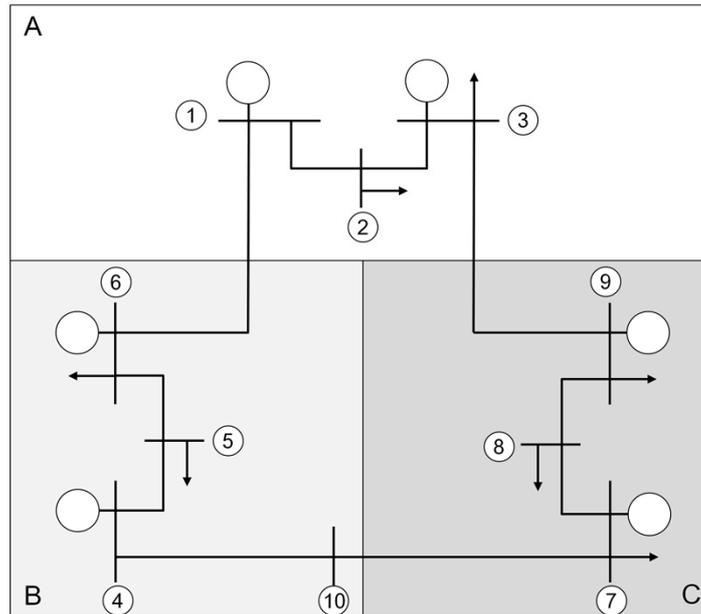


## Example grid for capacity calculation



All lines in the grid have the same impedance

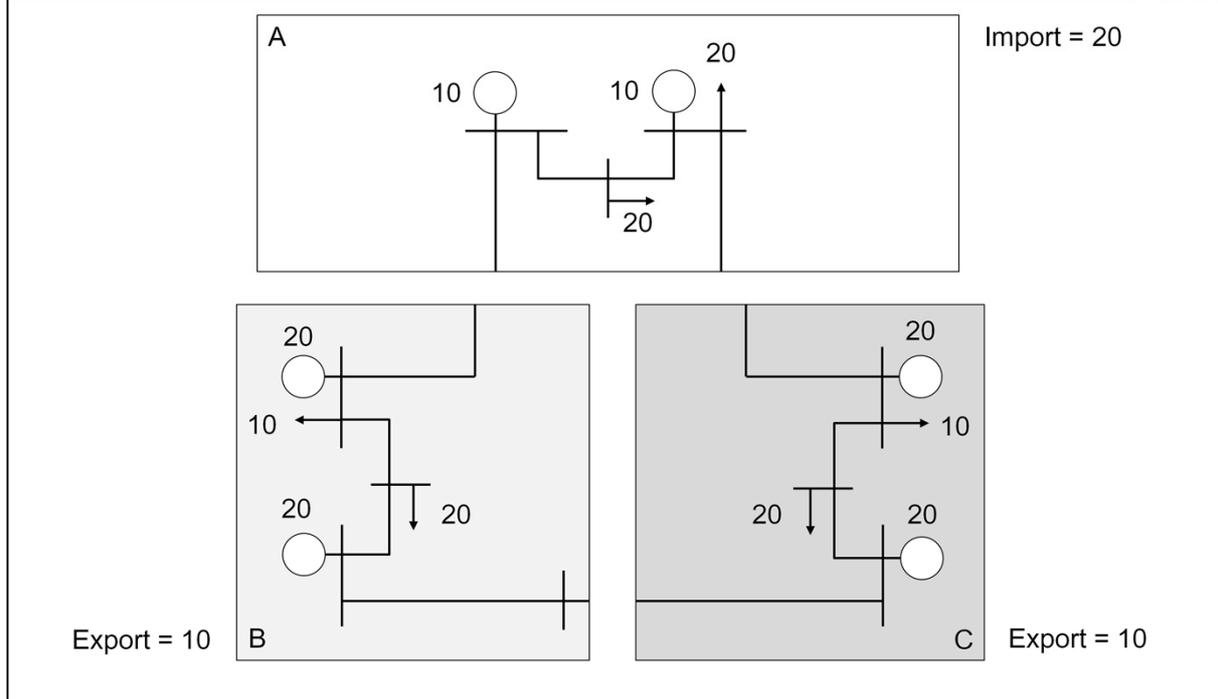


A 10-node network is used as an example to demonstrate the CWE Flow-Based (FB) capacity calculation.

The nodes (or substations) are numbered 1..10. The loads in the grid are indicated by the arrows (e.g. on node 8). The generation in the grid is indicated by the circles (e.g. on node 9).

The grid spans three zones / TSOs (A, B, and C).

All lines in the grid have the same impedance.



#### Section 2.1.4. D2CF Files, reference Programs

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

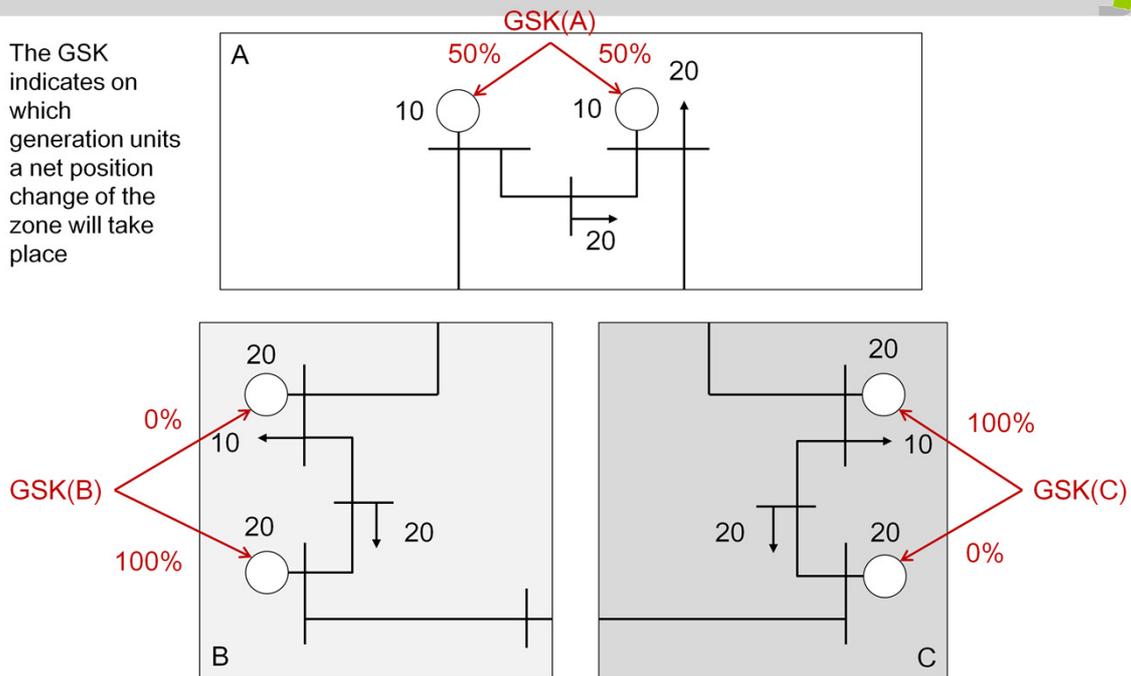
Each TSO produces for its zone D2CF files (24 files per day) which contain the net exchange programs of a reference day. In our example, on the reference day, zone A was importing 20 MW whereas zone B and C were exporting 10 MW each.

