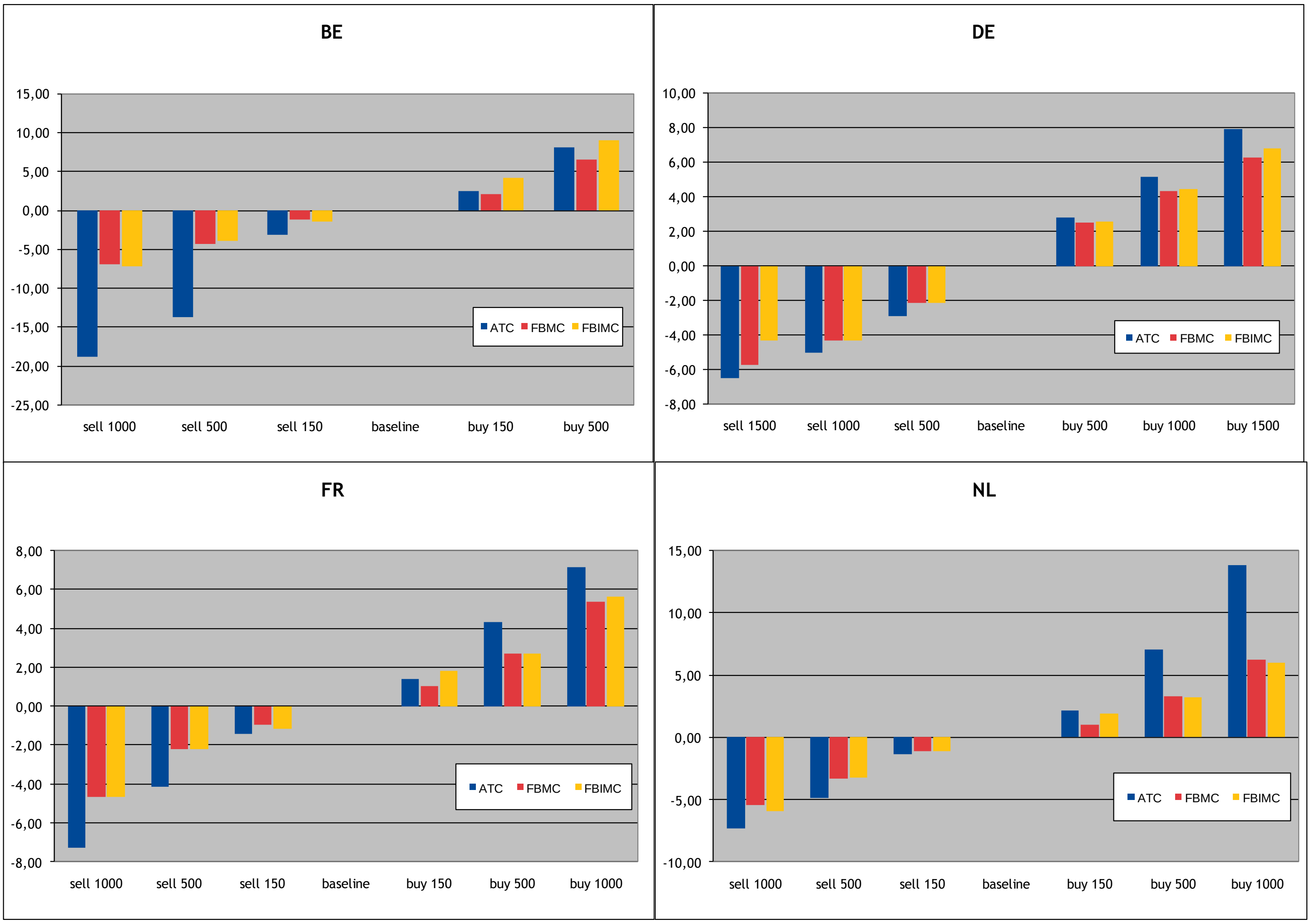


Figure 38: Resilience per bidding area at 97.5% in €/MWh

3.4.15 Capacity parameter sensitivity study

Generally speaking, a sensitivity study aims at assessing the impact of modifications of input data on the output results. In the specific case of the market coupling algorithm, the outputs are the indicators presented in the paragraphs 3.4.4 to 3.4.13 (essentially prices and volumes) and two kinds of inputs are found:

- The capacity parameters:
  - Either the NTCs;
  - Or the FB parameters for each critical branch;
- The order books.

The sensitivity to variations of the order books is analysed through the resilience study (cf. paragraph 3.4.15). It allows comparing the resilience when using ATCMC or FBMC. The sensitivity to the FB parameters may also be analyzed in this perspective but, given the differences between ATC and FB capacity calculation, it is not realistic to plan such a study. Therefore, the capacity parameter sensitivity study is not in line with the resilience study as it does not compare FBMC with ATCMC.

Instead of doing this comparison, the capacity parameter sensitivity study aims at estimating the market clearing sensitivity to small variations of the inputs. By small, it is meant small compared to the precision (linked to data quality and approximations made by the model) and compared to the uncertainty (linked to the events happening between D-2 and real time). Ultimately, it will allow assessing the impact of remaining margins and PTDFs on the prices. The FRM assessment / model quality study (Section 5.6) will help to quantify these small variations.

The objectives of this sensitivity study are:

- the stability and the fairness of the model: to avoid that the FB model outputs (prices and volumes) are too heavily impacted by small changes in the capacity parameters (topology, GSK,…);
- the continuous improvement of the model: to define which capacity parameters need to be particularly monitored and tuned to guarantee correct outputs (prices and volumes).

3.5 Conclusions

Simulations comparing ATC, FBMC and FBIMC on 9 weeks sampled between December 2010 and July 2011 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 source-to-sink intuitiveness through FBIMC in COSMOS deteriorates only very slightly the indicators. Moreover, non-intuitive situations represent a minor proportion of the analysed cases.
- Overall, resilience is improved in FBMC for all hubs (including Belgium). In FBIMC, a siginificant decrease of the Belgian market resilience is observed.

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 TSOs and PXs recommend continuing to monitor the impact on the market while the project is ongoing in order to have at least one year of simulation with the final methodology before FB goes live. It will also allow configuring the coupling algorithm (intuitiveness). More precisely, non intuitive situations were found in FBMC. Using FBIMC removes these situations without unacceptable deterioration of other indicators. Additionally, to validate these positive results, some work is still needed regarding the model quality (operational FRM values defined by TSOs) and the capacity parameter sensitivity study (3.4.15).

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 and the Netherlands and Norway.
- 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.

As a pan-European coupling solution adapted to all regional initiatives, PCR (Price Coupling of Regions) is in line with the requirements of FB MC. PCR is a cooperation of 6 Power Exchanges for an European Price Coupling Solution (APX-Endex, Belpex, EPEX Spot, GME, Nord Pool Spot, and OMEL)

The current foreseen roadmap towards a single European price coupling is depicted:

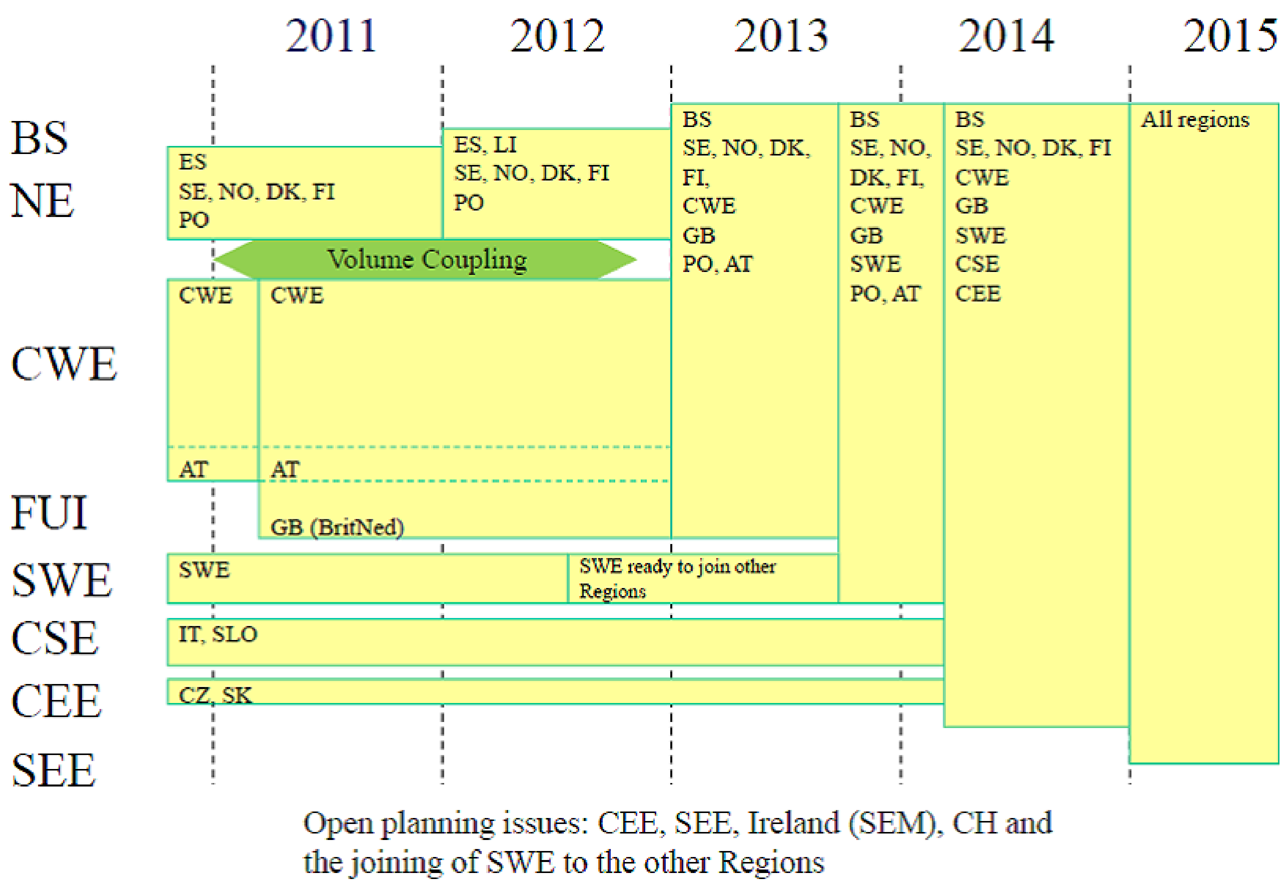


Figure 39 Florence forum roadmap[27]

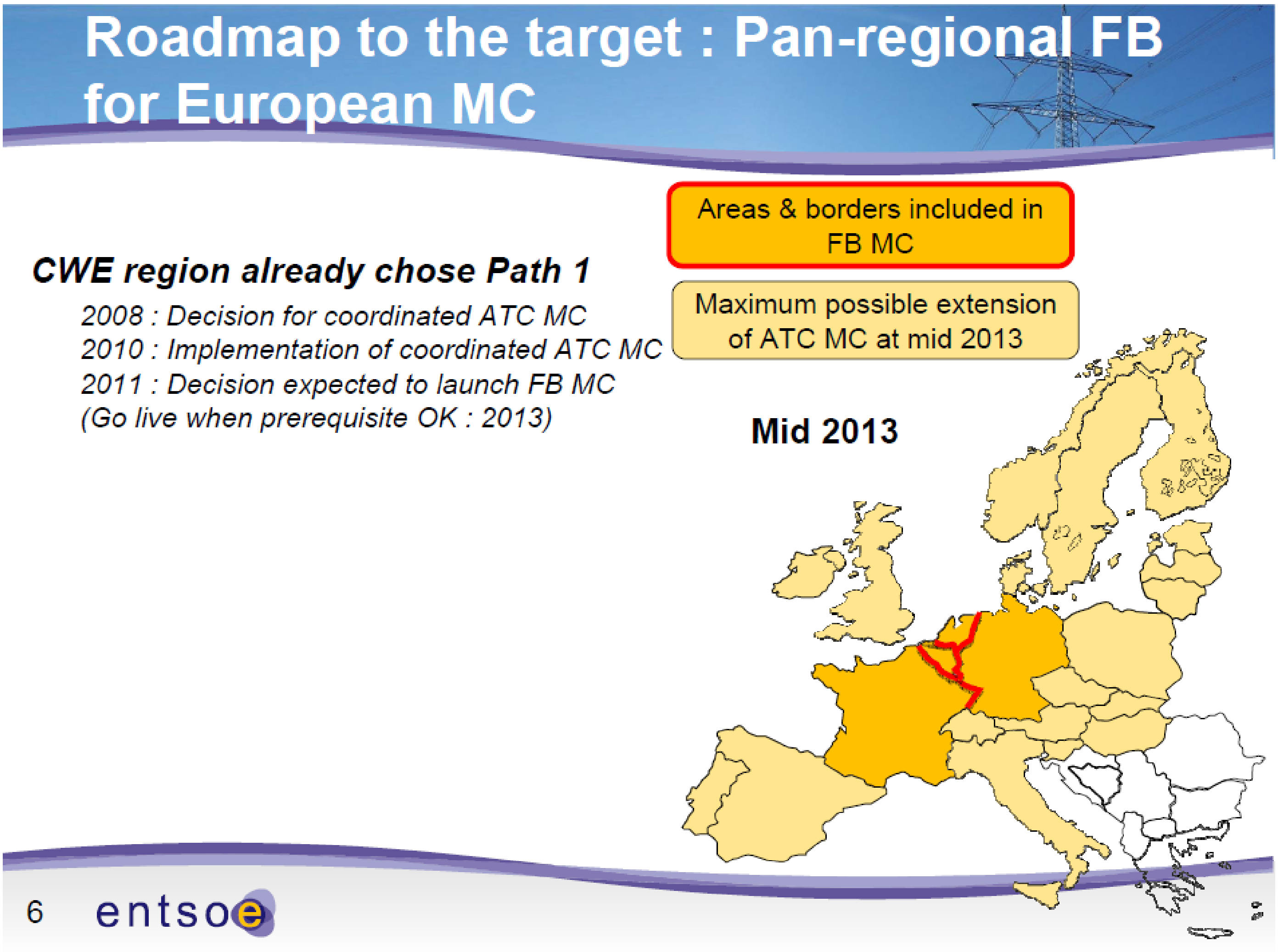
On the capacity calculation side, 2 paths from bilateral ATC explicit auctions to pan regional FB European Market Coupling were proposed at the same Florence forum:

- Either through regional ATC followed by regional FB, both progressively integrated into the European MC;

[27] http://ec.europa.eu/energy/gas_electricity/forum_electricity_florence_en.htm

- Or through regional FB with regional FB explicit auctions followed by regional FB progressively integrated into the European MC.

