Taking power further

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Determining securely available cross-border transmission capacity within Flow-based

Introductory remarks

TenneT and the other TSOs in the North West Europe region (NWE: Austria, Benelux, France, Germany, the UK, the Baltic states and the Nordics) with their coupled markets daily determine the maximum securely available cross-border transmission capacities and release them onto the European market. Market players are then free to enter into transactions on international energy exchanges within these pre-determined cross-border capacities.

Assessing the available cross-border capacities by the TSOs is a matter of coordination with respect to facilitating international markets to the greatest extent within the limits of secure and reliable operation of the transport network that underlies these market transactions. The European TSOs are currently working jointly in the light of this coordination issue on the new flow-based methodology, by means of which the available cross-border capacities will be calculated in the near future. On the 21st of March 2015, Flow-based (FB) Market Coupling turned into reality for Central West Europe region (CWE: Benelux, France and Germany) TSOs. In the rest of this document there will be an explanation on how TenneT, in cooperation with the TSOs in CWE, determines the cross-border capacity available to the market on the basis of the FB methodology. For detailed description of the methodology, the document for NRA approval can be found in the CASC website via the link:
http://www.casc.eu/media/140801%20CWE%20FB%20MC%20Approval%20document.pdf

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List of Abbreviations

ATC	Available Transfer Capacity
BEC	Bilateral Exchange Computation
CB	Critical Branch
CCP	Capacity Calculation Process
CCR	Capacity Calculation Region
CGM	Common Grid Model
CIA	**Congestion Income Allocation**
CO	Critical Outage
CWE	Central Western Europe
CZC	Cross-Zonal Capacity
D2CF	D-2 (2 days ahead) Congestion Forecast model
DACF	D-1 (day-ahead) Congestion Forecast model
EC	European Commission
FAV	Final Adjustable Value
FBMC	Flow-based Market Coupling
Fmax	Maximum allowable power flow (MW)
FRM	Flow Reliability Margin
GSK	Generation Shift Key
Imax	Maximum current on a Critical Branch (A)
LTA	Long-Term Allocated Capacity
MoU	Memorandum of Understanding
NTC	Net Transfer Capacity
PTDF	Power Transfer Distribution Factor
RAM	Remaining Available Margin
SA	Shadow Actions
TSO	Transmission System Operator

1. Introduction

1.1 CWE Flow-based market coupling in European market integration

Within the progressing European market integration, the CWE Flow-Based Market Coupling (CWE FB MC) project is a further optimization of how network capacities can be made available for market integration. Before CWE FB MC, the capacity calculation in the CWE-region was based on the so called ‘ATC’[1] method where transmission capacities were calculated in a coordinated way and result in bilateral values between bidding zones. The flow based approach more sophisticatedly considers the interdependencies and grid restrictions which are included in the market coupling. Within the same security limits, this will lead to a better physical observability of the grid plus even more increased welfare through cross-border trade (more price convergence and better price levels).

For TSOs such a more sophisticated method is needed because the rise across Europe of renewable energy production, in conjunction with a drop in the supply of conventional power in the recent years contributed to increased energy market volatility and increased unpredictability as well as complexity for TSOs grid operation. In such environment, where the trend is expected to endure, a more sophisticated method for security capacity calculation was needed.

In an integrated manner, Flow-Based takes account of the interdependencies between cross-border interconnections, the specific situations of national grids, and the greater unpredictability of power generation (e.g. due to the presence or absence of wind).

The method considers far more information than its predecessors and generates a more accurate capacity result of a more complex reality, and thus provides energy players, policymakers and authorities with a better basis for decision-making on investments in generating facilities and network infrastructure.

Figure 1 CWE Capacity Calculation region

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[1] *ATC stands for Available Transfer Capacity*

1.2 Dutch border connections

The Dutch high-voltage grid operated by TenneT is linked via various transport connections to the high-voltage grids of the surrounding countries in the NWE region.

- NorNed cable (Direct Current – DC) to Norway
- BritNed cable (Direct Current – DC) to the UK
- Overhead lines connections with countries in the CWE region (Alternating Current – AC):
    - Two connections with Belgium
    - Three connections with Germany

Market players wishing to import electricity to or export electricity from the Netherlands are in a position to buy or use cross-border transport capacity either via the capacity auctions (explicit allocation used for the forward allocation) or by means of the market coupling via the European energy exchanges (implicit allocation used for the shorter timeframes). To this end, capacity is provided at various points in time by TenneT, in cooperation with neighbouring TSOs, for long- and short-term contracts in the forward markets for transport via these cross-border connections.

The cross-border capacity trade on the energy exchanges is determined at various points in time by the TSOs. Here a distinction is drawn between the capacities on the DC links, NorNed and BritNed, and those on the AC links with Belgium and Germany within the CWE region. The capacity on the DC links available to the market is, under normal circumstances, equal to the nominal design capacity of the link. For the BritNed and NorNed links, this means that respectively 1,000 MW and 700 MW are made available to the market. The transport capacity for the BritNed link is released in various forward contract products, on the NorNed link there is no forward allocation today.

The cross-border capacity on the AC links is made available in the form of long-term products and short-term products. On the long-term markets, annual capacities (TenneT: 1,300 MW) and monthly capacities (TenneT: from 400 to 850 MW) are released for allocation towards market participants. These transport capacities to be made available for long-term allocation ensue from the current Dutch legislation and regulations. In addition, cross-border capacity is released on the day-ahead market (or 'D-1') and on the intraday (same-day) market.

	Products					
Interconnectors	Y	Q	M	W	D-1	ID
NorNed (DC-cable)					✓	✓
BritNed (DC-cable)	✓	✓	✓	✓	✓	✓
CWE (AC links)	✓		✓		✓	✓

Figure 2 Capacity products on the Dutch border links within the NWE region

The day-ahead capacity is offered through implicit auction in the market coupling via the energy exchanges. This means that market players wishing to import or export electricity are able to acquire both the energy and the necessary transport capacity through a single transaction on the energy exchange. In order to make these daily capacities available, a *Flow-based domain* is determined daily by the TSOs in the CWE region within which a day-ahead market coupling exists.

The volume of the FB domain constitutes the capacity available for commercial transactions in the day-ahead market. The year- and month *NTC* is the capacity available for the year- and month auctions.

1.3 Availability of cross-border capacity on AC links

1.3.1 Day-ahead FB Capacity Calculation

Market Coupling relies on the principle that when markets with the lowest prices export electricity to markets with the highest prices, there is day-ahead market welfare created by these exchanges, under the assumption that FB intuitive is the chosen methodology. The Flow-based is the method indicated in the Network Code on Capacity Calculation and Congestion management (CACM). Flow-based Market Coupling (FBMC) algorithm will optimize the day-ahead market welfare for the whole region, based on the capacity constraints (flow-based capacity parameters; including the critical branches and the PTDF-matrix) and the energy orders. Because the flow-based parameters are based on a DC load flow computation, the influence of loop and transit flows is directly taken into account by the methodology. When one or more of the constraints is hit by the market coupling algorithm, different market prices are the 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 and no congestion income is collected.

Under FBMC algorithm TSOs provide FB parameters and FB constraints, which respect the Security of Supply. In figure 3, the two-dimensional representation of the FB domain is coloured yellow and it is bounded by several physical constraints. The FB domain can be determined by making assumptions with regard to the foreseen grid situation and by performing contingency analyses. For example: if we imagine a country A, that is interconnected with country B and country C, the two-dimensional representation of the FB domain of country A could look like the figure below.