Given those net exchange programs, the TSOs make a best estimate where on day D the corresponding production and consumption in their grid takes place, as is reflected in the example by the generation infeed and the consumption. Indeed, if we add up the generation infeed in zone A (20 MW) and subtract the total consumption in zone A (40 MW), the result equals the import position of the reference day (being 20 MW).

## GSK (Generation Shift Key)



The GSK indicates on which generation units a net position change of the zone will take place



### Section 2.1.7. GSK

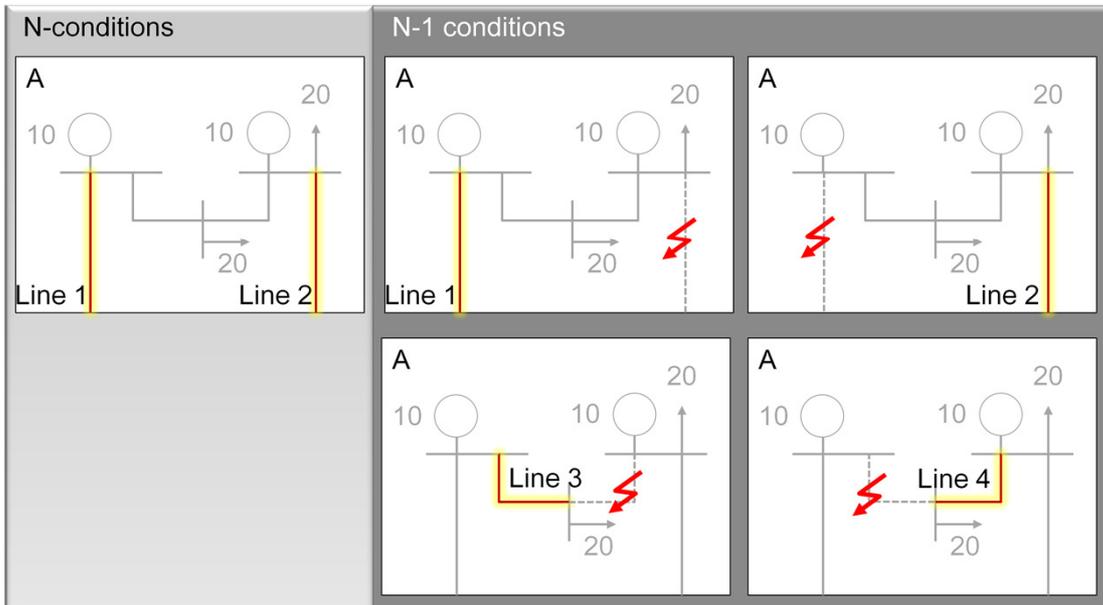
The Generation Shift Key (GSK) defines how a change in net position is mapped to the generating units in a bidding area. For that, it contains the relation between the change in net position of the market area and the change in output of every generating unit inside the same market area.

The TSO in zone A, for example, estimates that a net position of zone A, as it will be determined by the FBMC, will alter the generation infeed of the two units in its grid equally.

## CBs (Critical Branches)



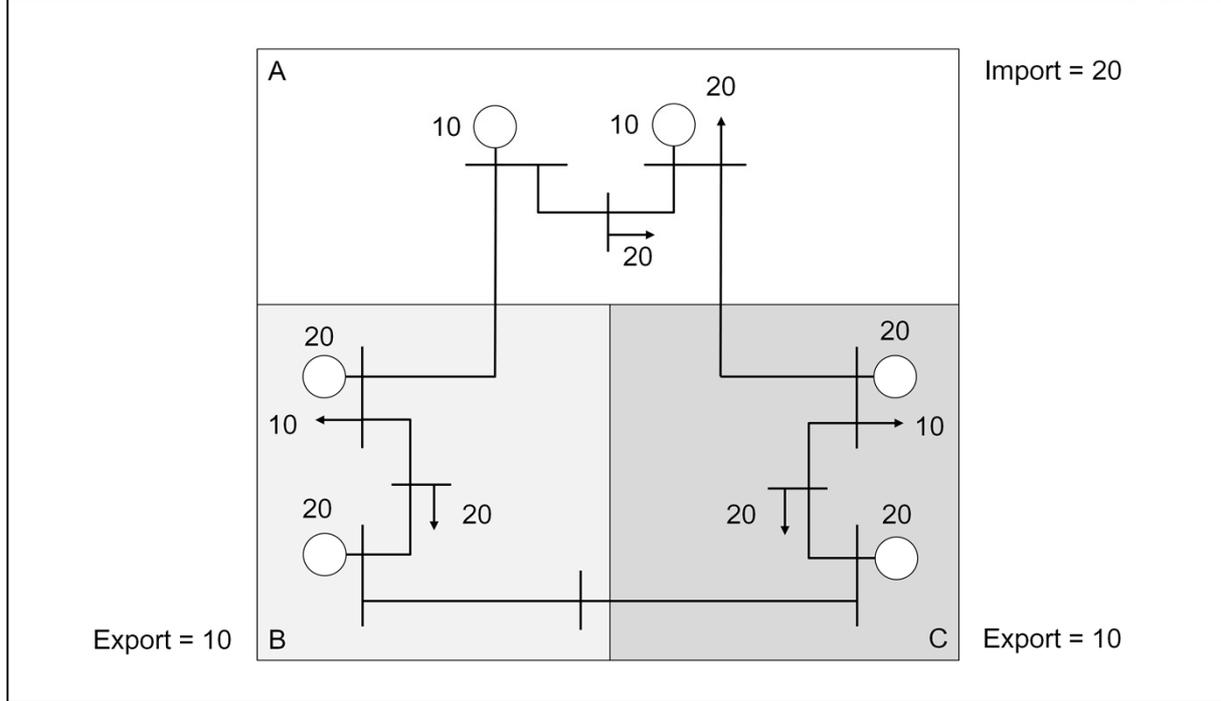
Branches monitored by TSO A (Line 1 / 2 / 3 / 4, marked in yellow):



### Section 2.1.5. CBCO-selection

A Critical Branch (CB) is a network element, significantly impacted by 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 TSO for its own network according to agreed rules.

In this example, the CBCOs as determined by TSO A are shown. The monitored elements (CBs, indicated by the red lines with yellow highlight) are line 1 and line 2. Those lines are monitored under N-conditions (i.e. no outages), as well as certain N-1 conditions (i.e. a scenario where a grid element is out of service, indicated by the red flash).