The CWE region has already chosen the first path:



CEE initially chose the second path. Discussions on future direction are ongoing until end 2011.

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
- 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 Section 5.9), 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[28] 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 40) 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.

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.

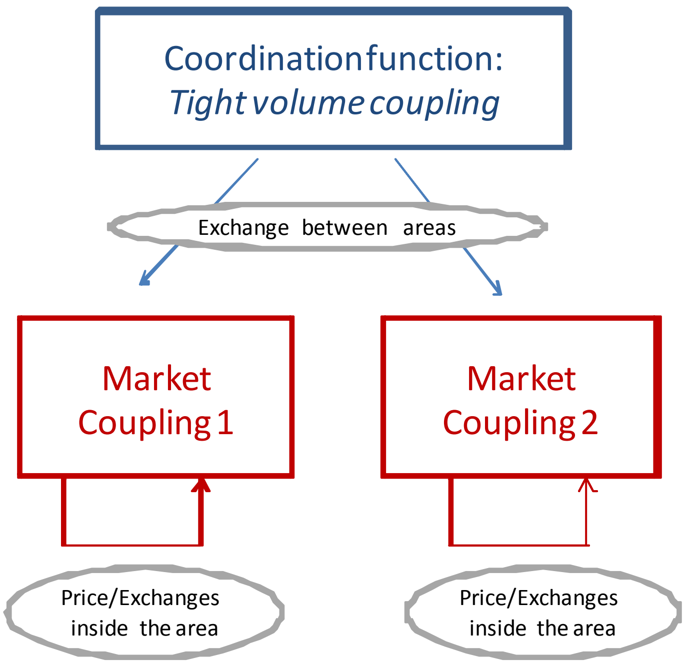


Figure 40: Tight volume coupling system

[28] 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.

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

The NWE enduring solution and PCR will both support FBMC and FBIMC in general and in the CWE region in particular. Given current plannings and the current state of coordination of the 2 projects, the simultaneous launch of the NWE enduring solution and/or PCR on the one side and of FB MC in the CWE region is possible and is the preferred option.

In its current state, ITVC uses CWE ATCs (among other data) to perform its volume coupling and cannot use FB constraints instead. Therefore, if a delay on both PCR and the NWE enduring solution occurs, the CWE FB MC project would have two options:
- Either to postpone the CWE FB MC go live;
- Or to use a back-up solution in order to allow that FB MC goes live with ITVC.

In this second case, two decisions are possible:
- Either implement FB into ITVC that would be used only for the period between the CWE FB MC go live and the NWE enduring solution go live, but would keep Nordic-CWE adverse flow to their current level;
- 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. doing capacity splitting between borders. This would be a coordinated choice decided at the time it is needed. It is likely to create more adverse flows than today between the Nordic countries and CWE, but only until the enduring solution goes live.

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. Note that it is clearly the “worst case”. Indeed, as explained below, it is probably possible to find a better methodology to build specific ATCs for ITVC. The results on 2x2 weeks in December and January 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[29]. 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, and thus the implication of EMCC (to compute new volumes to be included in CWE order books) and Nord Pool Spot (to compute new Nordic prices so as to evaluate the adverse flows).

4.2.5 Concerning the specific case with CEE

As mentioned in section 4.2.2, there is no incompatibility between on the one hand side CWE MC FB initiative and on the other hand side the CEE initiative. In this context an expert group has been set up within the CEWE FB initiative in order to exchange on a technical level the experiences gained

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 5.9, such as scenarios CWE+UK and CWE+Nordic countries.

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

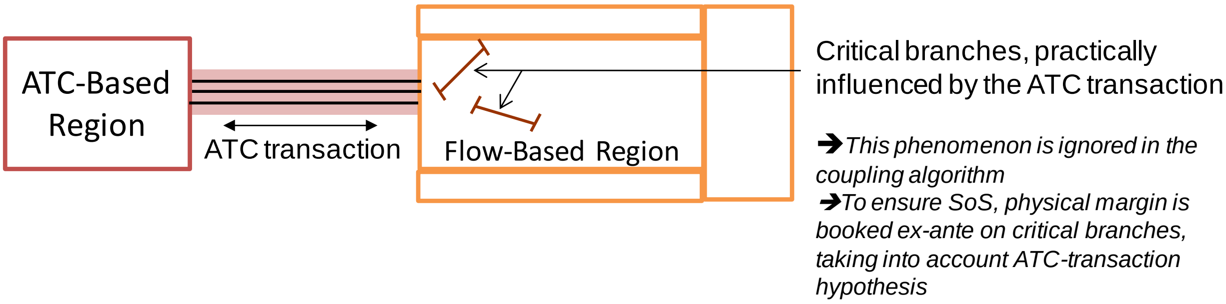
The difficulty in a hybrid model is to take fairly into account the influence of one model over another: if a critical branch is influenced by an ATC transaction (which might be the case in a meshed grid), not taking into account the influence of the ATC transaction on this branch is sub-optimal, since 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.

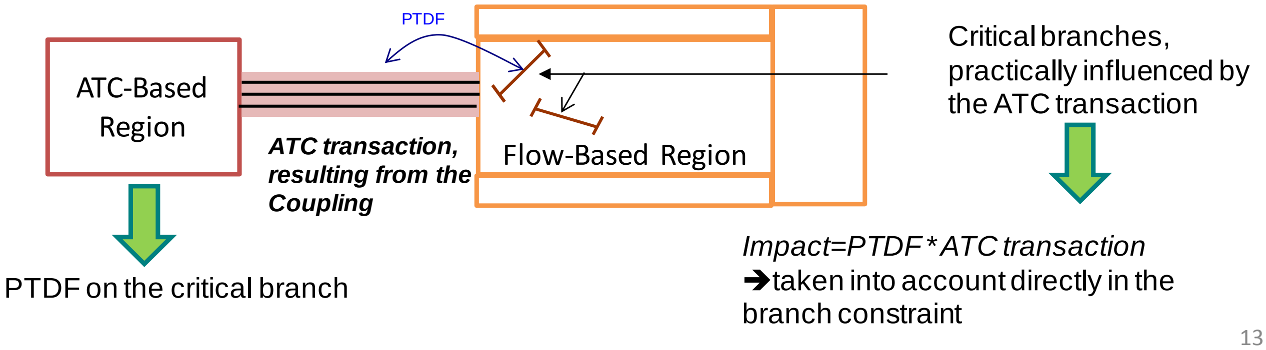
For example, in CWE, it makes a huge difference for the French grid whether to import 2000 MW from the United Kingdom or to export 2000 MW to the United Kingdom. In the capacity calculation process done ahead allocation, TSOs need to take hypothesis on the direction of the FR-UK exchange in order to 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 5.9 and 5.10).

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.



- 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.

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

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:

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

This equation can be summed up into:

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

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:

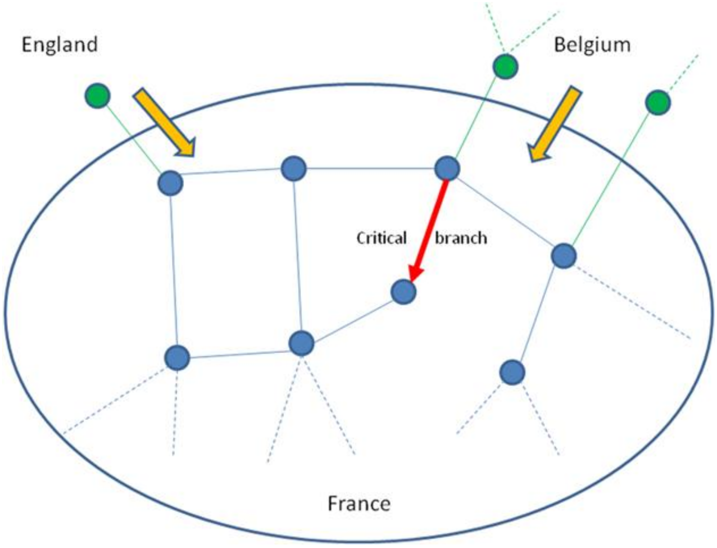
- For ATC transaction in a synchronous area (through AC connections), what is important is the influence of the net position of the area on the FB model (and not the transaction ATC itself): the overall net position of the ATC area is to be considered.
- For ATC transaction on a DC cable, what is important 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[30] to compute the PTDFs of the ATC-based zone)

- **Consequences**

Concerning the "side effects" of the "advanced" approach: the behaviour of ATC borders concerning coupling high level properties changes:

  - There could be <u>different prices on each side of an ATC border whereas the exchange over this border is not equal to the ATC</u>, because the limiting element is a critical branch of the FB model. Figure 41 illustrates this on IFA: the exchange between GB and FR is not limited by the capacity of the ATC but by a critical branch inside the FB area. Let us assume that NL and DE NEX are 0 MW and that the constraint associated to the congested branch is:

    $$NEX(BE)+Exchange(IFA \Rightarrow FR) \leq 2600 \text{ MW}$$

    In this special case, as BE and IFA have the same PTDF (1.0), the BE and GB clearing prices will be equal as long as the exchange on IFA is below 2000 MW. With the raw approach, it would have been

[30] GSK and D2CF are needed for meshed and synchronous areas only.

impossible as a non-null price difference between GB and FR can occur only if IFA is used to full capacity.

- Besides, it also creates a new kind of non-intuitive situations: indeed, whereas in rough hybrid coupling, non-intuitive exchanges on DC cables are impossible, they may appear in advanced hybrid coupling and are not currently solved by the FBIMC version of COSMOS. Figure 42 illustrates this on IFA: the exchange between GB and FR goes from a high price to a low price area. Let us assume that BE and NL NEX are 0 MW and that the constraint associated to the congested branch is:

  $0.1*NEX(FR)- Exchange(IFA \Rightarrow FR) \leq 2700$ MW

  In this situation, the exchange on IFA is created to decrease the congestion on this critical branch, thus destroying welfare, in order to allow the exchange from FR to DE which creates more welfare than the welfare destroyed.

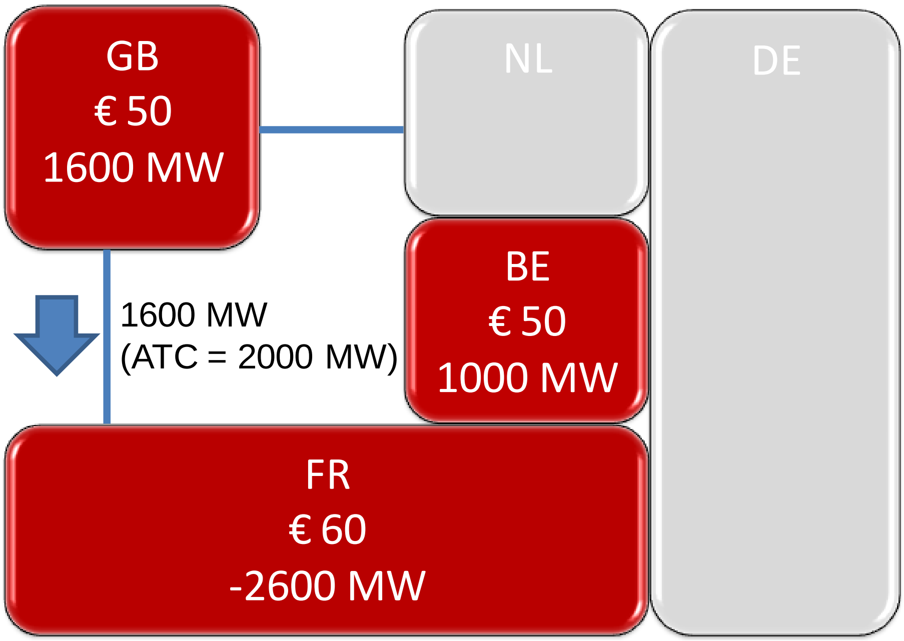


Figure 41: Example of advanced hybrid clearing with a price difference without ATC congestion.

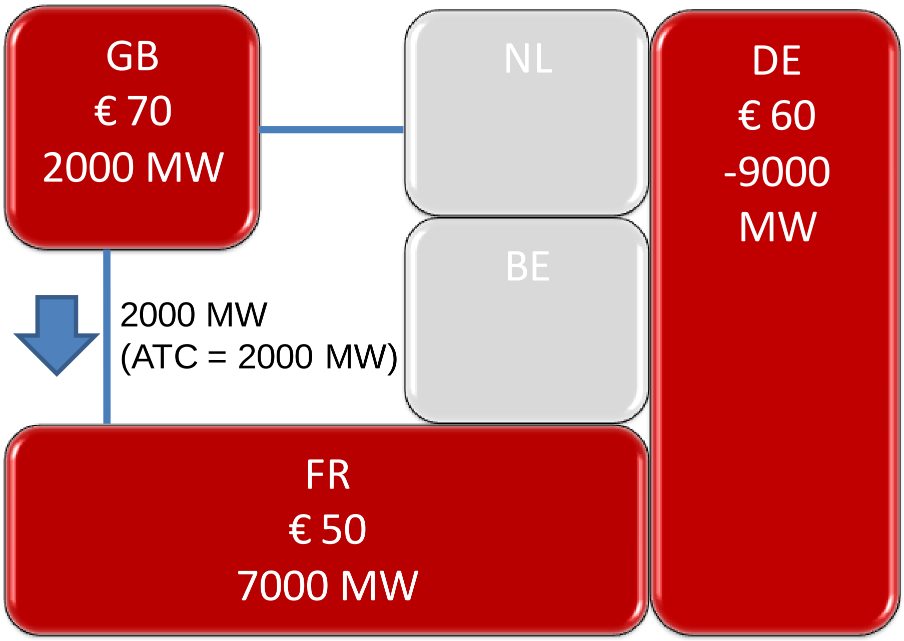


Figure 42: Example of advanced hybrid clearing with non intuitive flow on a DC cable.