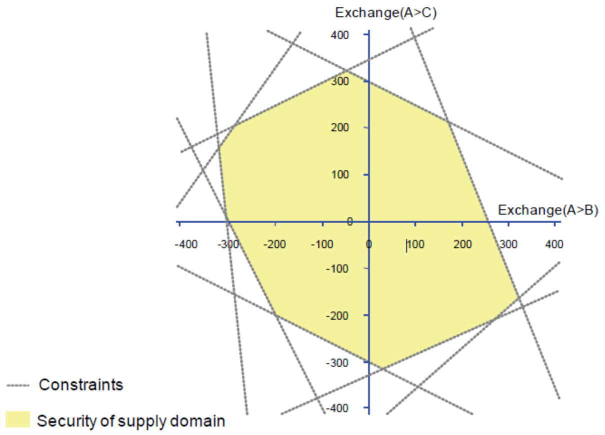

Figure 3 Partial (two-dimensional) representation of the three dimensional FB domain

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 methodology that will be described in this document.

1.3.2 Domestic and foreign influencing factors

When determining available, TenneT and the other TSOs must take into account domestic factors, such as outages of grid components and expectations on the quantities - and geographic spread – of production and demand within the national transport network. In TenneT's Individual Grid Model generation, it makes use of the transport prognoses sent in by market players, among other factors,[1] in order to be able to determine the cross-border capacity available for the market on the basis of as accurate as possible expectations on the quantity and spread of production and demand on the Dutch grid.

Secure available cross-border capacity is also dependent on foreign factors. For example, the design capacities of the network, or planned maintenance work on grids in neighbouring TSOs can result in limitations. There are still major uncertainties surrounding the ultimate physical power flows as a result of international market transactions right up to the day of execution. FB capacity calculations will decrease these uncertainties.

The figure below shows two examples, on the basis of actual transports, of various physical flows in the CWE region resulting from a transaction of 100 MW from Germany to the Netherlands. It can be seen that usage of the various cross-border interconnectors may vary considerably under the influence of the location of production and demand. In Figure 4a, the resulting power flows of a transaction between the southern part of Germany and the southern part of the Netherlands are shown. The physical flows are almost evenly split between the Belgian border and German border. This is in contrast to a transaction between the northern part of Germany and the northern part of the Netherlands (Figure 4b) where the physical flows are almost entirely from Germany to the Netherlands.

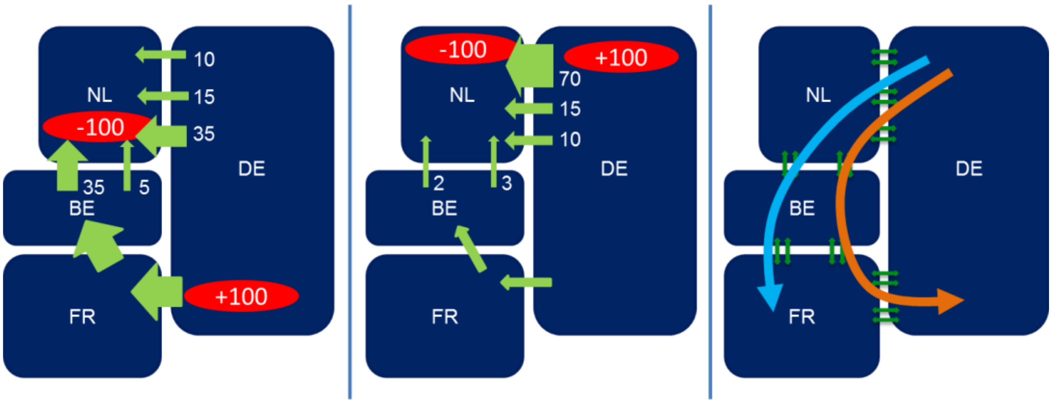

Figure 4 Varying physical flows in the CWE region with transaction from North and South Germany to the Netherlands; and on the right loop flows (orange) and transit flows (blue) via the Netherlands.

[1] Transport prognoses: Daily submission of the programmes of responsible parties and regional grid operators showing production and demand and their location on the high-voltage grid operated by TenneT.

An important source of uncertainty may be found in the international physical flows to be expected as a result of international market transactions in energy and production and demand abroad. These flows find their way in the European high-voltage grid in accordance with the laws of physics - “the path of least resistance”. In this regard, TenneT’s transport network, just as those of other TSOs, is regularly used as “transit route” for market transactions that take place completely outside the Netherlands (loop flows and transit flows, see Figure 4). Flows of this kind may restrict to a considerable extent the export and import capacity available to the market from and to the Netherlands.

1.4 Coordinated European process within CWE

After the successful launch of the trilateral market coupling between France, the Netherlands and Belgium in November 2006, the ministries, regulators, transmission system operators (TSOs), power exchanges and representatives of large producers of the CWE-region united in the Pentalateral Energy Forum (PLEF), concluded that this coupling of energy wholesale markets should be extended over the whole CWE-region (e.g. including Germany). Not only did they agree on the coupling of markets, also on further coordination by TSOs and better reflection of the effect of the cross zonal electricity flows into the capacity calculation.

This agreement was supported in June 2007 by the signature of a Memorandum of Understanding (MoU) on Market Coupling and security of supply in CWE endorsed by all the relevant parties of the region. One of the main objectives of this MoU[2] was the implementation of a flow based market coupling in line with the Annex of Regulation 1228/2003 (later replaced by Regulation 714/2009) in the CWE region. In June 2013 the Ministries of the region reiterated their political support towards a soon implementation of flow based market coupling in a Political Declaration.

In the context of this MoU and Political Declaration, the TSOs involved[3] have set up a completely coordinated process, called the *Capacity Calculation Process (CCP),* for calculating the *Cross Zonal Capacity (CZC)* available daily to the market in the *Capacity Calculation Region (CCR)* of CWE. This process consists of exchanges of information and operations at specific points in time, by means of which the TSOs are put in a position to assess European predictions. The result of this coordinated process is maximum levels of secure available Cross Zonal Capacity per hour: the so-called Flow Based parameters. In line with article 16(3) of Regulation (EC) 714/2009: "The maximum capacity of the interconnections and/or the transmission networks affecting cross-border flows shall be made available to market participants, complying with safety standards of secure network operation."

[2] Memorandum of Understanding: Agreements between the ministers of the Pentalateral Energy Forum, supervisory authorities, TSOs, trading markets and representatives of market players in the CWE region.
[3] TSOs collaborating within the CWE: Amprion, Creos, Elia, TenneT TSO BV, TenneT TSO GmbH and RTE.

2. Coordinated FB Day-ahead Capacity

The calculation of the day-ahead *FB capacity* (24 hourly capacity values per border, per direction) is carried out daily at the European level within the CWE. This *Coordinated Calculation Process* consists of tasks that have to be carried out by the individual TSOs like TenneT, along with tasks that are carried out by the Flow-based *Common System*[4] or by a *Service Provider*[5].