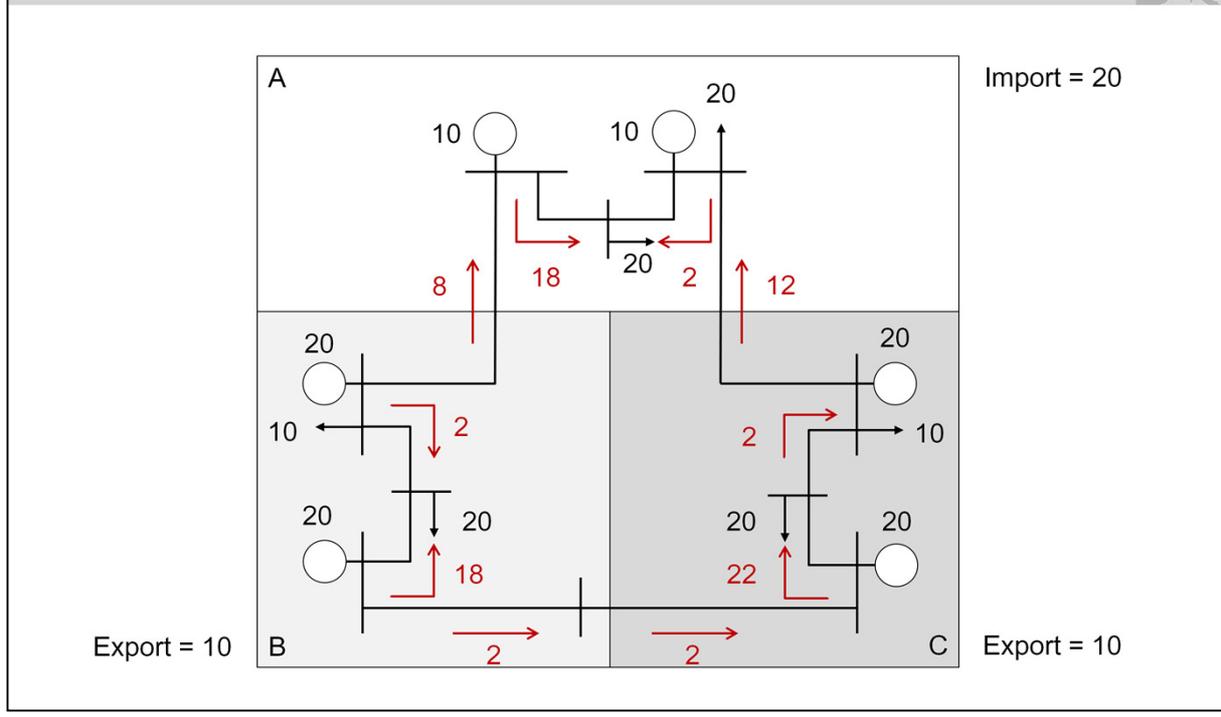
### Section 2.2.1. Merging

We have already seen that each TSO produces for its zone D2CF files which contain the net exchange programs of a reference day.

The basis for the calculation process is a model of the whole grid (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 the individual grid models.

The individual grid models 'fit' to one another, as the net exchange programs of the reference day have been used by all TSOs when generating their D2CF file: the zones B and C export what A is importing.

The merged model is called the base case.



### Section 2.2.3. Centralized Initial-FB parameter computation

The reference flow (Fref) under N conditions 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.

For line 1, the Fref, line1 = 8 MW.

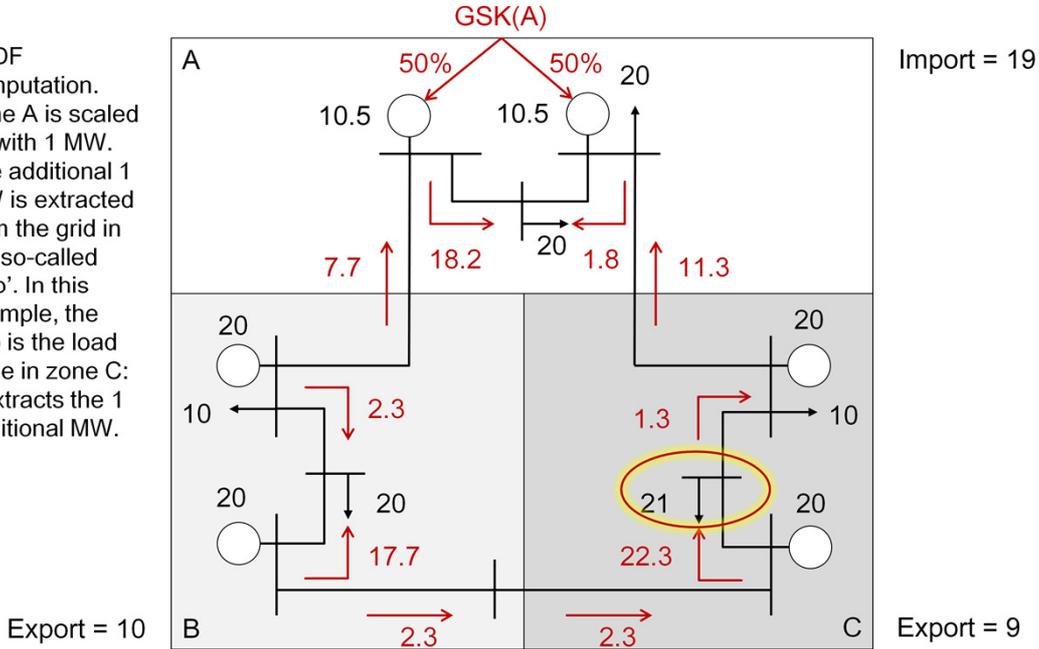
For line 2, the Fref, line2 = 12 MW.

Note that we monitor the CBs in a certain direction: line 1 (from node 6 to node 1) and line 2 (from node 9 to node 3).

FB parameter computation: increase of generation in zone A with 1 MW



PTDF computation. Zone A is scaled up with 1 MW. The additional 1 MW is extracted from the grid in the so-called 'hub'. In this example, the hub is the load node in zone C: it extracts the 1 additional MW.



Section 2.2.3. Centralized Initial-FB parameter computation

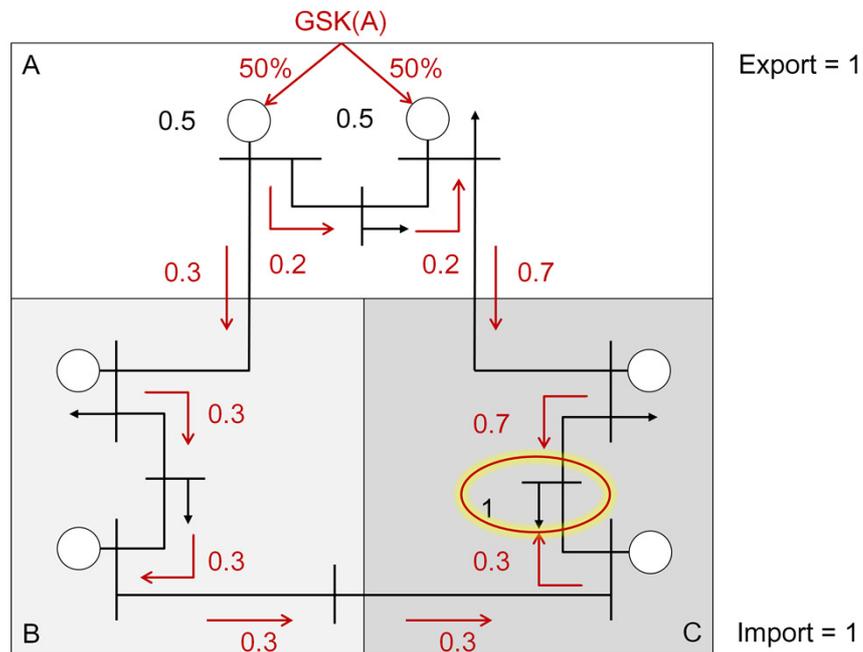
The sensitivities of the critical branches are called PTDFs. These FB parameters are calculated in the following way:

The PTDFs are calculated by varying the exchange program of a zone (=market area), taking the corresponding GSK into account. For every single zone-variation the effect on every CB loading is monitored and the effect on the loadflow is calculated. 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.