4.3.2.2 Feasibility of "advanced" approach:

COSMOS can handle both configurations: the "rough" and the "advanced" one.

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.

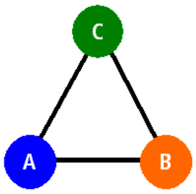
In hybrid coupling combining both ATC and FB constraints, special attention should be paid to the way the influence of ATC transactions on the FB model is taken into account:

- 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).

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 areas: A, B, and C.



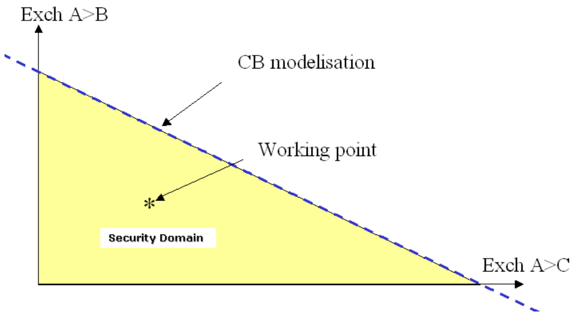
Security of Supply domain (based on 1 critical branch)

If we consider a critical branch in area A where:

- flows are only impacted by the $Exchange_{A \to B}$ and $Exchange_{A \to C}$ 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:

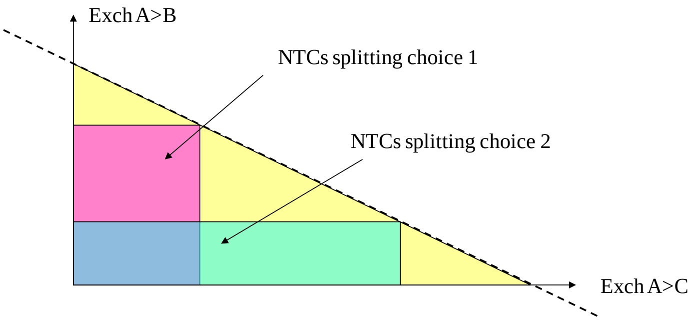
$PTDF_{A \to B} \cdot Exchange_{A \to B} + PTDF_{A \to C} \cdot Exchange_{A \to C} \leq Margin$



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

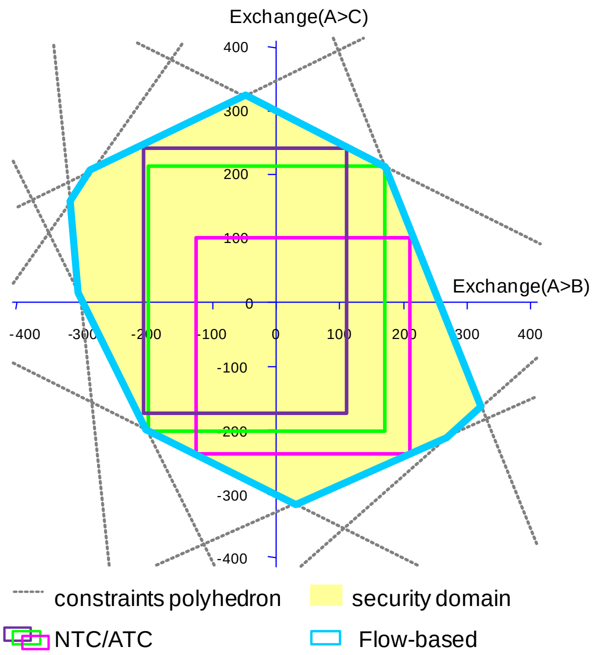
NTC splitting principle (based on a domain defined by 1 critical branch)

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.

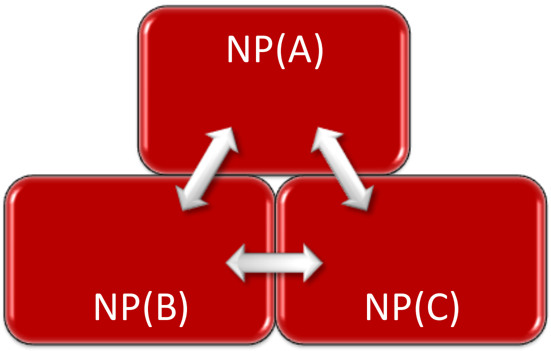


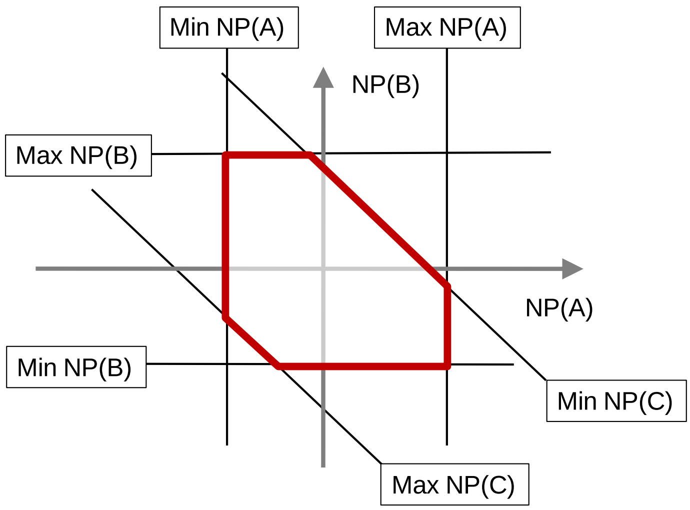
Please note that the FB domain is the SoS domain, whereas the NTC domain is one of the possible choices (of which three have been shown in the figure above) within the FB domain. For a practical figure, the reader is referred to section 2.2.6.

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-area 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-area example, where the sum of the net positions equals zero: NP(A)+NP(B)+NP(C) = 0.





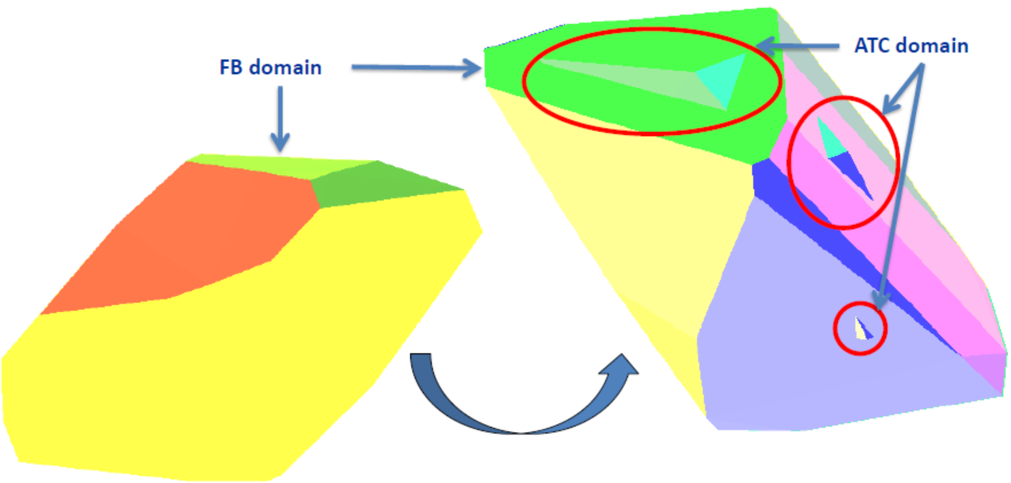
ATC and FB domain for CWE

The FB and ATC domain for the four areas of CWE can be represented as 3-dimensional bodies[31]. In the graph hereunder, both the ATC and FB search space are depicted in the same graph.

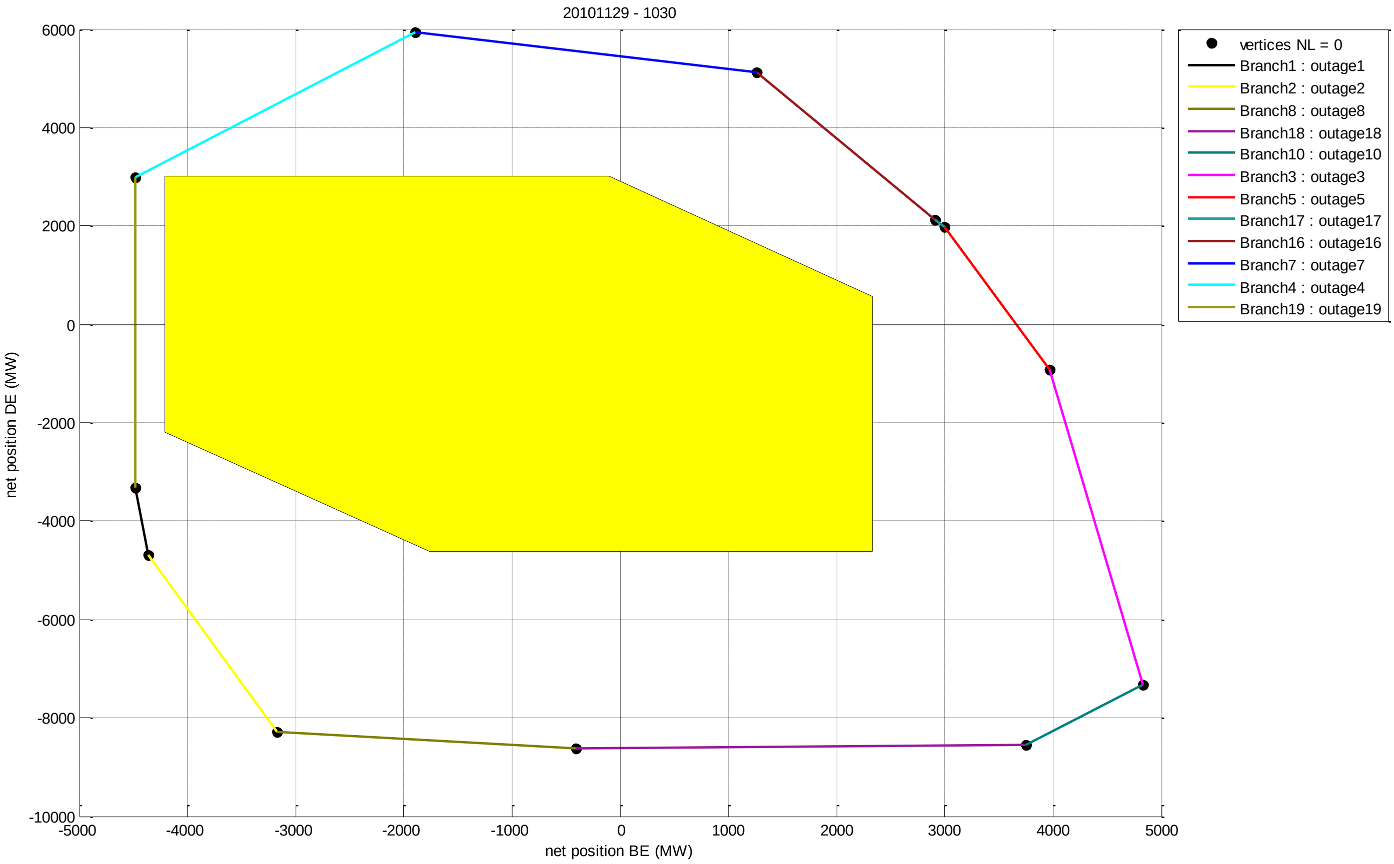
[31] Because the sum of the 4 CWE net positions equals zero, one net position can be written as a combination of the three remaining ones:

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

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.

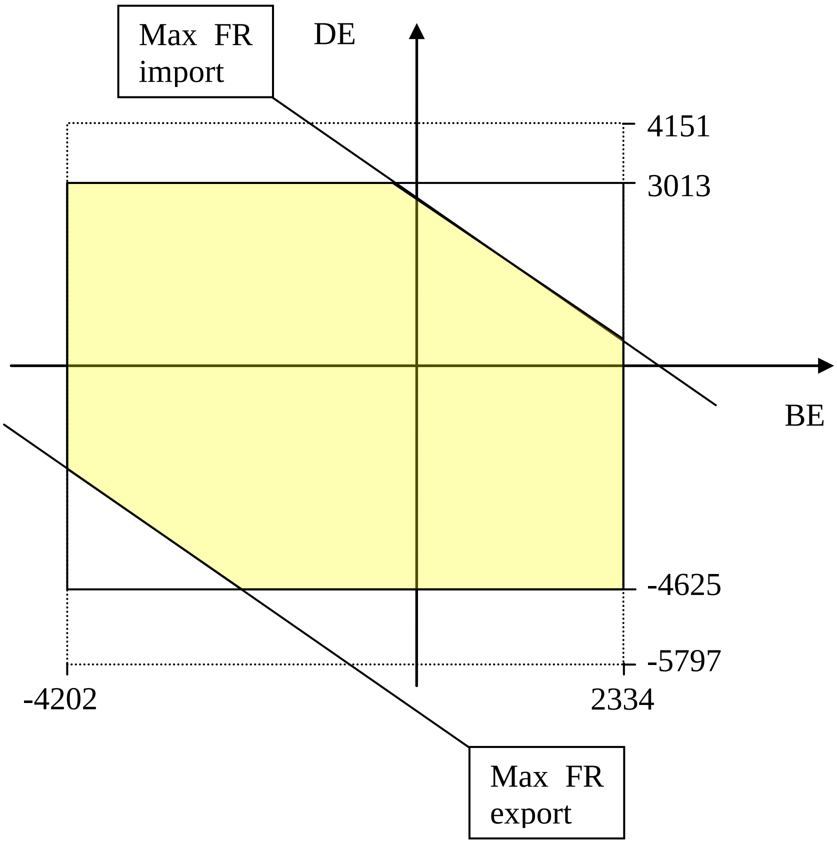
For this day and timestamp the following ATC values applied:

	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.