Figure 5 shows a schematic overview on how the calculation of the Flow-based capacity is jointly prepared by the CWE TSOs and other relevant stakeholders. The following paragraphs of this document explain in detail the main steps in the process by which TenneT, in cooperation with other CWE TSOs, determines and makes available the daily cross-border capacities to the market. For more detailed information, the approval document is available at:
http://www.casc.eu/media/140801%20CWE%20FB%20MC%20Approval%20document.pdf

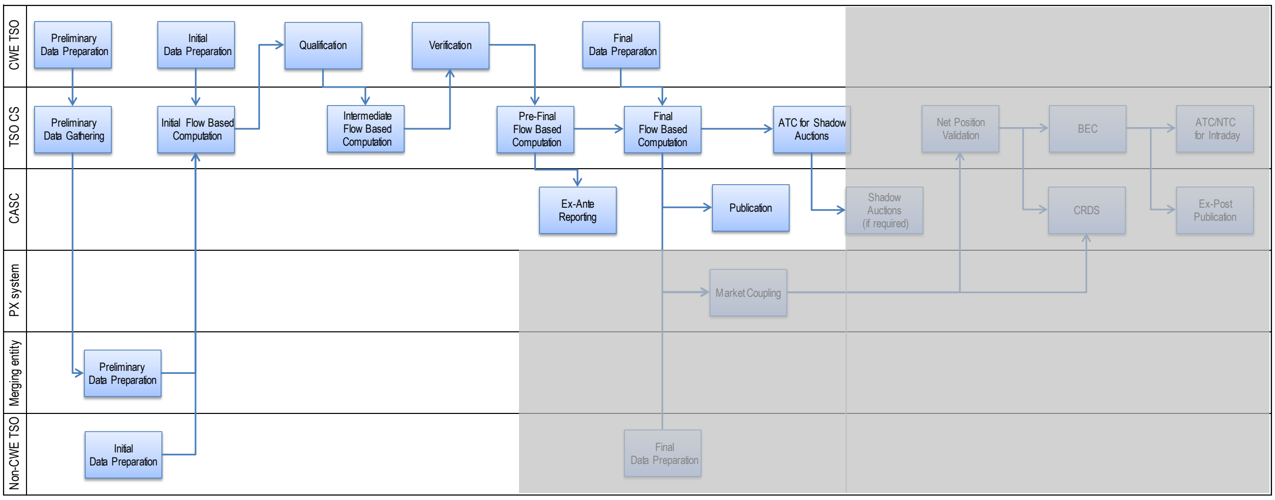

Figure 5 Coordinated process model for determining the FB capacity within the CWE

The CWE FBMC is assembled by the following main stages: pre-coupling, post-coupling and Market coupling. The pre-coupling stage represents the coordinated preparation of grid constraints, provided to the market coupling and covers sub-processes such as Initial Data Gathering, Initial FB Computation, Intermediate FB Computation, Final Data Gathering, Final FB Computation, FB parameters for CIA and ATC Calculation for Shadow Auction.

The market coupling is covered by the MC system (not part of TSO CS). An external PMB (PCR Matcher and Broker) system receives anonymized pre-solved final flow based parameters and non-CWE CZCs and

[4] Tasks are carried out in turn via the *Common TSO System* by the various TSOs on behalf of the joint TSOs.
[5] A *Service Provider* carries out support services on behalf of the TSOs, such as for example merging files, conducting analyses and advising TSOs. Final responsibility for the tasks and processes remains with the TSOs.

calculates the market outcome within the FB constraints. The output of market coupling is sent back to the TSO CS. The post-coupling process represents the evaluation of market coupling results and covers the following sub-processes: Net Positions Validation, Bilateral Exchange Computation and Intraday ATC Calculation. Data Archiving is an integral part of the pre-coupling and post-coupling processes. Both market coupling and post-coupling stages are not in scope of this document.

Following data is needed for FB calculation: List of Critical Branches / Critical Outages, which constraint the available market capacity, D2CF Files, reference Programs, Remedial Actions, Generation Shift Keys (GSK), External constraints, long-term nominations, reference NTCs, and long-term allocated capacity.

For simulating the network flows due to foreign exchange flows a modelling of the nodal injection is needed. Thus the TSOs need to know which generators will be implied. Such partition of the generation is defined by constant coefficients – Generation Shift Keys (GSK). Each TSO will assess the GSK for the participating nodes where the injection varies significantly during a variation of the zonal balance.

The outcome of the load flow analysis are the FB parameters (RAM=remaining available margin per CB, and PTDF matrix) which define the constraints for the MC algorithm. The nodal PTDF matrix encompasses the influence of the injections, the influence on a critical branch of every additional MW injected to the node. Due to the Direct Current approximation the PTDFs only depend on the characteristics of the branches and the network topology. Once the nodal PTDFs are calculated, the Zonal PTDF, which represents a production shift due to the exchanges, can be calculated by using the GSK matrix. Finally the Remaining Available Margin (RAM) is calculated giving the margin which is available on all CB's for Market Coupling.

2.1 FB Input Data

2.1.1 Drawing up the Individual Grid Model for the Netherlands

The 2-Days Ahead Congestion Forecast files (D2CF files), provided by the participating TSOs for their grid two-days ahead, are a best estimate of the state of the CWE electric system for day D.

TenneT starts the D2CF creation process with a grid study model. This model which represents the topology of the business day by making use of the information of the local outage-planning (including network components and generation planned outages) as known at time of preparation of D2CF, which is between 17:00-18:00 at D-2.

The model is then adapted for the Load & Production forecasts (directly derived from the forecasts received from the market) and cross-border nominations of the reference day, which become available at 17:00.

After the forecasts have been imported, TenneT starts to redistribute the production of all operational available units (which are not in maintenance) above 60MW (further called: GSK Units). This redispatch of production is done in order to match the GSK methodology as described in the GSK chapter of this document. All GSK units are redispatched pro-rata on the basis of predefined maximum and minimum production levels for each active unit. The total production level remains the same.

The PST tap position is put at 0 in all PSTs in D2CF file. From this neutral tap position, PST taps are coordinated within CWE in the Qualification phase.

For the DC cables the Exchange programs of reference days are used. In case the cable is out of service on the target day, the program of the cable will be distributed over the loads.

Afterwards, production and load are redistributed and an AC load flow is performed in which the grid is checked for congestions and voltage problems.

2.1.2 Generating a Common Grid Model

Basis for the calculation process is a model of the grid, the Common grid Model (CGM) that represents the best forecast of the corresponding hour of the execution day (day D). Due to the timeline within the process, the creation of the CGM has to be performed two-days ahead of day D. The CGM is a data set created by merging individual grid models by a merging entity.

This data set contains

- the single D-2CF data sets from CWE TSOs: Elia (BE), RTE (FR), TenneT (NL), TenneT (DE), Transnet BW (DE), Amprion (DE), 50HzT (DE) and APG (AT)
- the DACF data sets from the non-participating TSOs of continental Europe

The network of German Control Block (GCB) is composed of EnDK (DACF), TenneT DE, Transnet BW, Amprion, 50Hertz and CREOS in a pre-merge. DC cables linked to other control blocks are handled as injections in the model. The schedules on these cables are consistent with the forecasted reference exchange programs (e.g. from a reference day).

The DACF data sets of non-participating TSOs, corresponding to the agreed reference timestamp, are needed to take the physical influences of these grids properly into account when calculating transfers between FR-BE-NL-DE.