In the example, zone A is scaled up with 1 MW. The additional 1 MW is extracted from the grid in the so-called 'hub'. In this example, the hub is the load node in zone C: it extracts the 1 additional MW. The 1 MW shift in net position in zone A is spread evenly between the two generation units, as dictated by the GSK of zone A.

The flows resulting from the changed net positions are shown in the slide.

FB parameter computation: increase of generation in zone A with 1 MW  
 - Difference compared to the basecase -



Section 2.2.3. Centralized Initial-FB parameter computation

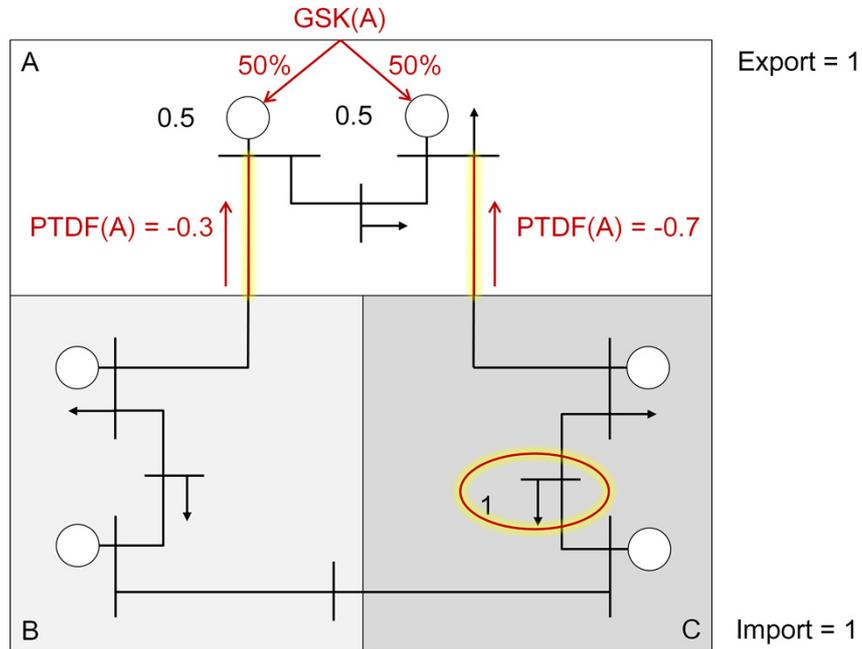
In our example on the previous slide, we scaled up zone A with 1 MW, while we extracted the additional 1 MW from the grid in the so-called 'hub' (in this example, the hub is the load node in zone C).

The difference compared to the base case (and the reference flows) is illustrated in the slide. Indeed, this is exactly what the PTDF factor is about: it translates the 1 MW shift in net position in zone A (and extraction of the 1 MW in the 'hub') into a flow on the grid elements.

**FB parameter computation: increase of generation in zone A with 1 MW**  
**- Difference compared to the basecase -**



PTDF factors resulting from the 1 MW exchange between zone A and the hub for the monitored branches in A under N conditions.



**Section 2.2.3. Centralized Initial-FB parameter computation**

Under N-conditions, the PTDF factors of the CBs line 1 and line 2, when changing the net position of zone A, are:

For line 1, the PTDF(A), line1 = -0.3 MW.

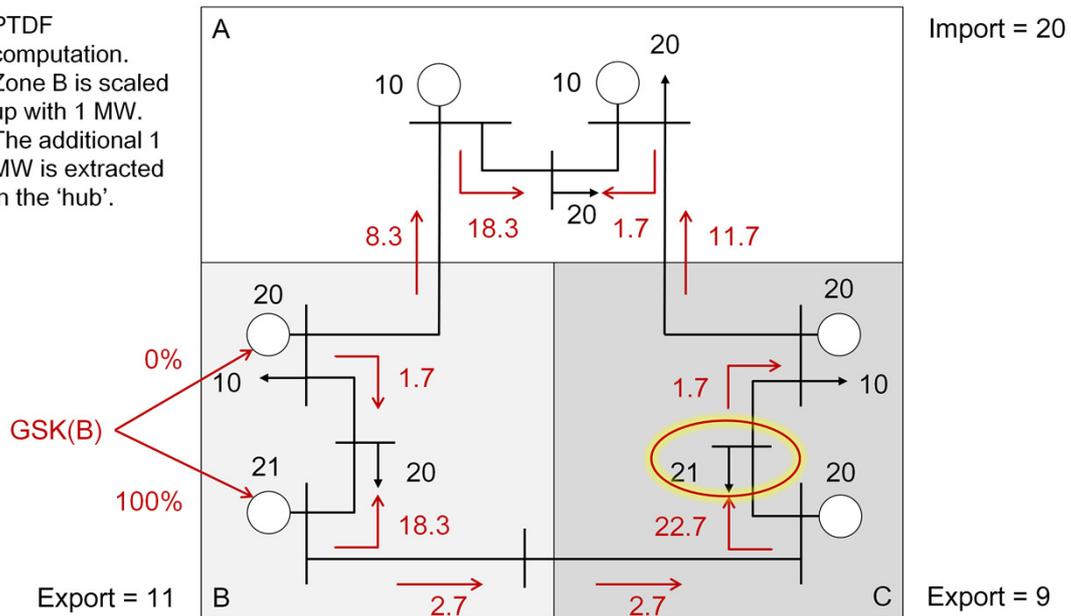
For line 2, the PTDF(A), line2 = -0.7 MW.

Note that we monitor the CBs in a certain direction: line 1 (from node 6 to node 1) and line 2 (from node 9 to node 3).

FB parameter computation: increase of generation in zone B with 1 MW



PTDF computation. Zone B is scaled up with 1 MW. The additional 1 MW is extracted in the 'hub'.