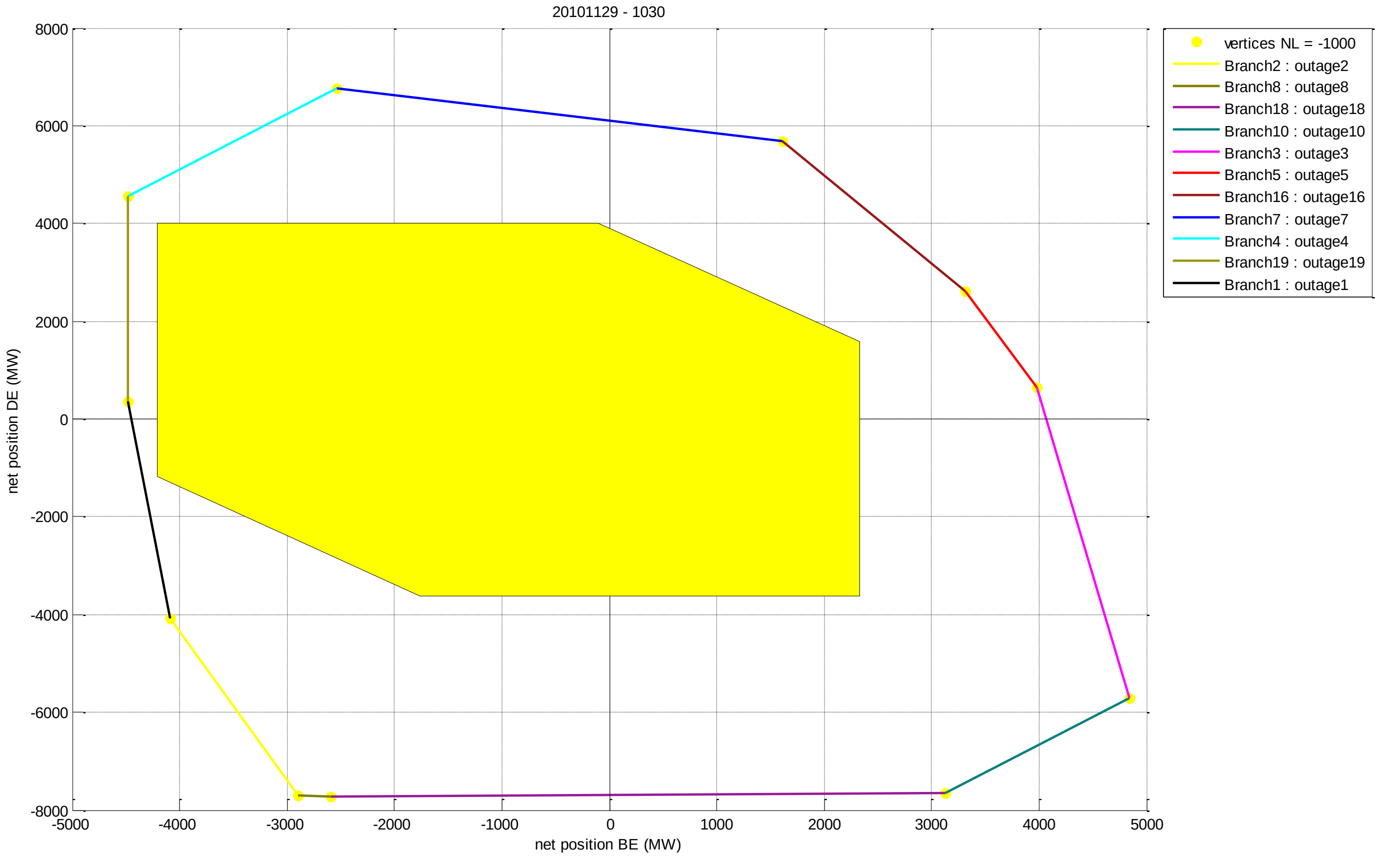
So the figure reduces, as shown by the solid rectangle in the graph above.

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)

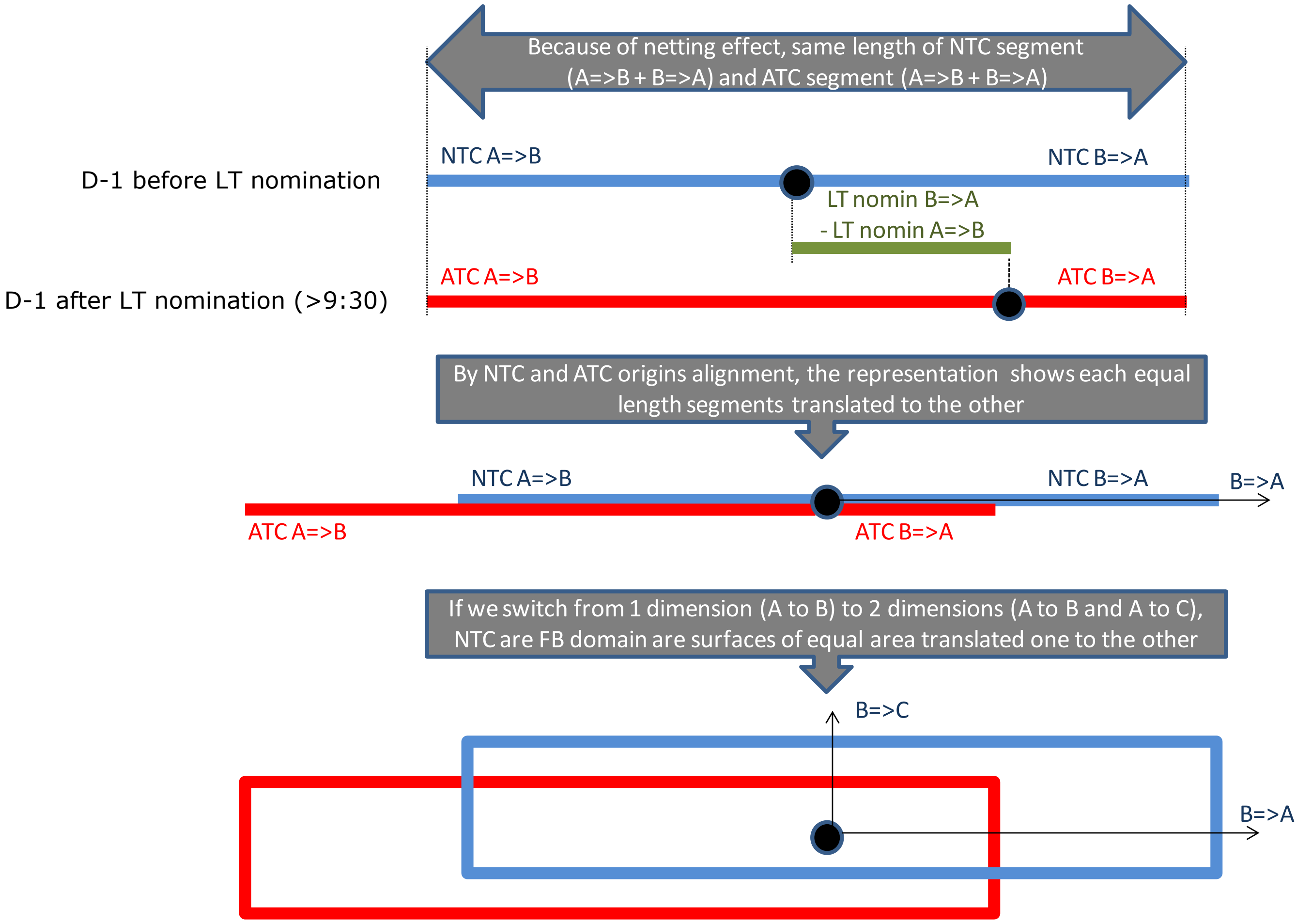
The following figure shows for two bidding areas A and B, that:

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;

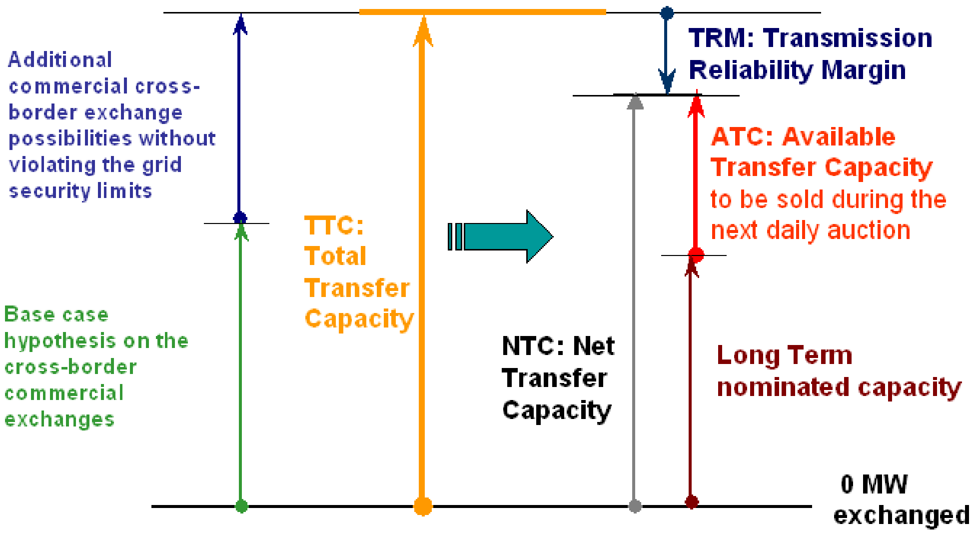
3) extension of the principle described above with three bidding areas (A, B and C).

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).

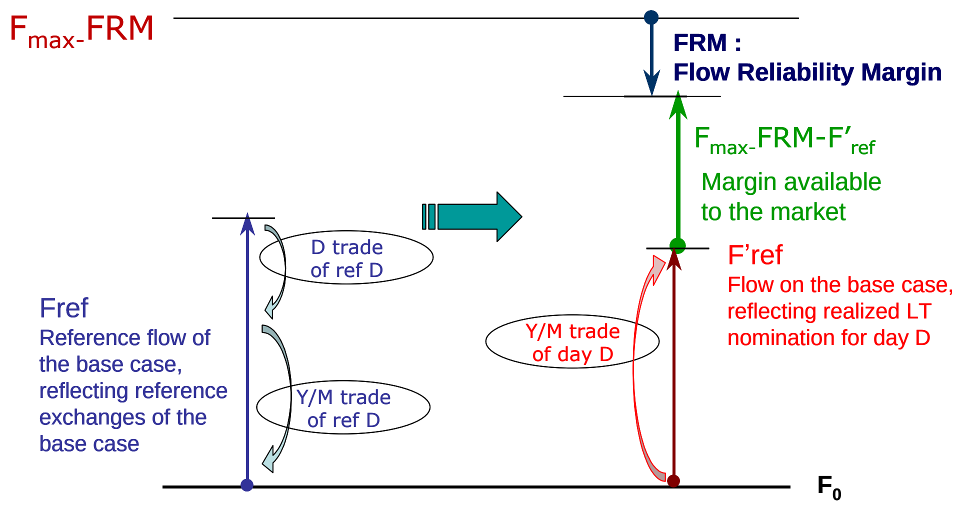


The adjustment of NTC and FB to long-term (yearly and monthly) nominations is represented in the following schemas.

In ATC:



In FB:



Or shown in another way :

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: NEX(BE) ≥ -4500 MW. It can also be written as a matrix expression, similar to that of the FB parameters:

$$[-1,0,0,0]\begin{bmatrix} NEX_{BE} \\ NEX_{DE} \\ NEX_{FR} \\ NEX_{NL} \end{bmatrix} \leq [4500\,\mathrm{MW}]$$

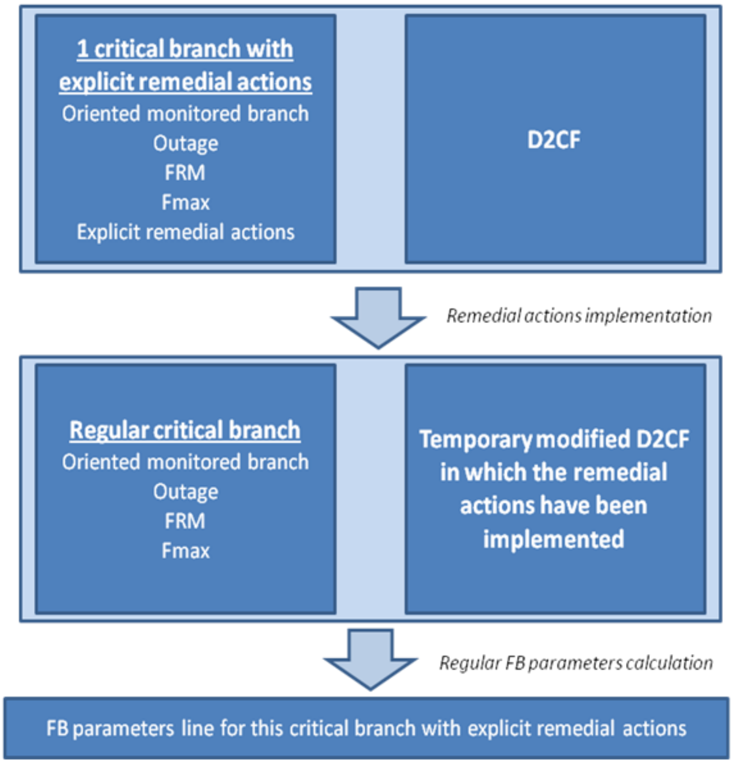
The 4500 MW appears as the available margin, and [-1,0,0,0] as the PTDF coefficients. Adding net position limitations only consists of adding lines to the FB parameters. Note that the net position should be adapted to long term nominations as well.