The merging process will be done in the following steps, according to the internationally agreed merging rules:

1. Check of individual data sets of the participating and non-participating TSOs:
   - Check for format
   - Check load flow convergence

2. Balance check (import/export situation) according to scheduled balance of reference timestamp. In case of mismatch, balance adjustment according to the internal CWE Merging Guidelines.
3. Merging process:
    - Check interconnector status. If necessary adjustment according to the CWE Merging Guidelines

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

2.1.3 CBCO-Selection

TSOs specify the technical parameters of relevant network constraints in a CB file. This file contains the following elements: CB, CO, RA, maximum current (Imax), maximum allowable power flow (Fmax), Final Adjustment Value (FAV), and Flow Reliability Margin (FRM).

Critical Branch

A Critical Branch [6](CB) is a network element, significantly impacted by CWE cross-border trade, which is monitored under certain operational conditions, the so-called Critical Outages (CO). The CBCOs (Critical Branches/Critical Outages) are determined by each CWE TSO for its own network according to agreed rules, described below.
The CBs are defined by:

- A line (tie-line or internal line), or a 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).

Critical Outage

Critical Outages (CO) can be defined for all CBs. CO can be:

- Trip of a line, cable or transformer
- Trip of a busbar
- Trip of a generating unit
- Trip of a (significant) load
- Trip of k elements

[6] Critical Branch is defined in the NC CACM as Critical Network Element (CNE)

CB selection

The assessment of critical branches is based on the impact of CWE cross-border trade on the network elements and based on operational experience. A set of PTDFs is associated to every CBCO after the initial FB parameter calculation which gives the influence of the net position of any bidding zone on the CBCO. If the PTDF = 0.1, this means the concerned hub has 10% influence on the CBCO, meaning that 1 MW in change of net position of the hub leads to 0.1 MW change in flow on the CBCO.

A CB is considered to be significantly impacted by CWE cross-border trade, if its maximum CWE zone-to-zone PTDF (Power Transfer Distribution Factor) is larger than a fixed threshold value. CWE FB experts have agreed to a threshold value of 5%.This current threshold has been set following thorough security assessments performed by TSOs, by the iterative process described below.

CWE TSOs constantly monitor the critical branches which are fed into the allocation system in order to assess the relevance of the threshold over time. During the external parallel run, active critical branches, i.e. the CBs having actually congested the market, have respected the threshold value of 5%..
Practically, it means that there is at least one set of two bidding zones in CWE for which a 1 MW exchange creates an induced flow bigger than 0,05 MW (absolute value) on the branch. This is equivalent to say that the maximum CWE “zone to zone” PTDF of a given grid element should be at least equal to 5% for it to be considered objectively “critical” in the sense of FB capacity calculation.

For each CBCO the following sensitivity value is calculated:
Sensitivity = max(PTDF (BE), PTDF (DE), PTDF (FR), PTDF (NL)) - min(PTDF (BE), PTDF (DE), PTDF (FR), PTDF (NL))
If Sensitivity is above the threshold, then the CBCO is said to be significant for CWE trade.

A pre-processing is performed during the FB parameter calculation which will result in a warning for any CBCO which does not meet pre-defined conditions. The concerned TSO then has to decide whether to keep the CBCO or to exclude it from the CBCO file.

Although the general rule is to exclude any CBCO which does not meet the threshold on sensitivity, exceptions on the rules are allowed: if a TSO decides to keep the CBCO in the CB file, he has to justify it to the other TSOs; furthermore it will be monitored by the NRAs. Should the case arise, TSOs may initiate discussions on the provided justifications in order to reach a common understanding and a possible agreement on the constraints put into the capacity calculation process.

Imax

The maximum allowable current (Imax) is the physical limit of a critical branch (CB) determined by each TSO in line with its operational criteria. Imax is the physical (thermal) limit of the CB in Ampere, except when a relay setting imposes to be more specific for the temporary overload allowed for a particular critical branch-critical outage (CBCO).

The thermal limit and relay setting can vary in function of weather conditions, Imax is usually fixed at least per season.

When the Imax value depends on the outside temperature, its value can be reviewed by the concerned TSO if outside temperature is announced to be much higher or lower than foreseen by the seasonal values. Imax is not reduced by any security margin, as all margins have been covered by the calculation of the Critical Outage, by the Flow Reliability Margin and Final Adjustment Value.

Fmax

The value Fmax describes the maximum allowable power flow on a CBCO in MW. It is given by the formula:

$$Fmax = \sqrt{3} * Imax * U * \cos(\varphi) / 1000 \; [MW],$$

where Imax is the maximum permanent allowable current (in A [Ampere]) for a CB. The value for cos(φ) is set to 1, and U is a fixed value for each CB and is set to the reference voltage (e.g. 225kV or 400kV) for this CB.

FAV

With the Final Adjustment Value (FAV), operational skills and experience that cannot be introduced into the Flow Based-system can find a way into the Flow Based-approach by increasing or decreasing the remaining available margin (RAM) on a CB for very specific reasons which are described below. Positive values of FAV in MW reduce the available margin on a CB while negative values increase it. The FAV can be set by the responsible TSO during the qualification phase and during the verification phases. The following principles for the FAV usage have been identified:

- A negative value for FAV simulates the effect of an additional margin due to complex remedial actions (RA) which cannot be modelled and so calculated in the Flow Based parameter calculation. An offline calculation will determine how many MW can additionally be released as margin; this value will be put in FAV.
- A positive value for FAV as a consequence of the verification phase of the Flow Based domain, leading to the need to reduce the margin on one or more CBs for system security reasons. The overload detected on a CB during the verification phase is the value which will be put in FAV for this CB in order to eliminate the risk of overload on the particular CB.

Any usage of FAV will be duly elaborated and reported to the NRAs for the purpose of monitoring the capacity calculation. Applying a manual FAV through the CB-Editor leads to request for justification that need to be given in the System (CBE). This justification will be automatically included within the NRA reports

Remedial Actions

During FB parameter calculation CWE TSOs will take into account remedial actions (RA) that are allowed in D-2 while ensuring a secure power system operation, i.e. N-1 criterion fulfilment. In practice, RAs are implemented via entries in the CB file. Each measure is connected to one CBCO combination and the FB parameter calculation software treats this information.

The calculation can take explicit and implicit RAs into account. An explicit remedial action (RA) can be:

- changing the tap position of a phase shifter transformer (PST)
- topology measure : opening or closing of a line, cable, transformer, bus bar coupler, or switching of a network element from one bus bar to another
- curative redispatching: changing the output of some generators or a load

Implicit RA can be used when it is not possible to explicitly express a set of conditional remedial actions into a concrete change in the load flow. In this case a FAV will be used as RA.

The TSO CS applies these measures during the FB parameter calculation and hence determines the effect on the CBs directly. The influence of implicit RA on CBs is assessed by the TSOs upfront and taken into account via the FAV factor, which changes the available margins of the CBs to a certain amount.

2.1.4 Generating Shift Key

The Generation Shift Key (GSK) defines how a change in net position is mapped to the generating units in a bidding area. Therefore, it contains the relation between the change in net position of the market area and the change in output of every generating unit inside the same market area. The GSK aims to deliver the best forecast of the impact of a net position change on Critical Branches.