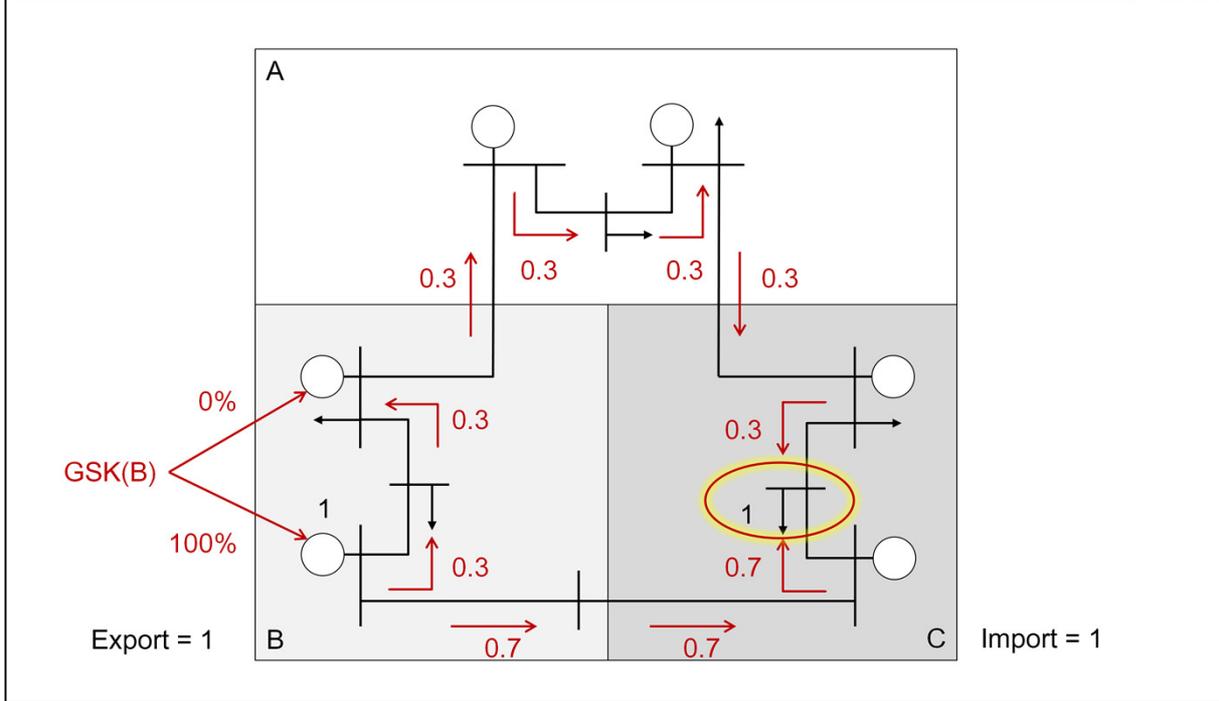


Section 2.2.3. Centralized Initial-FB parameter computation

In the example, zone B is scaled up with 1 MW. The additional 1 MW is extracted from the grid in the so-called 'hub'. In this example, the hub is the load node in zone C: it extracts the 1 additional MW. The 1 MW shift in net position in zone B is spread non-evenly between the two generation units, as dictated by the GSK of zone B.

The flows resulting from the changed net positions are shown in the slide.

FB parameter computation: increase of generation in zone B with 1 MW  
- Difference compared to the basecase -

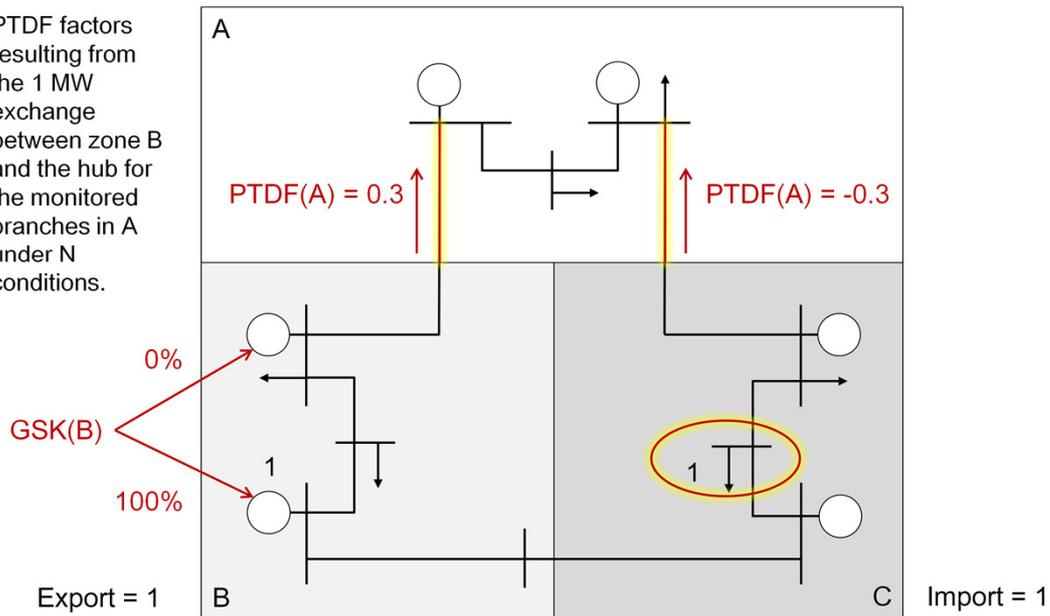


The slide above shows the difference to the base case.

**FB parameter computation: increase of generation in zone B with 1 MW  
- Difference compared to the basecase -**



PTDF factors resulting from the 1 MW exchange between zone B and the hub for the monitored branches in A under N conditions.



**Section 2.2.3. Centralized Initial-FB parameter computation**

Under N-conditions, the PTDF factors of the CBs line 1 and line 2, when changing the net position of zone B, are:

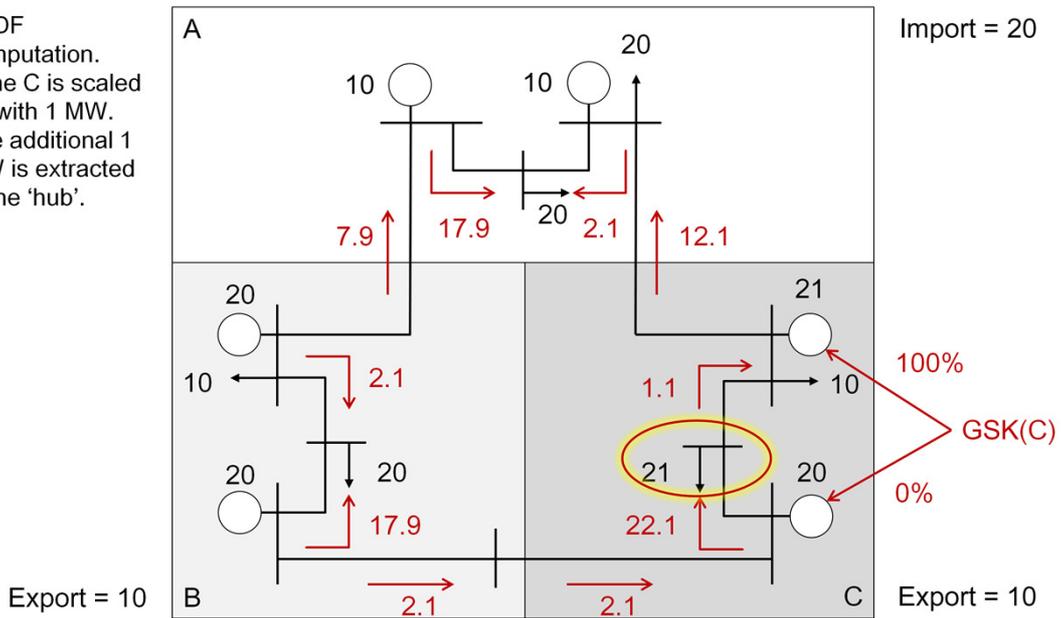
For line 1, the PTDF(B), line1 = 0.3 MW.