How the remedial actions are taken into account during FB parameter calculation

Refinement of the FB search space by incorporating the impact of remedial actions can be established in four 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 making explicit each remedial action and associating them to the critical branches or critical outages definition (this allows taking 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:



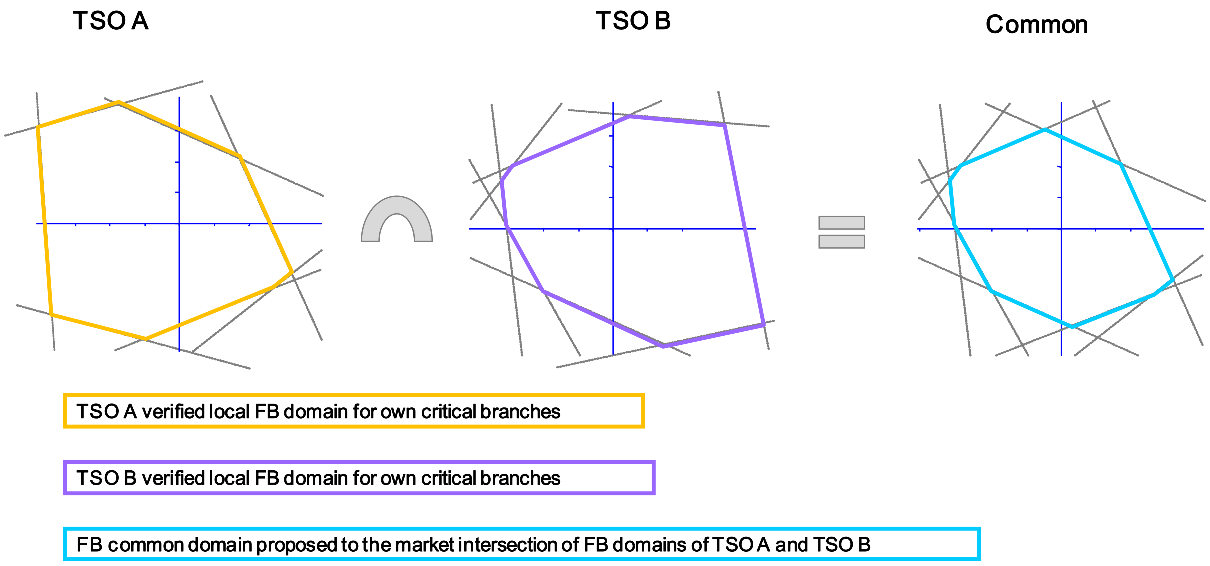
5.4 How the TSO will run D-2 "FB qualification" and "FB verification" without interfering with neighboring TSO's operational timing

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:

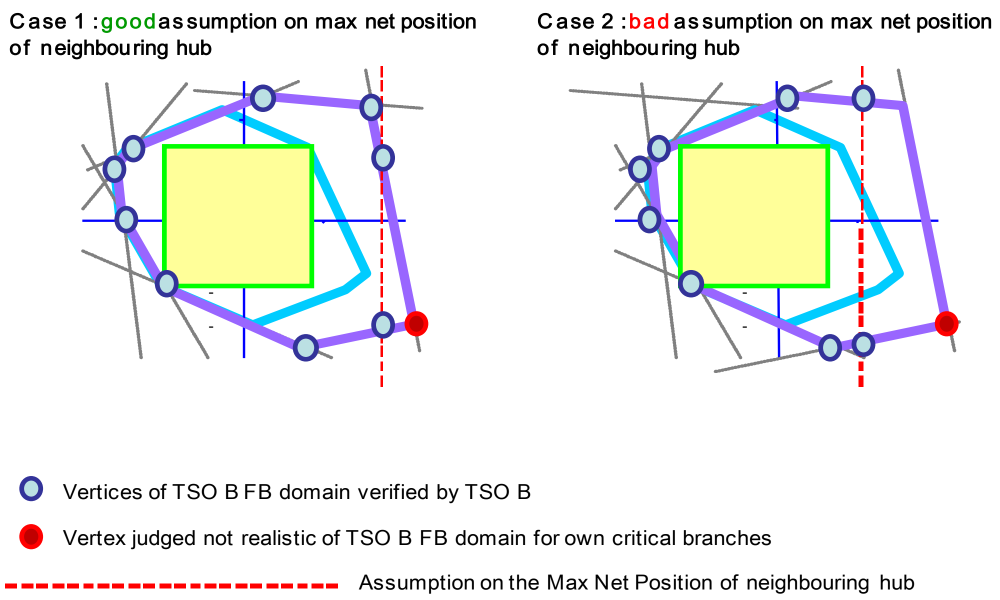


Remark: if by using only the own CBs, in the local FB domain, some vertices seem not to be realistic, then this TSO can:

- 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:



During the experimentation, the verification step has not been systematically tested by TSOs. The practical way of doing these verifications efficiently is still under investigation by most TSOs.

5.5 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 some have already implemented tools 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.

5.6 FRM settlement / model quality study

5.6.1 FRM: methodological introduction

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.

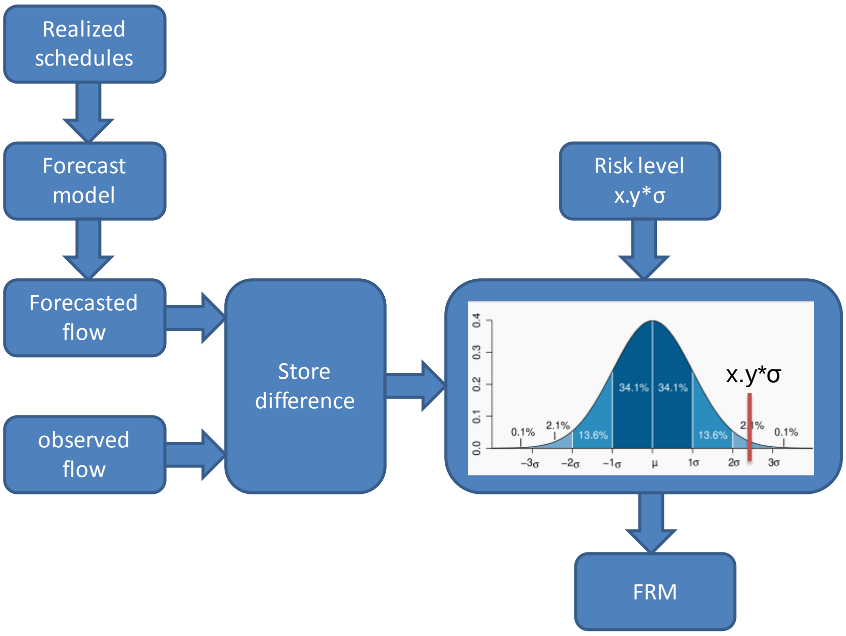
The FRM is a margin taken on the critical branch flow to take into account:

- 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 in principle 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, a practical assumption of an FRM level of 10% of Fmax has been made.

5.6.2 FRM analysis: status update

In July 2011, the TSOs were able to start the FRM analysis

The basis of the FRM analysis is a six months database, covering the period November 2010 up to and including April 2011, consisting of:

- About 3500 SNs per TSO (a 'photo' of the TSOs grid, i.e. a grid model reflecting its timely state) (more than 25 000 SNs in total). The considered timestamps are only HH:30 snapshots.
- About 3500 merged D2CF files
- GSK, CB and realized schedules files

Most of the data is now available, and a computational tool has been developed to run the analysis.

The FB model is determined from the merged D2CF file, as it is done in the normal FB process as well. Note however that the focus in this case is on the PTDF factors and the reference flow (Fref) only, i.e. not the Fmax. This means that the non-automated steps in the normal FB process, such as the qualification and verification, can be skipped for the FRM analysis. This explains why the number of weeks covered by the FRM analysis is and can be larger than the number of weeks covered by the FB experimentation of the corresponding time period.

The reference flow (Fref) is the physical flow computed from the merged D2CF file, and reflects the loading of the critical branches given the exchange programs of the chosen reference day. The reference flow is adjusted to take into account the realized schedules in CWE of the execution day (as such, the FRM analysis is always an ex-post process). The adjustment of the reference flows is performed by using the PTDF factors, as explained in section 2.2.10.

Why do we use the CWE realized schedules to adjust the reference flows of the FB model? As ID trade is not part of the uncertainty linked with the Day-Ahead capacity determination, the impact of ID trade, present in the observed flows (SNs), should be present in the predicted flows (FB model) as well. The realized schedules are the schedules that occurred in real-time, and include the Y/M/D/ID trade. As the realized schedules are the ones being reflected in the flows that we observe in the SNs, taking into account the realized schedules within our predictive (FB) model gives a fair basis to compare the observed and predicted flows (to a certain extent at least, to be explained later on).

By following this approach, the subsequent differences, are covered by the FRM analysis:

- Unintentional flow deviations due to operation of load-frequency controls
- External trade (both trades between CWE and other regions, as well as trades in other regions without CWE being involved)
- Internal trade in each bidding area (i.e. working point of the linear model)
- Wind generation forecast
- Load forecast
- Generation pattern
- Generation Shift (GSK)
- Topology
- Application of a linear grid model

Disclaimer: difference between raw FRMs and future operational FRMs:

> The outcome of the FRM analysis at this moment is raw data, and the step to make it information is a labour intensive and time consuming one. Although the TSOs put a lot of effort in those analyses, it will take another few months to have a stable outcome of the FRM analysis, being a well-considered flow reliability margin per critical branch.

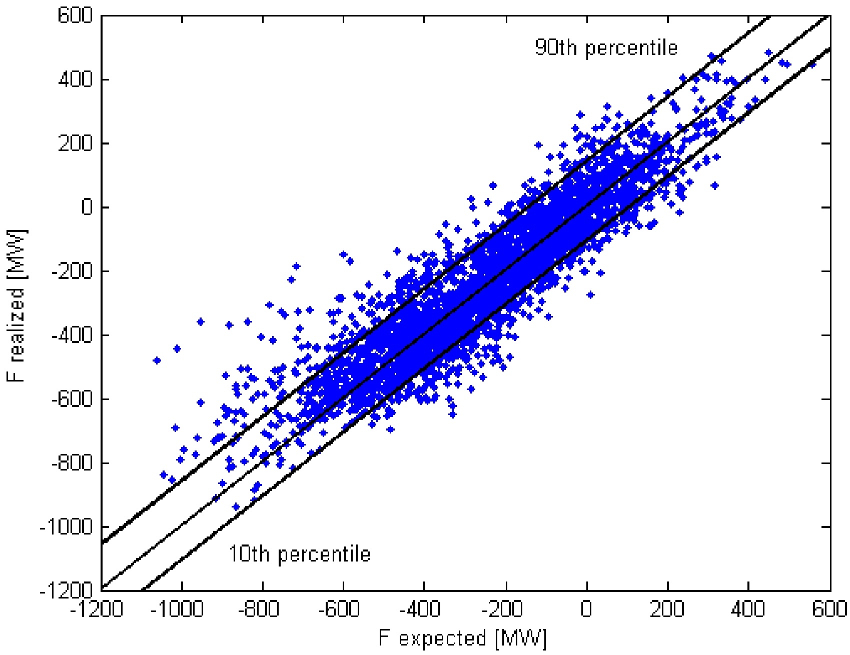
It is evident that the FRM analysis is not a black and white analysis. In the SNs, all effects that the grid is subjected to in real time are reflected; from unforeseen outages, seasonal manoeuvres, topological countermeasures, phase shifting transformer tap changes, tripped power plants, redispatching, temporary unbalances, to weather conditions The comparison between snapshots and FB model encompass some differences which are not real uncertainties but actions which are decided by TSOs. For example PST tap changes are not really an uncertainty since TSOs would not change PST taps if it endangers security. That is why raw FRM results have to be thoroughly analysed in order not to overestimate the FRM values. At the moment CWE TSOs intend to assess the part of the raw FRM which is not a real uncertainty. Another aspect that should be investigated is the clustering of data. The uncertainty that TSOs are faced with for bank holidays is different from the uncertainty on ordinary days. But even between weekdays and weekend days a different level of uncertainty could be expected. In addition, the raw information needs to be put into perspective. For example, a large deviation between forecasted and observed flow is less relevant for a lightly-loaded line than that it is for a highly-loaded one.

5.6.3 FRM analysis: raw data presentation

A first quantitative insight is provided in this section for illustration/demonstration purposes only. Please keep in mind that the figures and the numbers are raw data. All data available, is shown in the figures and the numbers as presented here; no additional analysis has been made and could be made at the time of writing this report.

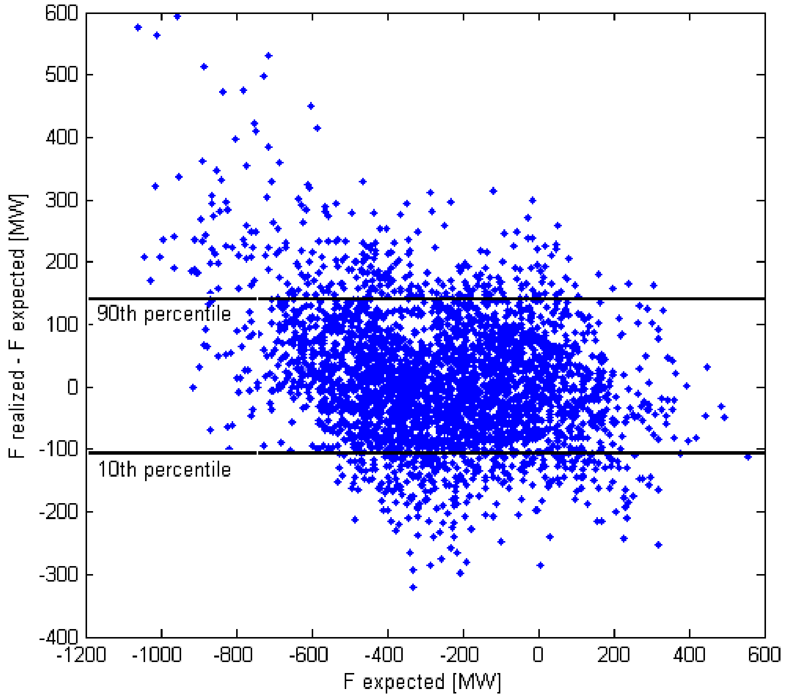
For illustration purposes, we focus on one typical branch, kept anonymous, in this document:

In the graph hereunder, the expected flow on the branch (F expected) is shown on the x-axis, whereas the realized flow (F realized) is shown on the y-axis. The realized flow is the flow observed in the snapshots (SNs). The expected flow is the flow computed from the FB model by taking the CWE realized schedules into account.