Due to convexity pre-requisite of the Flow Based domain, the GSK must be linear. Every unit that is participating to the GSK of a market area receives a GSK contribution factor. These GSK contribution factors can vary for every hour and they are given in dimensionless units (a value of 0.05 for one unit means that 5% of the change of the net position of the market area will be realized by this unit). Every TSO assesses a GSK for its control area taking into account the characteristics of its network. In general, the GSK includes power plants that are market driven and that are flexible in changing the electrical power output. This includes the following types of power plants: gas/oil, hydro, pumped-storage and hard-coal. TSOs will additionally use less flexible units, e.g. nuclear units, if they don’t have sufficient flexible generation for matching maximum import or export program or if they want to moderate impact of flexible units.

The GSK methodology applied in the Netherlands is called *selective GSK (selGSK).* The selGSK determination seeks to limit the participating units to the volume needed to match the maximum import and export positions of the market area. Furthermore, the units are selected based on best possible forecast considering generation schedules, generator outages and historical operational hours (*dispatch order*).

The high level process of the selGSK determination in the Netherlands is illustrated on Figure 6.

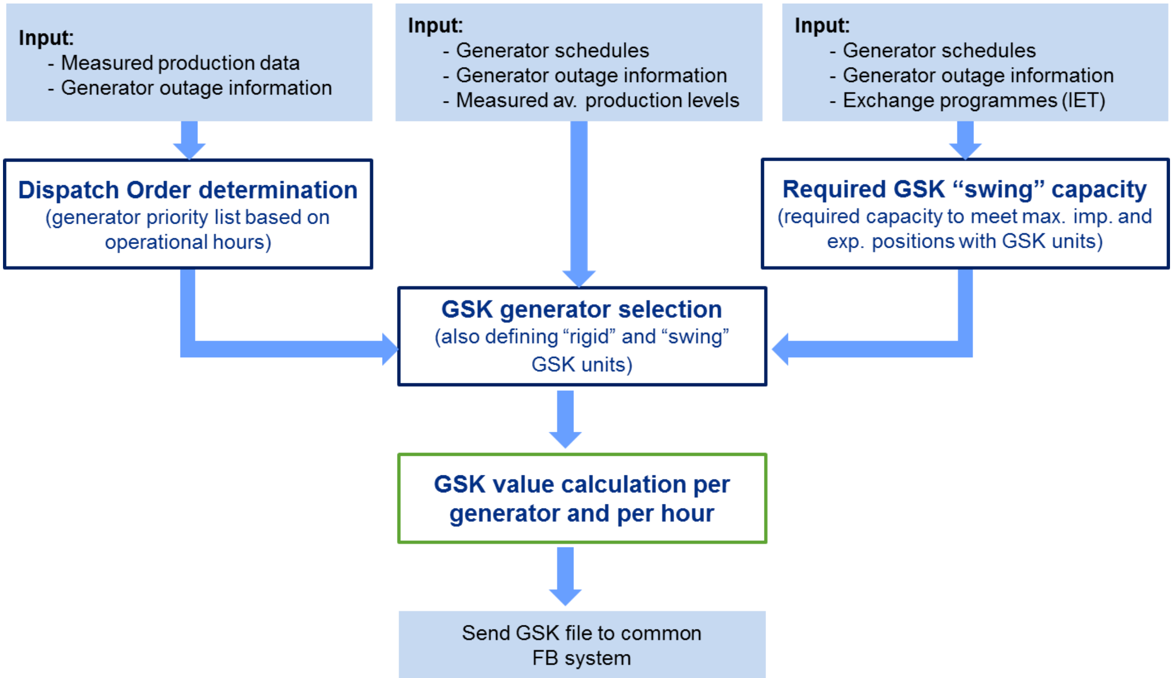

Figure 6 SelGSK determination process as applied in the Netherlands

The dispatch order is a generator priority list based on the operational hours of the four weeks preceding the week of realization. Generator outages within this four week period are corrected with reference operational hours of the generators of a eight week period preceding the four week period.

The required GSK "swing" capacity is determined for every hour of a day. It is the maximum export capacity plus the maximum import capacity (NP_max + NP min). Furthermore the maximum and the minimum required GSK capacity need to be determined per hour :

$$P\_GSK\_\min = Load + \ ImportExport\ schedule - scheduled\ Generation\ from\ nonGSK\ units$$

$$P\_GSK\_\max = P\_GSK\_\min + GSK\ swing\ capacity$$

The variables are illustrated on the following figure.

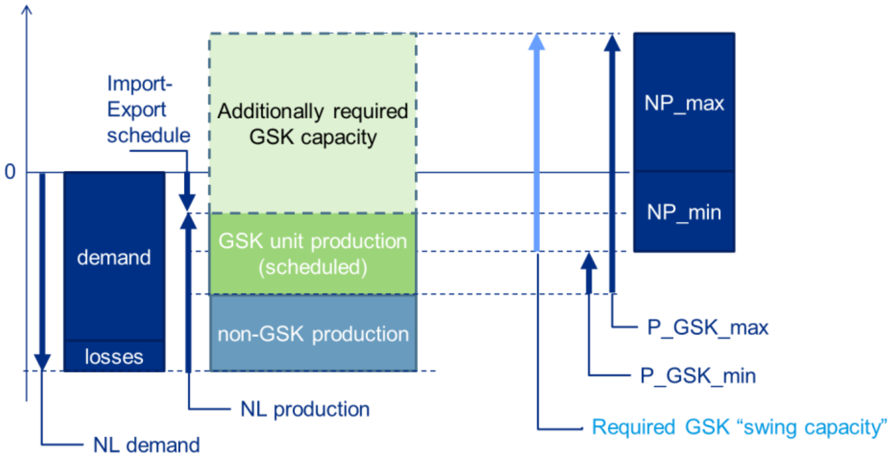

Figure 7 Determination of GSK swing capacity and min. and max. GSK capacity

In the GSK generator selection process the required GSK capacity is selected based on the following criteria:

1. Generator are available (no outage information received)
2. Generator is operating according information from dispatch schedule (T-prognosis)
3. Position in the dispatch order (generators with high operational hours are prioritized)

During the selection process generators are attributed to the "rigid" generators, to the "swing" generators or to the "idle" generators. The rigid generators are the generators with the highest priority. They only contribute a share of their capacity to the GSK, while the remaining capacity is assumed to continuously operate. The "GSK swing" of the rigid generators is the delta between their nominal capacity and their average production level (*Pmax – Paverage*). The rigid generator capacity is equivalent to the capacity of P_GSK_min. The "swing" production of P_GSK_max – P_GSK_min is performed by the next priority generators. These "swing" GSK generators contribute with their full capacity to the GSK (*Pmax – Pmin*). All generators not needed to reach the required GSK "swing capacity" are idle generators which are not dispatched.