For line 2, the PTDF(B), line2 = -0.3 MW.

FB parameter computation: increase of generation in zone C with 1 MW



PTDF computation. Zone C is scaled up with 1 MW. The additional 1 MW is extracted in the 'hub'.

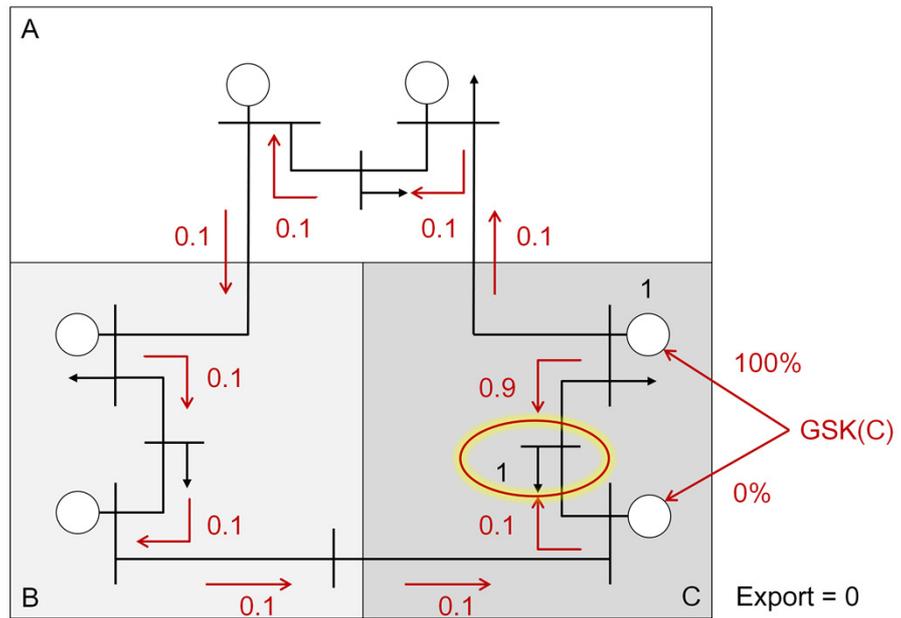


Section 2.2.3. Centralized Initial-FB parameter computation

In the example, zone C is scaled up with 1 MW. The additional 1 MW is extracted from the grid in the so-called 'hub'. In this example, the hub is the load node in zone C: it extracts the 1 additional MW. The 1 MW shift in net position in zone C is spread non-evenly between the two generation units, as dictated by the GSK of zone C.

The flows resulting from the changed net positions are shown in the slide.

FB parameter computation: increase of generation in zone C with 1 MW  
- Difference compared to the basecase -

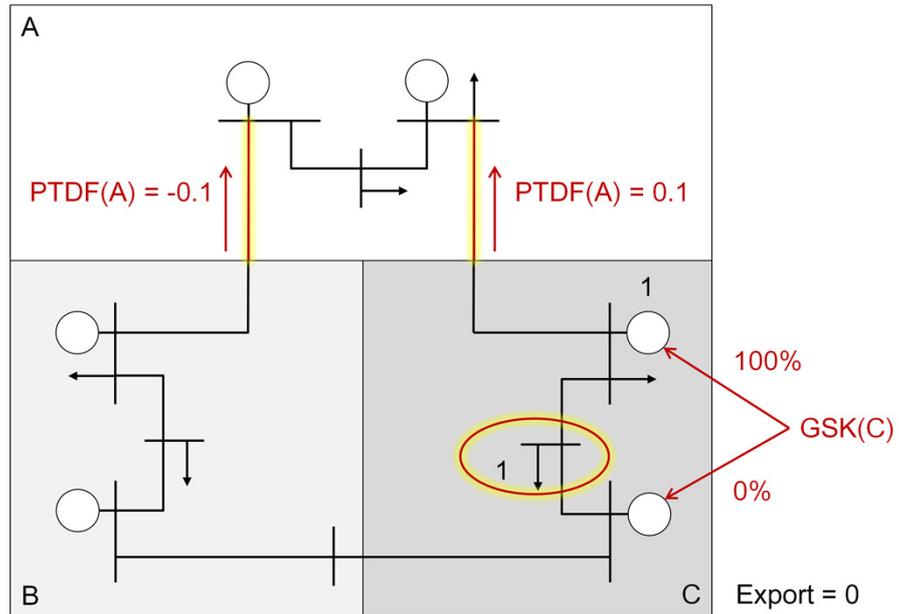


The slide above shows the difference to the base case.

**FB parameter computation: increase of generation in zone C with 1 MW**  
**- Difference compared to the basecase -**



PTDF factors resulting from the 1 MW exchange between zone C and the hub for the monitored branches in A under N conditions.