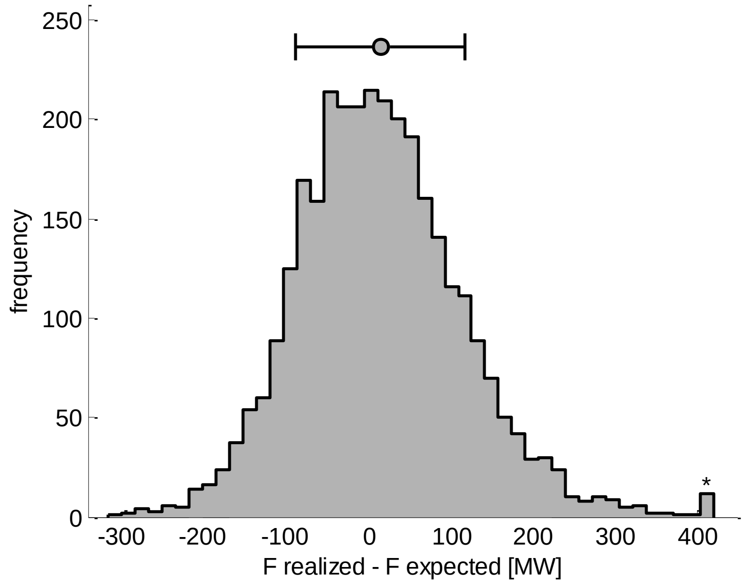


In the graph three black lines are drawn. One line starts in the lower left corner and ends in the upper right one. As the x and y axis have the same scale, this line indicates the one-to-one relation between the expected and the realized flow. It is evident that due to all uncertainties involved, the actual numbers are scattered around this line, represented by the blue dots. The two remaining black lines, labelled with 10^{th} percentile and 90^{th} percentile, indicate the 10% of the blue dots where the difference between the realized and the predicted flow (F realized – F predicted) is the smallest and the largest respectively.

In the graph below, the difference between the realized and the predicted flow (F realized – F predicted) is shown on the y-axis with the expected flow again on the x-axis again. Note however that the scale of the x and y axis are not the same this time. We can see that the flow difference looks independent from the expected flow. This result is important because it is a prerequisite of the FRM concept since FRM computation is based on flow differences whatever the flow. This assumption will have to be checked for all branches. The dangerous situations we want to identify are the ones where the flow differences get higher when the flow is close to the maximum flow, which corresponds to the bottom-left and top-right corners on the graph.



The distribution of the difference between the realized and the predicted flow (F realized – F predicted) is shown in the graph below.



We can see from the distribution that there is a tail on the right side, where some larger differences occur. The asterisk above the last bar on the right indicates that there is a tail that exceeds the values currently displayed on the x-axis; the total number of cases for which this applies is represented by the height of the bar. The mean, indicated by the circle above the distribution, is close to zero. The two vertical lines next to the circle above the distribution indicate the standard deviations.

The descriptive statistics are shown in the table hereunder.

Descriptive statistics	**Value**
Number of data points	3129[32]
Mean of the difference (F realized – F predicted)	13.57 [MW]
Median of the difference (F realized – F predicted)	6.46 [MW]
Standard deviation of the difference (F realized – F predicted)	103.31 [MW]
90th percentile of the difference (F realized – F predicted)	141.27 [MW]
90th percentile of the difference (F realized – F predicted)/Fmax	0.09
95th percentile of the difference (F realized – F predicted)	188.46 [MW]
95th percentile of the difference (F realized – F predicted)/Fmax	0.12

We can see from the table that the values of the median and the mean are close to one another and close to zero, indicating roughly that the distribution is approximately a centered one without too much offset (as can be observed from the distribution in the graph as well).

The value of the 90th percentile of the difference (F realized – F predicted) indicates that 10% of the values is higher than 141.27 MW. In relative terms, which is the default way to express an FRM value, this 90th percentile corresponds to roughly 9% of the Fmax (the maximum allowed flow on the critical branch).

CWE TSOs have not yet decided which risk level they will choose. Note that risk as input in FRM computation and real risk level maybe two different things. It mainly depends on the physical and financial consequences of the cases where the flow difference is actually higher than the FRM. The impact may be low when there are non costly remedial actions at hand, but it may also be high when only limited and costly remedial actions are at hand.

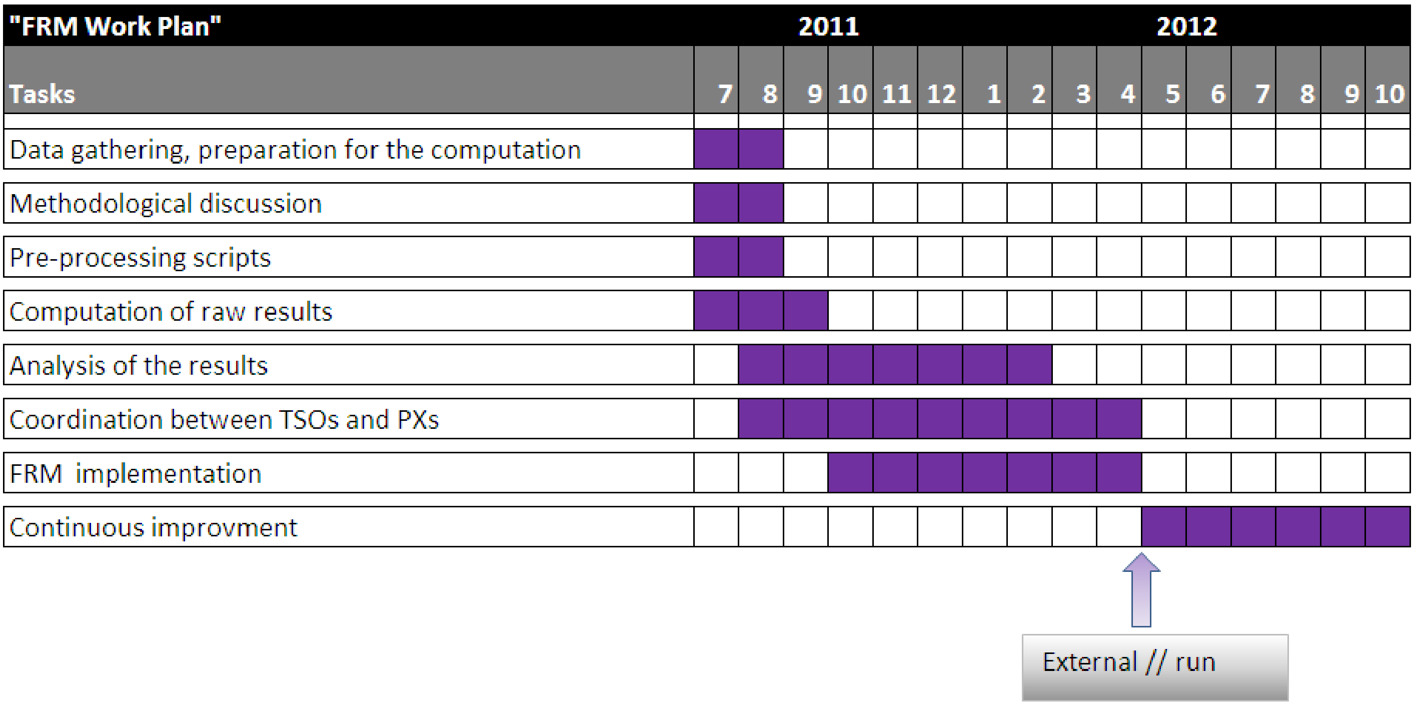
5.6.4 Conclusion and next steps

CWE TSOs are now engaged in a thorough study in order to implement FRM values in their FB operational process; this will guarantee the quality, stability and safety of the FB approach CWE TSO propose to put in place. As expressed in the section above, the reasons why this FRM settlement phase represents a significant workload are threefold:

- On the one hand, the amount of data to process in order to compute raw data only is very heavy.
- On the second hand, raw data will then have to be analyzed in order to extract valuable information.
- Finally, CWE TSOs will have to adjust their operational process in order to integrate the FRM values. For this reason, FRM implementation implies a significant effort from TSOs on the operational side.
- The assumption regarding the FRM values used during the experimentation phase has to be fine-tuned. Operational FRM values have to be defined in order to validate the results presented in this report (in terms of capacity and market results).

In this framework, CWE TSOs propose the following roadmap in order to define and implement operational FRM.

[32] We can only compute flow differences when we have both D2CF and snapshots, and some are missing. That is why we have less observations than the total number of hours.



The main features of this workplan are the following:

- The target for FRM implementation is May 2012, that is the launch of the external parallel run
- FRM definition and implementation will be carried out by TSOs, but in coordination with Power Exchanges within dedicated workstreams of the CWE FB project.
- After implementation, FB results will be closely monitored. Especially, data quality improvements will be investigated. To this respect, FRM values are assumed to be reliable quantitative indicators.

5.7 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.

5.7.1 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.

5.7.2 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.

5.7.3 Elia

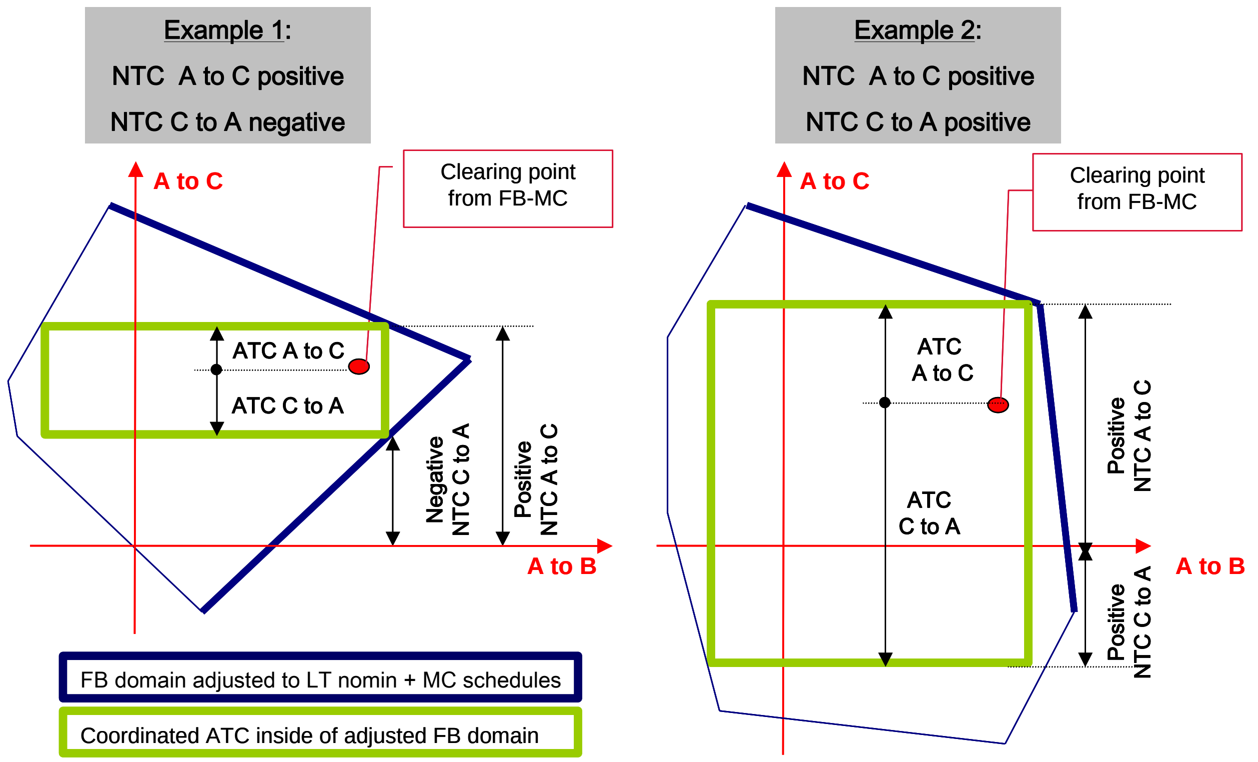
Elia includes in its GSK all flexible and controllable generation units connected to its grid. As their behaviour is different from other classical units, nuclear power plants and pump stations are excluded from this GSK. As a consequence, the GSK of Elia only includes classical generation units connected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

5.7.4 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.

5.8 Calculation of ID ATC and not ID NTC

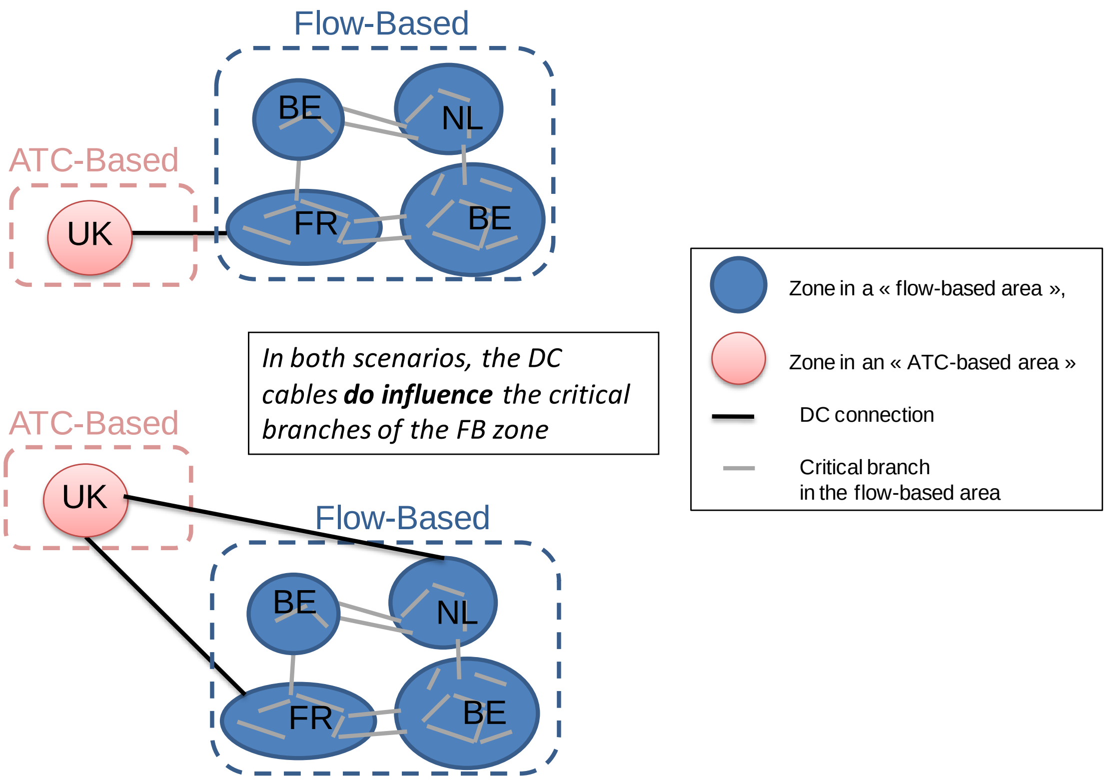
After switching to FB in D-1, ID ATCs are computed and not ID NTCs (since in some cases it would lead to negative NTCs, as illustrated in the figures below). This is the consequence of giving the whole implicit FB domain to the market in D-1, including possible areas that cannot be reached by any set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