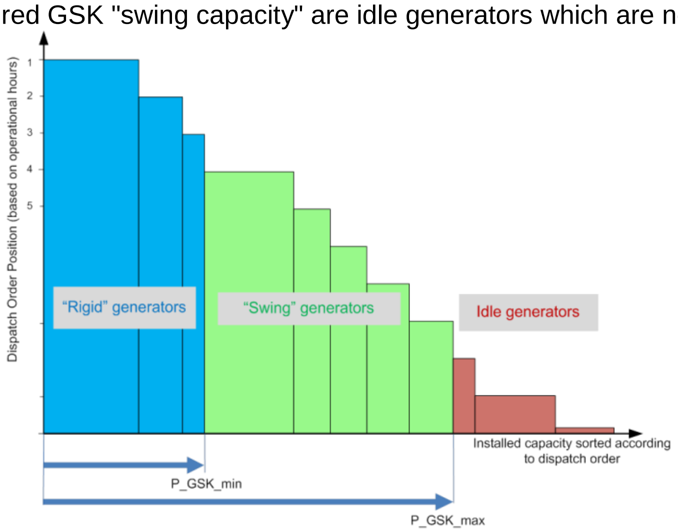

Figure 8 Assignment of rigid, swing and idle generators to reach required swing capacity (simplified illustration)_

Based on the selected generators the the GSK contribution factor per generator i (GSK_i) per hour is determined.

$$GSKi = \frac{Pmax_i - Pmin_i}{\sum_k Pmax_k - \sum_k Pmin_k}$$

Where k is the index over all active GSK units.

Finally, to avoid that the GSK can dispatch generators above Pmax or below Pmin, the initial dispatch of the model is redistributed according to the formula underneath:

The initial formula to calculate the redispatch value P_{i1} and the GSK contribution factor per generator i:

$$P_{i1} = Pmin_i + (Pmax_i - Pmin_i)\frac{\sum_k P_{k0} - \sum_k Pmin_k}{\sum_k Pmax_k - \sum_k Pmin_k}$$

Where k is the index over all active GSK units, P_{i1} being the redistributed dispatch and P_{i0} being the initial dispatch according to schedule of unit i.

2.1.5 Flow Reliability Margin

According to ENTSO-E Operational Handbook policy 4 and according to the CACM GL article 22 "Reliability margin methodology", TSO must hedge against uncertainties of capacity calculation by applying reliability margins. Due to the presence of uncertainties, the TSO is not able to predict with accuracy the operating conditions, which then result in unpredictable flows in the network. The flows in the critical branches are crucial when calculating capacity, because they influence the market constraints.

The origin of the uncertainty involved in the capacity calculation process for the day-ahead market comes from phenomena like external exchanges, approximations within the FB methodology (e.g. GSK) and differences between forecasts and realized programs. This uncertainty must be quantified and discounted in the allocation process, in order to prevent, that on day D TSOs will be confronted with flows that exceed the maximum allowed flows of their grid elements. This has a direct link with the firmness of market coupling results. 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 that is provided to the market to facilitate cross-border trading must be reserved to cope with these uncertainties.

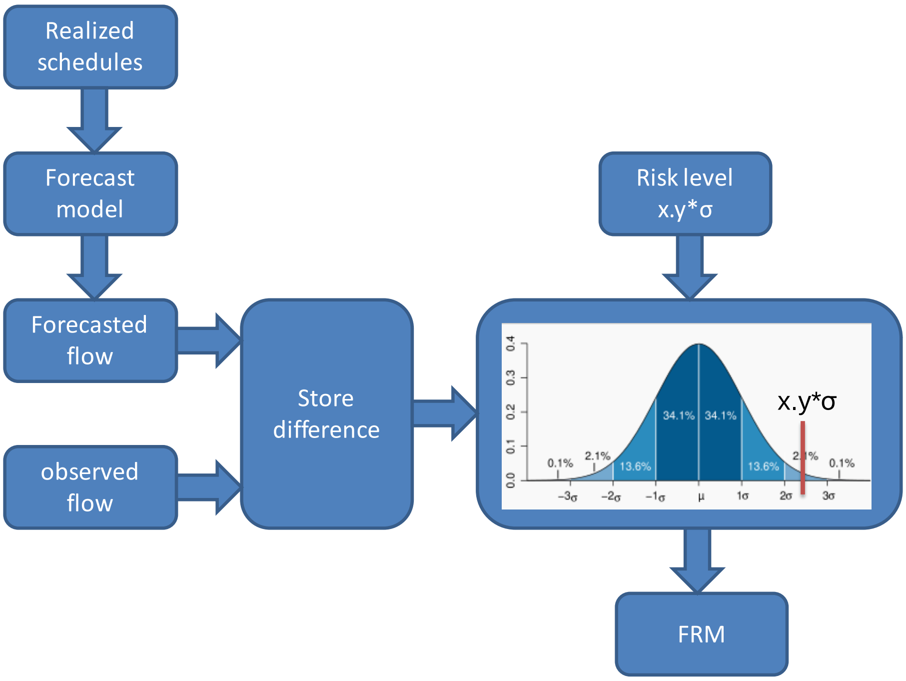

Figure 9 FRM Assessment Principle

The FRM quantifies the uncertainty by comparing the FB model (adjusted to the realised schedules corresponding with the instant that the snapshot was created) to the observation of the corresponding timestamp in real-time, i.e. the difference between the D-2 expected flow and the actual snapshot flow. To perform this calculation, TSOs store the information in order to build up a database, which allows them to perform the statistical analysis on a significant amount of data.

By following the approach, the subsequent effects 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)
- Uncertainty in wind generation forecast
- Uncertainty in Load forecast
- Uncertainty in Generation pattern
- Assumptions inherent in the Generation Shift Key (GSK)
- Topology
- Application of a linear grid model

The FRMs are regularly updated by the CWE TSOs in a separate process. The new FRM values will be analysed, discussed and coordinated upon by the TSOs before implemented in the CWE CB files. TSOs may potentially apply a so-called “operational adjustment” before practical implementation into their CB file.

This adjustment is expected to be exceptional and small. The differences between operationally adjusted and theoretical values shall be systematically monitored and justified.

2.1.6 External constraint

Since the FB method is based on the evaluation of the remaining available margin in critical branches (which do not represent the complete network as mentioned in the 2.1.3 CBCO section) calculated through a DC load flow, the resulting net position can be higher than the current maximum NTC. The flow-based domain is limited only by thermal limits of the critical branches. Moreover, in the FB computation a generation shift key is used to perform the generation shift from the base case to extreme import and export position, which may not correspond to the best generation forecast and is used for both upwards and downwards generation shift, i.e. import and export directions, as explained in the 2.1.4 GSK section. This approach was selected to avoid extensive and not realistic under- and overloading of the units for extreme import or export scenarios. In addition, other specific limitations may be necessary to guarantee a secure grid operation. These additional constraints can be justified by stability limits which are more restrictive than thermal limits, e.g. voltage stability. Import/Export limits declared by TSO are taken into account as “special” critical branches, in order to guarantee that the market outcome does not exceed these limits. TSOs remind here that these constraints are NOT new, since already taken into account implicitly when computing NTCs. With FB, they appear explicitly and their usage is justified below.

In summary, the main reasons for a TSO to use external constraints are:

- Avoid market results which lead to stability problems in the network, detected by system dynamics studies.
- Avoid market results which are too far away from the reference flows going through the network in the base-case, and which in exceptional cases would induce extreme additional flows on grid elements, leading to a situation which could not be verified as safe by the concerned TSO during the verification step.

The application of External Constraints is responsibility of the local TSO. During its determination, voltage problems, specific stability problems, and other issues such as the impact of different generation schedules are examined. For instance, voltage or stability problems can arise in the situation when the number of running generators in the Netherlands is small, and therefore the reactive power control capability is reduced. External constraints will to limit the net position and/or transit flows in the network, and its determination is performed off-line on scenario based system studies.