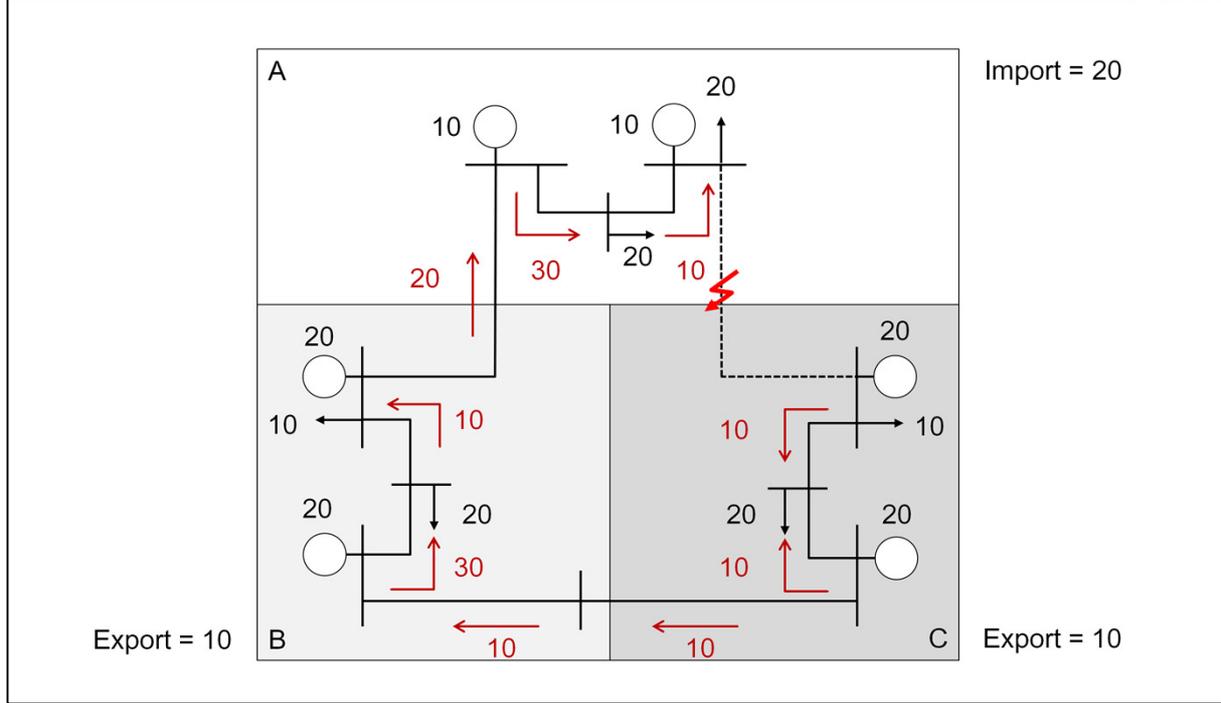


**Section 2.2.3. Centralized Initial-FB parameter computation**

Under N-conditions, the PTDF factors of the CBs line 1 and line 2, when changing the net position of zone C, are:

For line 1, the PTDF(C), line1 = -0.1 MW.

For line 2, the PTDF(C), line2 = 0.1 MW.



Section 2.2.3. Centralized Initial-FB parameter computation

The reference flow ( $F_{ref}$ ) under N-1 conditions is the physical flow computed from the common base case when an outage scenario is applied, and reflects the loading of the critical branches given the exchange programs of the chosen reference day.

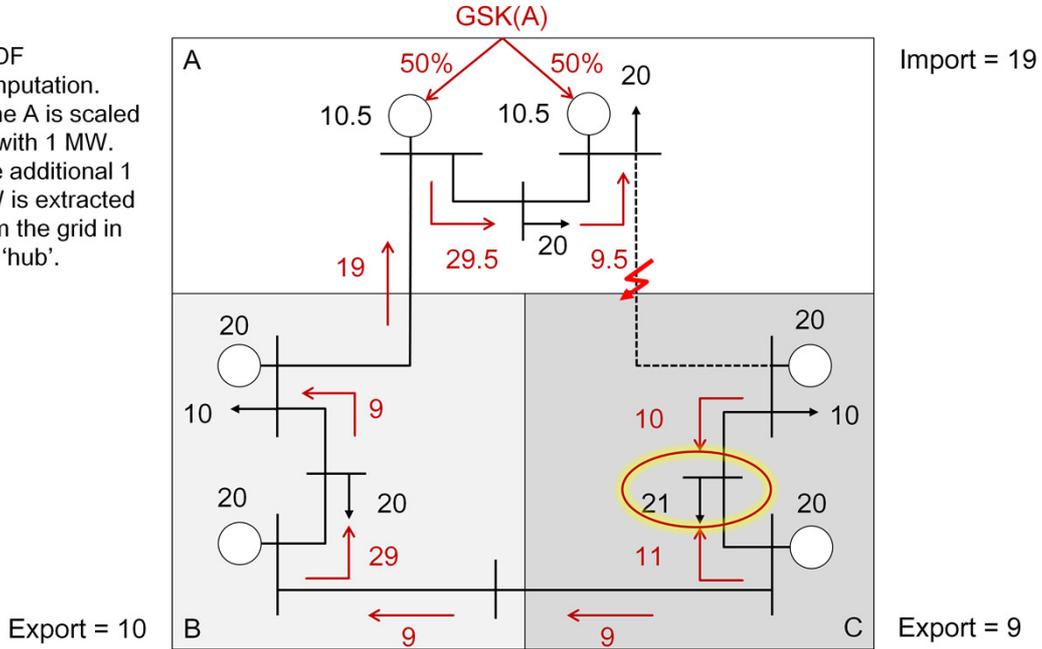
For line 1, the  $F_{ref, line1} = 20$  MW.

Line 2 is out.

FB parameter computation (N-1): increase of generation in zone A with 1 MW



PTDF computation. Zone A is scaled up with 1 MW. The additional 1 MW is extracted from the grid in the 'hub'.



Section 2.2.3. Centralized Initial-FB parameter computation

In the example, zone A is scaled up with 1 MW. The additional 1 MW is extracted from the grid in the so-called 'hub'. In this example, the hub is the load node in zone C: it extracts the 1 additional MW. The 1 MW shift in net position in zone A is spread evenly between the two generation units, as dictated by the GSK of zone A.

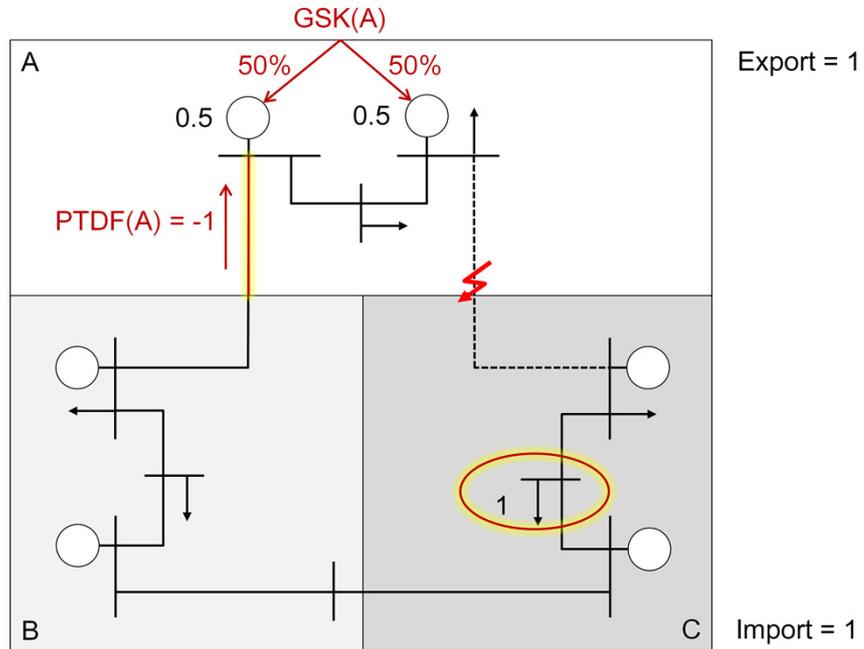
The flows resulting from the changed net positions are shown in the slide.



**FB parameter computation (N-1): increase of generation in zone A with 1 MW**  
**- Difference compared to the base flows in the N-1 scenario -**



PTDF factor resulting from the 1 MW exchange between zone A and the hub for the monitored branch in A under a N-1 condition.



**Section 2.2.3. Centralized Initial-FB parameter computation**

Under the N-1 scenario where line 2 is out of service, the PTDF factor of the CB line 1, when changing the net position of zone A, is:

For line 1, the  $PTDF(A), line1 = -1$  MW.

This step is repeated for the other zones in a similar way ...