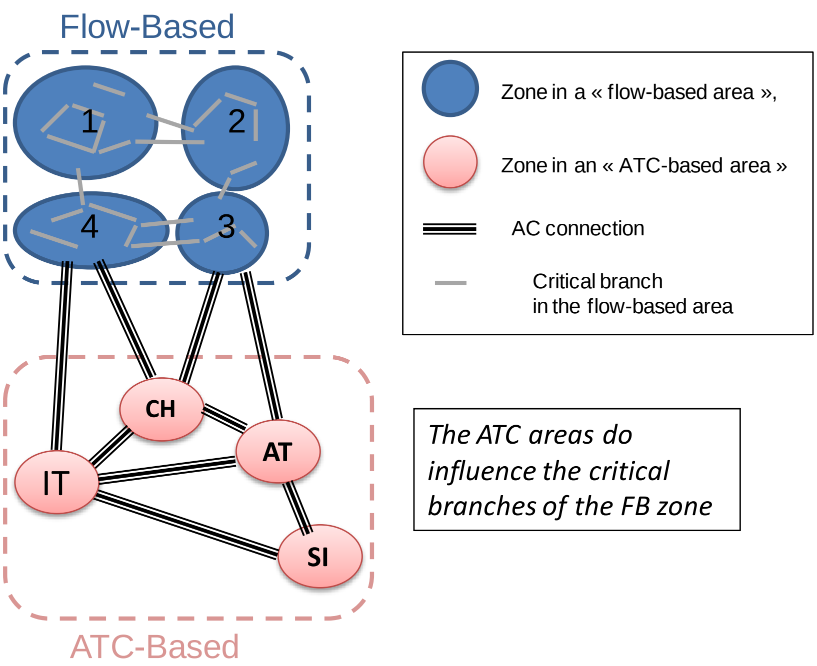
5.9 Elementary scenarios of coupling to other initiatives

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.

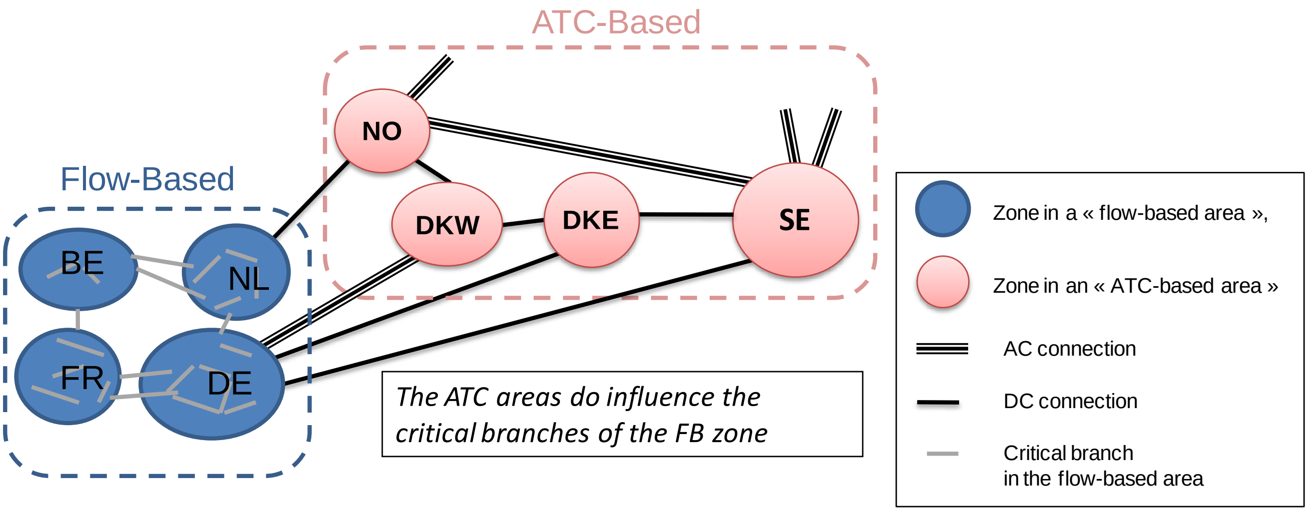
5.9.1 CWE+UK (FB area + ATC area with DC cables)



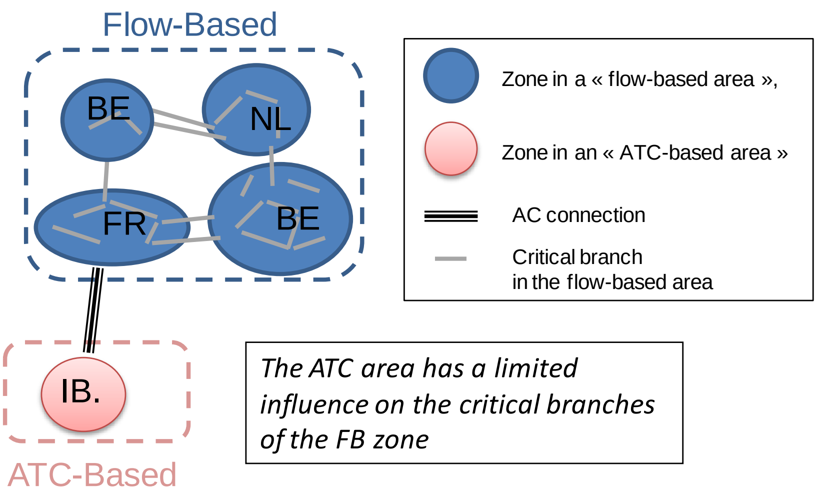
5.9.2 CWE+CSE (FB area + ATC area with AC connection)



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



5.9.4 CWE+Iberian peninsula



5.10 What is the “advanced” hybrid ATC FB price coupling: Examples

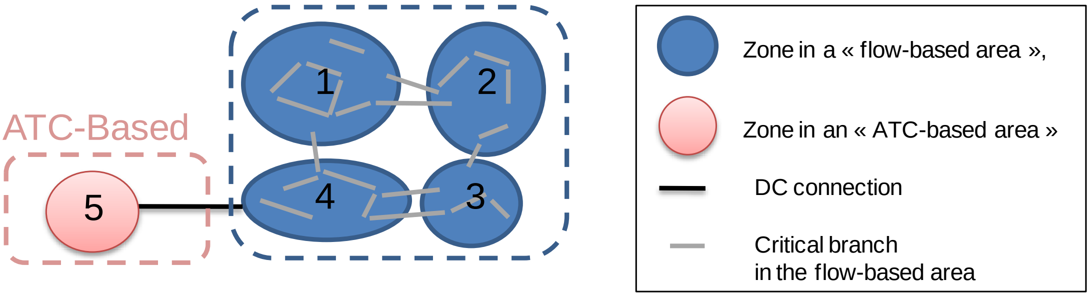
The annex details the approach of “advanced” hybrid ATC FB price coupling. For the sake of clarity, we will detail three examples:

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.

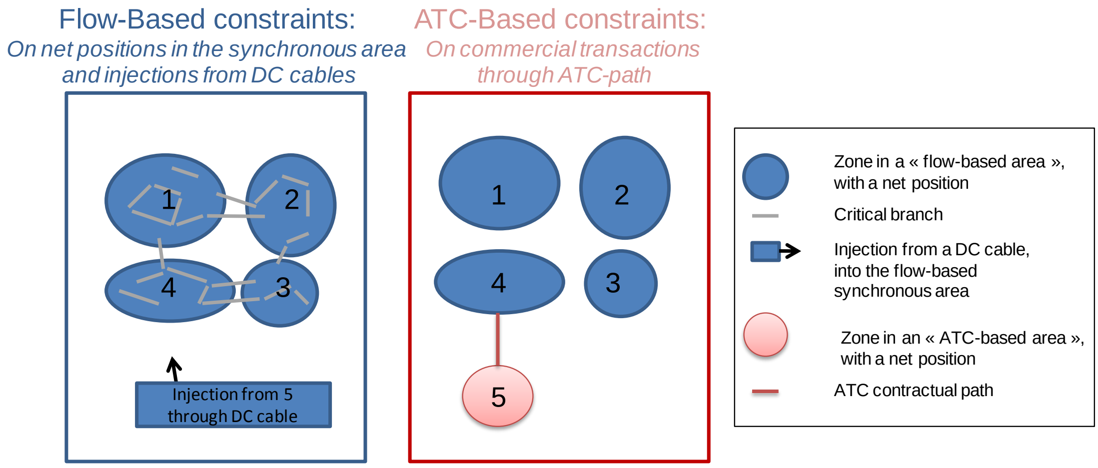
An introduction to the “advanced” hybrid ATC-FB price coupling method is given in section 4.3.2.

5.10.1 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:**

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

- **Flow-Based constraints:**

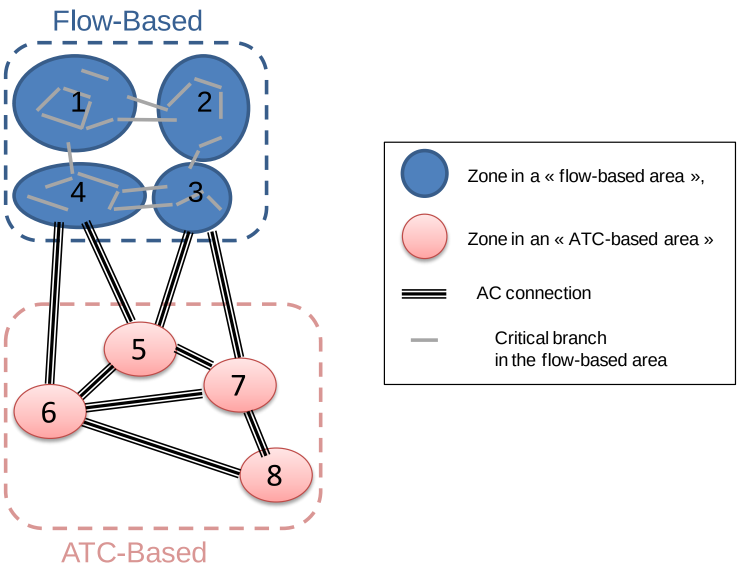
$$\sum_{A=1,2,3} \text{PTDF}_A^k \cdot \text{NEX}_A^{FB} + \text{PTDF}_4^k \cdot (\text{NEX}_4^{FB} + \text{Exchange}_{5\to 4})$$

$$+ \text{PTDF}_{cable5\to 4}^k \cdot \text{Exchange}_{5\to 4} \leq \text{RAM}^k$$

- **ATC-based constraints:**

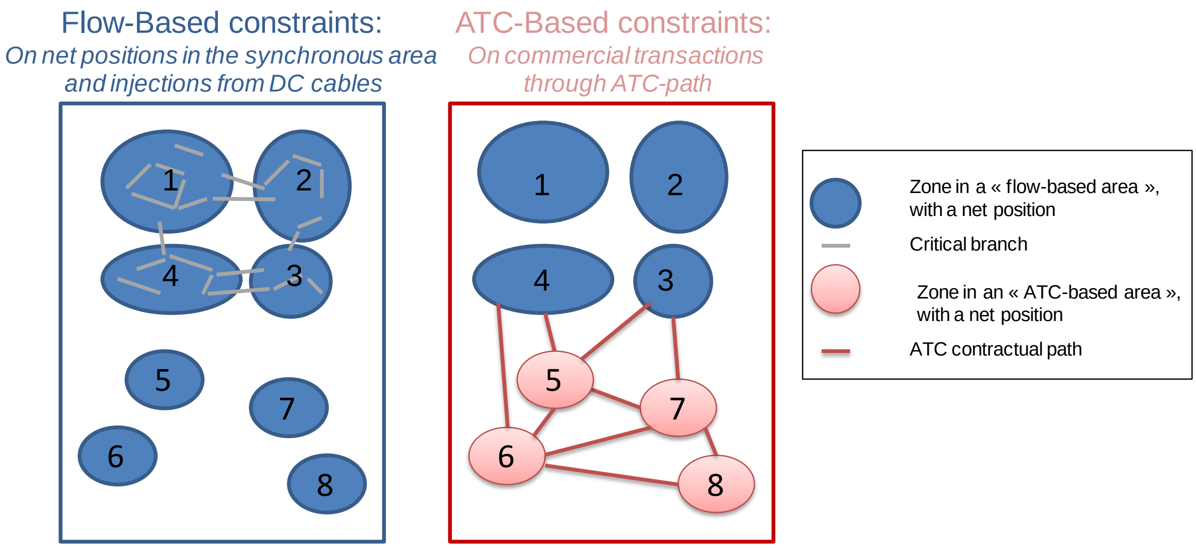
$$\text{ATC}_{5\to 4}^{DOWN} \leq \text{Exchange}_{5\to 4} \leq \text{ATC}_{5\to 4}^{UP}$$