2.2 Centralised Flow-based parameter computation: Initial, Intermediate and Final

Before the Initial Flow Based Computation procedure performs the determination of the reliability margin, the critical branches and critical outages set, the generation shift keys and the external constraints need to be prepared for the calculation. These data are therefore specified as input into the Initial Data Gathering module. Factually these concrete steps are called the non-cyclic (preparatory) procedures.

For all FB computations, the input data may require adjustment. For instance, the data for the intermediate computation is adjusted with the outcome of the Qualification. After the preparation of the FB data necessary for the FB domain computation, the subsequent step is the FB domain computation. The Flow Based parameters computation is centralized. As the whole grid is linearized, the calculation can be done with the much faster DC approach and delivers two main classes of parameters needed for the following steps of the FB MC: RAM and PTDFs.

Remaining Available Margin (RAM)

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. Out of the formula:
RAM = Fmax – Fref – FRM - FAV
The calculation delivers, with respect to the other parameters, the free margin for every CB. This RAM is one of the inputs for the subsequent process steps.

Power Transfer Distribution Factors (PTDFs)

The PTDFs are calculated by varying the exchange program of a zone (=market area), taking the zone-GSK into account. For every single zone-variation the effect on every CB loading is monitored and the effect on the loadflow is calculated in percent (e.g. additional export of BE of 100 MW has an effect of 10 MW on a certain CB => PTDF = 10%). The GSK for the zone has an important influence on the PTDF, as it translates the zone-variation into an increase of generation in the specific nodes.
The PTDF characterizes the linearization of the model. In the subsequent process steps, every change in the export programs is translated into changes of the flows on the CBs by multiplication with the PTDFs.

2.3 Flow-Based parameter qualification

The operational FB parameter qualification process covers amongst others the following actions. For each CB limiting the FB-domain in pre-defined reference points, the involved RSCIs together with the CWE TSOs check, if agreed remedial actions (RA) are available, that could enlarge the FB-domain. These RAs consist of network topology changes (topological RAs) and the change of PST taps. The RAs will be applied in the TSO´s CB-files in coherence with the TSO´s local capacity calculation procedures and risk policies. Close coordination between CWE RSCIs and TSOs is needed for the application of the before mentioned cross-border RAs. A coordination of these agreed RAs by a common process enhances the security of supply and can increase the capacity offered to the market.

The aim is to include all LTAs and ref NTCs of likely market directions in the FB domain respecting the TSO’s risk policies. Depending on the nature and the complexity of the specific RA, the RAs could be applied explicitly in the CB-file by a detailed description or, if too complex and the effect is known or can be estimated, by adapting the Final Adjustment Value (described in section 2.1.3 FAV).

CWE TSO have agreed on basic high level principles for the application of RAs during FB capacity calculation. Each CWE TSO defines the available RAs in its control area, and available at one common list of RAs. The agreed RAs are assumed binding with respect to availability for real time operations (high level principle 12). The coordination of these additional RAs between TSOs will be organized through the CWE RSCIs: SSC which is representing TenneT TSO BV, TenneT TSO GmbH and Amprion; Coreso which is representing RTE and Elia. Transnet will participate in the process, if needed. The coordination of RAs will first focus on commonly selected likely market directions. The guidelines for the application of RAs imply that the RAs described in the CB files can change during the daily FB process in the qualification (e.g. as a result of the coordination process). The verification phase is not used for optimizing the FB domain, a decrease is possible for TSO's with the use of positive FAV or changing the external constraint.

<u>Phase-shifting transformers</u>
One of the control measures available to TenneT is the adjustment of tap positions of phase-shifting transformers in Meeden. A phase-shifting transformer offers TSOs a certain measure of management and control of the international power flows. For example, the phase-shifting transformer in the northern Netherlands at the border link between Meeden and Dielen (DE) places TenneT in a position to better distribute flows from Germany across the links between Germany and the Netherlands.

2.4 Flow Based parameter verification

After the qualification phase, the TSOs might provide an updated CB file. Based on this updated CB-file, the intermediate FB-parameter calculation is started. This calculation delivers an enlarged (qualified) FB domain that respects the Security of Supply. During the verification step, TSOs check whether the computed FB domain is still secure, with a possibility to identify constraints through an AC load flow analysis or other studies. Therefore, at this step of the process, TSOs have the possibility to verify the FB parameters generated by the centralised intermediate FB computation:

- TSOs can check the grid security in the relevant points (e.g. vertices) of the FB domain by customizing the generation pattern (e.g. merit order, respect generator limits, etc.) to the commonly observed one for the corresponding vertex instead of using the linear GSK
- TSOs can perform a full AC load flow analysis of the relevant points, thereby taking into account reactive power flows and voltage adequacy limits.
- TSOs can assess voltage stability (voltage collapse)

- TSOs can investigate extreme net positions

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 adapting the Final Adjustment Value. In addition, the TSOs can update their external constraints. After the verification step and possible adaptation of the CB-file and External Constraints-file, the final FB-parameter calculation will be performed, which includes adjustment to long-term nominations and presolve steps.

The verification step is a local responsibility of the TSOs.

2.5 LTA inclusion

Given that Programming Authorizations for long term allocated capacity (LTA) have already been sent out in D-2 Working Days (according to the current version of the Auction Rules), the long-term-allocated capacities of the yearly and monthly auctions have to be included in the FB-domain which is calculated, before taking into account the cross-border nominations. An automatic inclusion is foreseen and further details can be found in the approval document for the NRAs:
(http://www.casc.eu/media/140801%20CWE%20FB%20MC%20Approval%20document.pdf).

2.6 LTN adjustment

As long as the LT nominations are unknown, the FB domain is based on the reference flow (Fref). The Fref is the physical flow computed from the Common Grid Model reflecting the loading of the critical branches. For the execution day there must be an adjustment to LT nominations in order to remove the assumption of the exchange programs. The Adjustment itself is done by Flow Based Computation module. Further details can be found in the approval document for the NRAs:
http://www.casc.eu/media/140801%20CWE%20FB%20MC%20Approval%20document.pdf.

2.7 Output Data

The Flow Based parameters that have been computed indicate what net positions, given the Critical Branches that are specified by the TSOs in CWE, can be facilitated under the Market Coupling without endangering the grid security. As such, the Flow Based parameters act as constraints in the optimization that is performed by the Market Coupling mechanism: the net positions of the bidding zones in the Market Coupling are optimized in a way enabling that the day-ahead market welfare is maximized while respecting the constraints provided by the TSOs. Although from the TSO point of view all Flow Based parameters are relevant and do contain information, not all Flow Based parameters are relevant for the Market Coupling mechanism. Indeed, only those Flow Based constraints that are most limiting the net positions need to be respected in the Market Coupling: the non-redundant constraints. The redundant constraints are identified and removed by the TSOs by means of the so-called presolve. This presolve step is schematically illustrated in the two-dimensional example below:

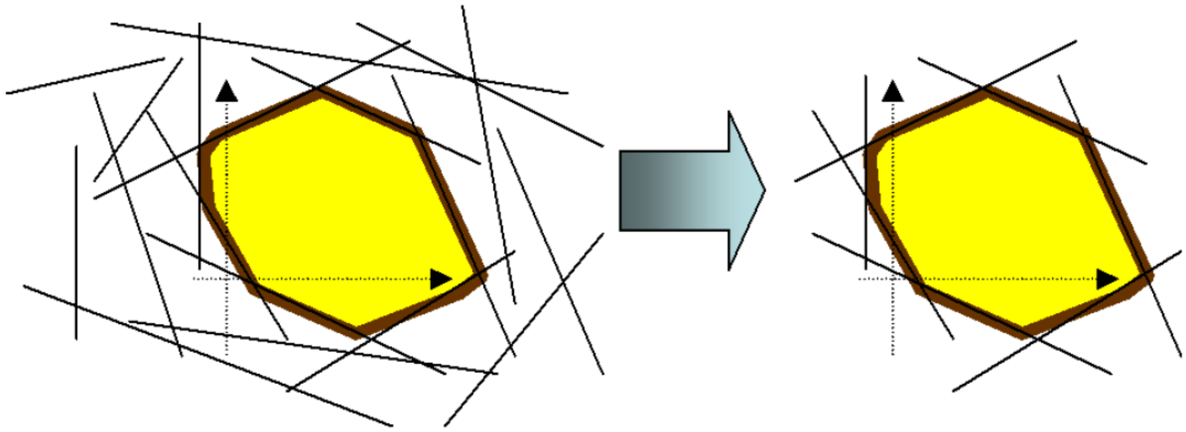

Figure 10 FRM Assessment Principle

In the two-dimensional example shown above, each straight line in the graph reflects the Flow Based parameters of one Critical Branch. A line indicates for a specific Critical Branch, the boundary between allowed and non-allowed net positions. As such, the non-redundant, or presolved, Flow Based parameters define the Flow Based capacity domain that is indicated by the yellow region in the two-dimensional figure above. It is within this Flow Based capacity domain (yellow region) that the net positions of the market can be optimized by the Market Coupling mechanism. The intersection of multiple constraints, in the two-dimensional example above, defines the vertices of the Flow Based capacity domain. The vertices provided in the file represent the vertices of a domain described by the limiting points in the domain.

2.8 ATC Calculation for Shadow Auction

In case of a decoupling in CWE, the philosophy re-mains the same as in ATC Market Coupling, explicit shadow auctions (SA) will be organized. With the TSO CS up and running, 24 Flow Based domains are determined as an input for the FB MC algorithm. In case the latter system fails, the 24 Flow Based domains will serve as the basis for the determination of the SA ATCs that are input to the Shadow Auc-tions. In other words: there will not be any additional and inde-pendent stage of ATC capacity calculation. As the selection of a set of ATCs from the Flow Based domain leads to an infinite set of choices, an algorithm has been designed that determines the ATC values in a systematic way. Further details regarding the algorithm can be found in the approval document for the NRAs:
http://www.casc.eu/media/140801%20CWE%20FB%20MC%20Approval%20document.pdf

3. Determining the Intraday capacity

The flow-based capacity calculation method is different compared to the NTC capacity calculation. The current Intraday capacity allocation mechanisms allocates capacity based on ATC's. In order to make the day-ahead flow-based method compatible with the current Intraday ATC method, some computations have to be performed. The aim is to assess Intraday ATC values deduced from the day-ahead Flow Based parameters, which have been adjusted according to the day-ahead FB market coupling results. The Intraday ATCs can be considered as a leftover of the day-ahead flow-based capacity, see underneath figure. With that respect the initial ID ATC computation is not a new capacity calculation process.

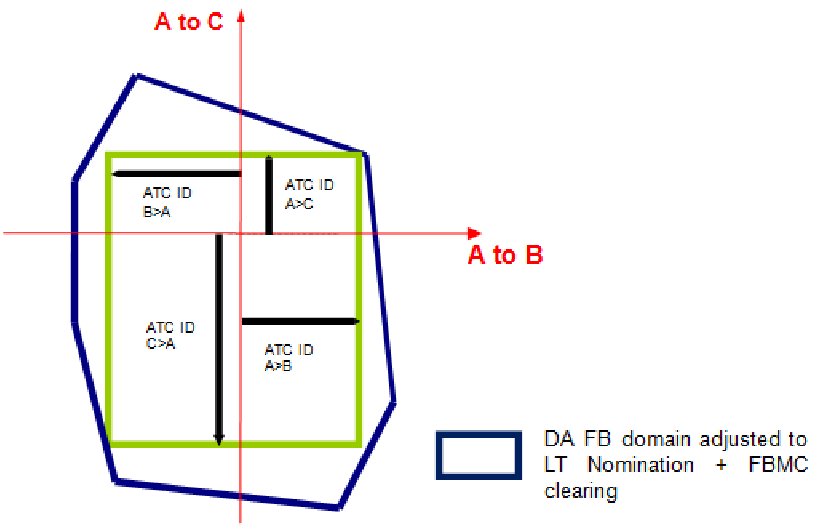

Figure 11: intraday left-over capacity representation

Once the CWE day-ahead market coupling has been executed, it is known which part of cross-border capacity has been taken up by annual, monthly and day-ahead contracts. The remaining cross-border capacity is available to the intraday market. However, calculations have to be performed in order to generate an ATC domain from the day-ahead flow-based domain (after market allocation). The TSOs have the option to increase or reduce the available cross-border Intraday capacity where possible or necessary.

3.1 Determination of the Intraday ATC

The ID ATC calculation is an iterative procedure and part of the so-called post-coupling process. First, the remaining available margins (RAM) of the pre-solved CBs, which were given to the day-ahead market at the end of the pre-coupling process, have to be adjusted to the market coupling results. The adjustment is performed using the net positions resulting from the day-ahead market coupling. The resulting margins serve as a starting point and represent an updated flow-based domain from which the ID ATC domain is determined. Subsequently, an iteration process will start in which the Intraday ATCs will be computed. The calculation leads to initial Intraday ATC values which are forwarded to the CWE TSO's.

3.2 Adjusting intraday capacity

Since January 2013, it has been determined daily on the intraday along with the Belgian TSO Elia, on the border with Belgium, whether there is available (at most) 200 MW in additional securely available cross-border capacity for the market on the Belgian-German border. Since January 2014 a similar intraday process is also in operation for the German-Dutch border, where currently at most 100 MW additional cross-border capacity is made available. Indeed, these processes were developed under an ATC based day-ahead market coupling. These processes on both the Dutch border will be continued.

New information on intraday
TSOs constantly exchange information on the actual and expected grid situation by means of *intraday congestion forecasts* (IDCF). TenneT uses this information to draw up a *rolling forecast* with reference to the expected grid security for the Dutch grid for the hours ahead. As the information used for this is drawn up close to the point of execution, this forecast exhibits fewer uncertainties than a day-ahead (D-1) or (D-2) forecast (which is used for determining the cross-border capacity on the day-ahead).

Conditions for the release of additional capacity on the Belgian and German border
In order to be able to respect agreements with respect to day-ahead capacity the following applies:

- System security problems cannot arise when the initial Intraday capacity is increased.

When no system security problems are being monitored, 300 MW in additional cross-border capacity can be released (usually in blocks of 4 hours in advance).

3.3 Trading platform intraday capacity

NL-BE & NL-DE
During the current day (intraday), the capacity still available is offered via an implicit auction for the Dutch-Belgian border. On the Dutch-German border, the capacity still available is offered via an explicit auction.