5.10.2 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**

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

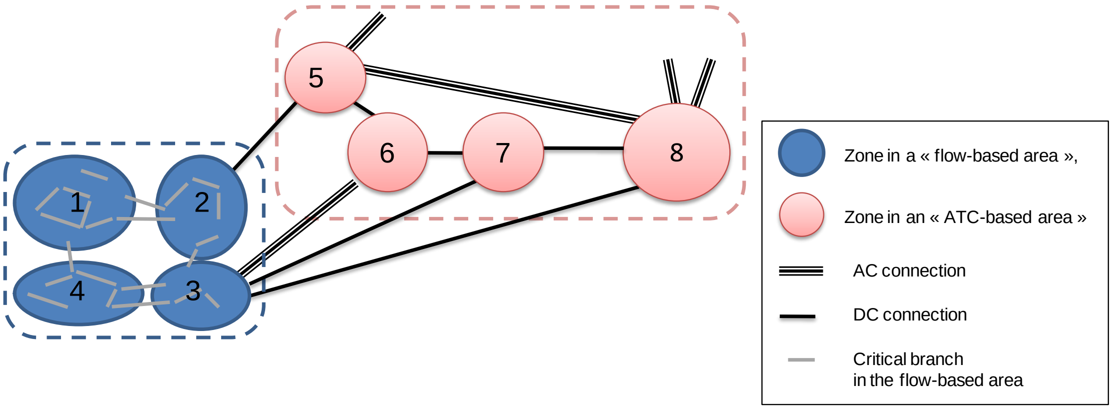
- **Flow-Based constraints**

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

- **ATC-based constraints:**

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

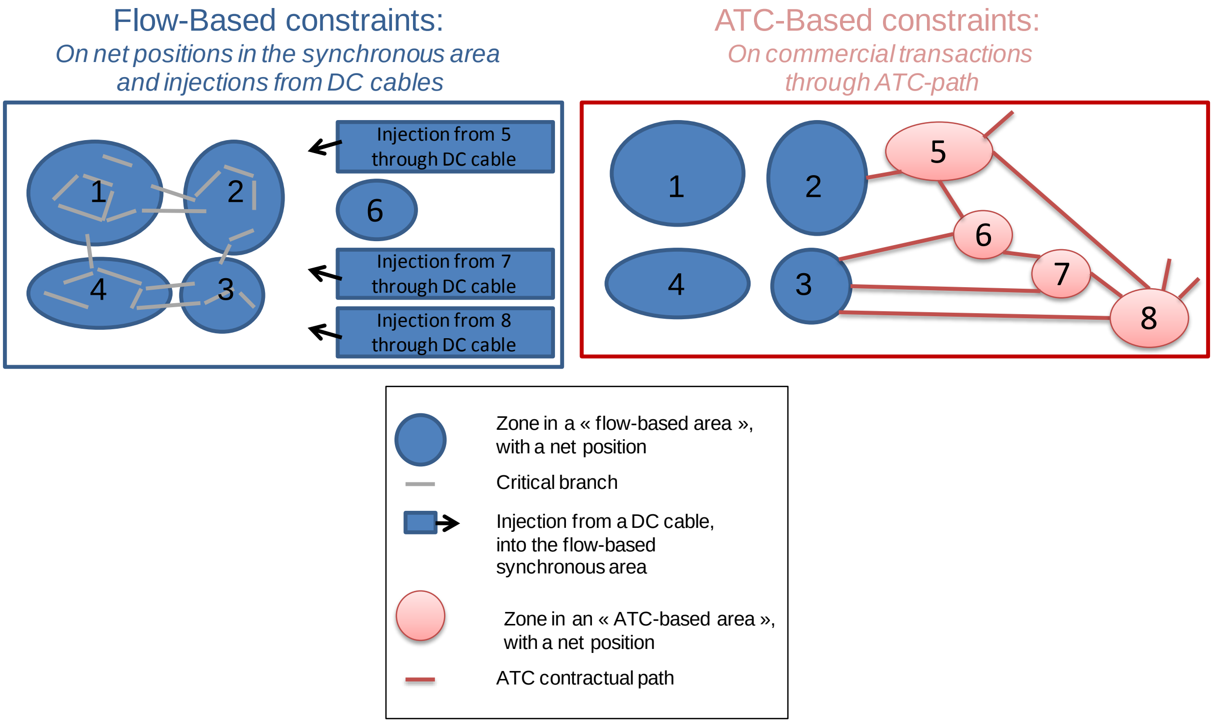
5.10.3 A FB area connected with an ATC-based area, with both AC and DC cable (CWE+Nordic countries)



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:

$$\begin{cases} \text{For A} = 1{,}4: \text{sale}_A - \text{purchase}_A = \text{NEX}_A^{FB} \\ \text{sale}_2 - \text{purchase}_2 = \text{NEX}_2^{FB} + \text{Exchange}_{\text{DC Cable}5\to2} \\ \text{sale}_3 - \text{purchase}_3 = \text{NEX}_3^{FB} + \text{Exchange}_{6\to3} + \text{Exchange}_{\text{DC Cable}7\to3} + \text{Exchange}_{\text{DC Cable}8\to3} \\ \text{For A} = 5{,}6{,}7{,}8: \\ \text{Sale}_A - \text{Purchase}_A = \sum_{I\neq A} \text{Exchange}_{A\to I} \end{cases}$$

- Flow-Based constraints

$$\begin{aligned} &\sum_{A=1,4} \text{PTDF}_A^k \cdot \text{NEX}_A^{FB} \\ &+ \text{PTDF}_2^k \cdot (\text{NEX}_2^{FB} + \text{Exchange}_{\text{DC Cable}5\to2}) \\ &+ \text{PTDF}_3^k \cdot (\text{NEX}_3^{FB} + \text{Exchange}_{6\to3} + \text{Exchange}_{\text{DC Cable}7\to3} + \text{Exchange}_{\text{DC Cable}8\to3}) \\ &+ \text{PTDF}_6^k \cdot (\sum_{I\neq6} \text{Exchange}_{6\to I}) \\ &+ \text{PTDF}_{\text{Cable}5\to2}^k \cdot \text{Exchange}_{\text{DC Cable}5\to2} + \text{PTDF}_{\text{Cable}7\to3}^k \cdot \text{Exchange}_{\text{DC Cable}7\to3} + \text{PTDF}_{\text{Cable}8\to3}^k \cdot \text{Exchange}_{\text{DC Cable}8\to3} \\ &\leq \text{RAM}^k \end{aligned}$$

- ATC-based constraints:

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

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

5.11 Market clearing algorithm

Here is a presentation of a simplified market clearing problem in order to illustrate the difference between infinite capacity MC, ATCMC, FBMC, and FBIMC.

5.11.1 Infinite capacity market coupling

Notations:

$z \in Z$: A bidding area z among the bidding areas Z

$b \in B$: A bidder b among the bidders B.

Parameters:

$\left(Q_b^z, P_b^z\right)$: The bid of bidder b in area z. The quantity Q_b^z (in MW) is negative if it is a supply bid and positive if it is a demand bid. The price is P_b^z in €/MW.

Variables:

x_b^z : The accepted proportion of the bid b, between 0 and 1.

nex_z : The net exchange position of the bidding area z in MW. It is positive if the bidding area is exporting.

Objective:

The objective is to maximize the DAMW (in €):

$$\max_{x_b^z} \sum_{z \in Z} \sum_{b \in B} Q_b^z \cdot P_b^z \cdot x_b^z$$

Constraints:

The balancing constraints imposes that what is supplied is equal to what is bought.

$$\sum_{z \in Z} nex_z = 0$$

Where:

$$nex_z + \sum_{b \in B} Q_b^z \cdot x_b^z = 0 \qquad \forall z \in Z$$

5.11.2 ATC market coupling

In ATC MC, the following variables and constraints are added to the infinite capacity model:

Parameters:

$\mathrm{NTC}^{z1,z2}$: The NTC (maximum allowable exchange) from z1 to z2 in MW.

Variables:

$E^{z1,z2}$: The exchange from z1 to z2, between 0 and $\mathrm{NTC}^{z1,z2}$ in MW

Constraints:

Exchange decomposition:

$$nex_z + \sum_{z' \in Z} E^{z',z} - E^{z,z'} = 0 \qquad \forall z \in Z$$

5.11.3 FB market coupling

In FB MC, the following constraints are added to the infinite capacity model:

Notations:

$l \in L$: A critical branch l among the critical branches L

Parameters:

$PTDF_l^z$: The PTDF of bidding area z on the critical branch l

RAM_l : The remaining available margin on the critical branch l in MW

Constraints:

$$\sum_{z \in Z} PTDF_l^z \cdot nex_z \leq RAM_l \qquad \forall l \in L$$

When such constraint is active, i.e. when a congestion occurs, the price in each area is directly linked to the constraint's PTDFs. In particular, the price in 2 different areas is equal only if the PTDFs of the 2 areas are equal. As it is unlikely to occur, partial convergence is unlikely to occur in FBMC.

5.11.4 FBI market coupling

5.11.5 Theoretical model

Formally, in FBI MC, the following constraints should be added to the FB model:

Variables:

π^z : The clearing price in the bidding area z in €

$E^{z1,z2}$: The exchange from z1 to z2, larger than 0

Constraints:

Exchange decomposition:

$$nex_z + \sum_{z' \in Z} E^{z',z} - E^{z,z'} = 0 \qquad \forall z \in Z$$

Source to sink intuitiveness constraints:

$$E^{z1,z2}\left(\pi^{z2} - \pi^{z1}\right) \geq 0 \qquad \forall z1 \in Z, z2 \in Z$$

(In other words, exchanges go from low price areas to high price areas)

On top of these constraints, bilateral intuitiveness constraints can be modeled as:

$$\text{No physical connection between z1 and z2} \Leftrightarrow E^{z1,z2} = 0$$

5.11.6 Implementation

However, COSMOS does not directly implement the theoretical model. Instead, it uses the following scheme:

- Solve the FB model.
- If the solution is intuitive, then OK, else mark the congested branches as 'active' and go to next step.
- Try to find the best possible set of positive ATCs :
    - Apply the 'intuitive patch' (see below) to 'active' branches and solve the updated model.

- If the solution is intuitive, then OK, else mark the new congested branches as 'active' and go back to the previous step.

The 'intuitive patch' consists in the following constraints:

Variables:

$E^{z1,z2}$: The exchange from z1 to z2, larger than 0.

Constraints:

For 'ordinary' branches, the 'ordinary' FB constraint:

$$\sum_{z \in Z} PTDF_l^z \cdot nex_z \leq RAM_l$$

For 'active' branches, the 'intuitive' FB constraint:

$$\sum_{\substack{z1 \in Z \\ z2 \in Z}} E^{z1,z2} \max\left(0, PTDF_l^{z2} - PTDF_l^{z1}\right) \leq RAM_l$$

To understand the link between the 2 FB constraints, note that the 'ordinary' FB constraint can also be written:

$$\sum_{\substack{z1 \in Z \\ z2 \in Z}} E^{z1,z2} \left(PTDF_l^{z2} - PTDF_l^{z1}\right) \leq RAM_l$$

It shows that the only difference between both is that the 'intuitive' FB constraint does not take into account the 'counter-exchanges associated with a negative PTDF difference to compute the flow on the critical branch.

The implementation of bilateral intuitiveness in COSMOS would mean that the following constraints are added:

$$\text{No physical connection between z1 and z2} \Leftrightarrow E^{z1,z2} = 0$$

Finally, on the one hand, COSMOS FBMC implementation is a heuristic that provides good guarantees on the quality of the results because:

- It would converge to the theoretical optimum if given enough time;
- It provides an upper bound of the error made when stopped after a limited time.

On the other hand, COSMOS FBIMC implementation is a heuristic that provides fewer guarantees on the quality of the result because:

- It does not necessarily converge to the optimum, even with infinite time;
- It does not give an estimate of the error made.

However, as the FBMC DAMW is an upper bound of the FBIMC DAMW and as the simulations showed a reasonable gap between both welfares, the quality of the heuristic is estimated to be satisfactory.

5.12 Some elements on downgraded modes

Disclaimer: please note that the timings given below are only indicative, and may change during implementation of the FB approach.

5.12.1 Back-up modes

In order to cope with minor incidents, back-up principles have been defined by the CWE TSOs. They are classified in four main categories:

Back-up type	Principles of actions
Missing mandatory files at target time	e-mail manual transmission
Sending failure from the TCS	e-mail manual transmission
Receive an updated file before the process is launched	put the process on hold and send by e-mail
Uncomplete subprocess at check point	organization of a coordination call

Timings			
D-2		D-1	
Target time	7:00 PM	Target time	9:30 AM
Check point	8:30 PM	Check point	10:00 AM
Critical end	9:30 AM D-1	Critical end	11:10 AM

Naturally, these principles are thoroughly described in dedicated operational procedures

5.12.2 Fall-back modes

This section describes briefly the principles of actions in case of serious events affecting the FB process:

- a D-2 system restart is needed
- severe problems with the TSO CS
- fallback values should be used if one or more files are missing

As in previous section, it is proposed to categorize fall-back situations in different types:

Fall-back type	Principles of actions
A : Missing / corrupted input data	Deploy replacement strategy
B : Missing LTnom data	Manual e-mail sending
C : Impossibility to compute FB parameters	Use of "replacement capacity constraints"

Timings			
D-2		D-1	
Target time	7:00 PM	Target time	9:30 AM
Check point	8:30 PM	Check point	10:00 AM
Critical end	9:30 AM D-1	Critical end	11:10 AM

The situations are also addressed in exhaustive operational procedures, however some explanations on fall-back strategies are proposed here:

A_Missing or corrupted input data:
If input files (mainly D2CF) are missing or corrupted, and according to the gravity of the corruption, TSO can either:

- replace the missing/corrupted file by another
- extrapolate the FB parameters which should be based on missing data from the calculated ones by using a "span" function.

B_Missing LTnom data:
As in the BU described above, the principle here is to perform manual sending of LTnom. This operation is more critical since, LTnom being the last set of data the FB domain definition, there is little time available.

Since there is no new reference point in the capacity domain, missing LTnom in FB lead to the impossibility of computing FB parameters.

C_Impossibility to compute FB parameters:
In case strategies A or B above do not succeed, TSO will have to submit replacement capacity constraints. Several possibilities are considered today, but basically they consist either in using:

- c1 : locally defined FB parameters
- c1': default FB parameters
- c2: locally defined NTC
- c2': default ATC

The feasibility and effectiveness (in terms of SoS and market impact) of these options are currently under investigations by the project partners. It is possible that according to the situation a given fall back strategy (or a combination of several) would be more adequate: for instance if a single TSO is not able to submit its D2CF file (which prevents the creation of a common base case), then strategy c1 may be appropriate. If we are in a situation of failure of FB parameters computation within the common tool, then strategy c1’ may be more useful. Strategies c2 and c2’ may be seen as “roll back” options. They seem straightforward but require that the PX’ MCS is able to switch to ATC MC in real time (under investigation today).

5.12.3 Short note on decoupling

As in ATC MC, the fall-back in this situation is the running of shadow auctions. The process will be the same as today, but requires that the TSO CS sends ATC to CASC. It is already foreseen that the TSO CS will compute a set of daily ATCs deduced from the FB domain, however the exact methodology to do so (as a matter of fact there is an infinity of “ATC domain”, i.e. of split of capacity, included in a FB one) is currently under investigation by TSOs.