FB parameter computation: summary



Monitored branch	Outage scenario	Zone A PTDF	Zone B PTDF	Zone C PTDF	RAM
Line 1	-	-0.3	0.3	-0.1	.
Line 2	-	-0.7	-0.3	0.1	.
Line 1	Line 2	-1	.	.	.
Line 2	Line 1	.	.	.	.
Line 3	Line 4	.	.	.	.
Line 4	Line 3	.	.	.	.
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Section 2.2.3. Centralized Initial-FB parameter computation

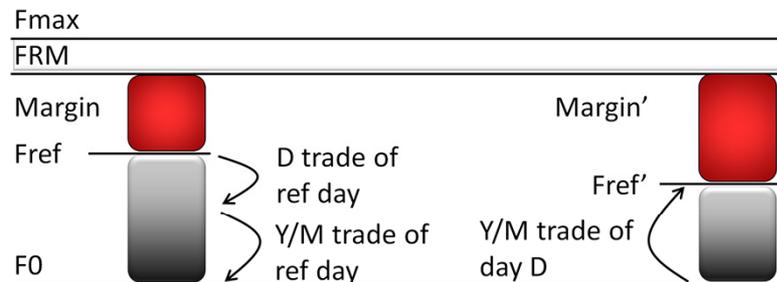
The FB parameters determined so far are depicted in the table on the slide. The exercise demonstrated on the previous slides is repeated for all CBCOs by applying net position shifts in all the zones (market areas).

The column labelled 'RAM' (Remaining Available Margin) is still empty, and will be elaborated upon in the next slides.

## FB parameter computation: Fref and Fref'



- In the flows observed in the D2CF basecase (the Fref) the impact of cross-border trade (of the reference day) is reflected. The flows are adjusted in accordance to the graph below



- For line 1:
  - $F_{ref} = 8$  (as computed on slide 6)
  - Net positions in the D2CF basecase:  $NP(A) = -20$ ,  $NP(B) = 10$ ,  $NP(C) = 10$
  - $F_0 = F_{ref} - (NP(A) \cdot PTDF(A) + NP(B) \cdot PTDF(B) + NP(C) \cdot PTDF(C)) = 8 - (-20 \cdot -0.3 + 10 \cdot 0.3 + 10 \cdot -0.1) = 8 - 8 = 0$
  - Assume that the net positions due to the long-term nominations equal:  $NP(A) = -10$ ,  $NP(B) = 5$ ,  $NP(C) = 5$
  - $F_{ref}' = F_0 + (NP(A) \cdot PTDF(A) + NP(B) \cdot PTDF(B) + NP(C) \cdot PTDF(C)) = 0 + (-10 \cdot -0.3 + 5 \cdot 0.3 + 5 \cdot -0.1) = 0 + 4 = 4$

### Section 2.2.7. LTN adjustment

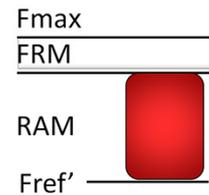
As the reference flow (Fref) is the physical flow computed from the common base case, it reflects the loading of the critical branches given the exchange programs of the chosen reference day. Therefore, this reference flow has to be adjusted to take into account only the effect of the LT nominations of the maturity day D as soon as they are known: Fref'.

Note that the PTDFs are used for this calculation step.

## FB parameter computation: Fmax, FRM, and RAM



- The maximum allowed flow on line 1 equals:  
 $F_{max} = 25$
- The Flow Reliability Margin (FRM) on line 1, the margin that the TSO needs to reserve in order to hedge against uncertainties, has been assessed to be equal to:  
 $FRM = 3$
- We computed the  $F_{ref}'$  on line 1, the flow that is expected to flow on line 1 prior to the allocation of the Day-Ahead capacity, to be:  
 $F_{ref}' = 4$
- The Remaining Available Margin (RAM) on line 1, the margin available for the market to be used under the FBMC, amounts:  
 $RAM = F_{max} - FRM - F_{ref}' = 25 - 3 - 4 = 18$



### Section 2.2.7. LTN adjustment

$$RAM = F_{max} - F_{ref}' - FRM - FAV$$

The calculation delivers, with respect to the other parameters, the free margin for every CB, which is called RAM. Indeed, this number reflects the number of MWs that can be used by market movements without endangering the grid security. Like PTDF, RAM is another FB parameter.

The value  $F_{max}$  describes the maximum allowable power flow on a CBCO in MW.

The value  $FRM$  describes the uncertainty on a CBCO, linked to the capacity calculation process, and that a TSO needs to hedge against, in MW.

The  $FAV$  (Final Adjustment Value in MW) is not reflected in the slide above. With the Final Adjustment Value ( $FAV$ ), operational skills and experience that cannot be introduced into the complex FB system can find a way into the FB-approach by increasing or decreasing the margin on a CB for very specific reasons. It goes beyond the scope of this example to touch upon the  $FAV$ .

FB parameter computation: summary



Monitored branch	Outage scenario	Zone A PTDF	Zone B PTDF	Zone C PTDF	RAM
Line 1	-	-0.3	0.3	-0.1	18
Line 2	-	-0.7	-0.3	0.1	.
Line 1	Line 2	-1	.	.	.
Line 2	Line 1	.	.	.	.
Line 3	Line 4	.	.	.	.
Line 4	Line 3	.	.	.	.
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Section 2.3. Output data

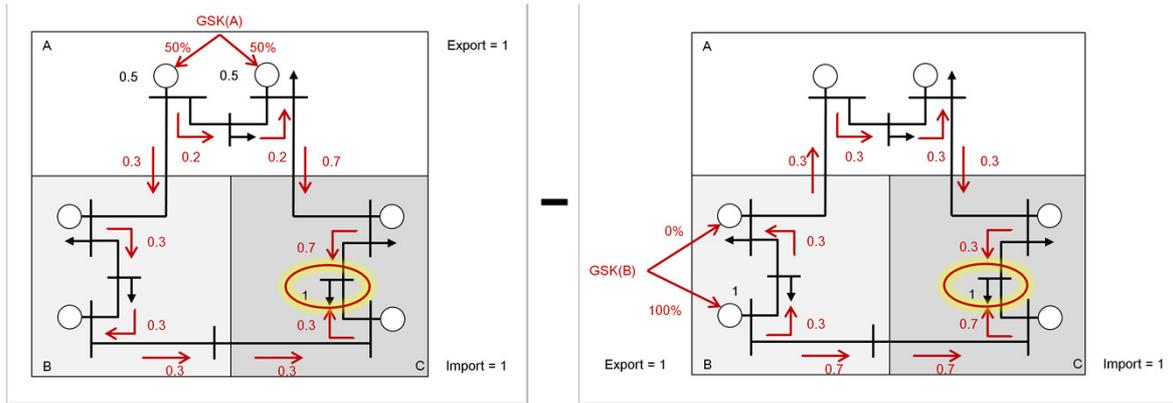
The FB parameters determined so far are depicted in the table on the slide. The exercise demonstrated on the previous slides is repeated for all CBCOs by applying net position shifts in all the zones (market areas).

With the PTDFs and the RAMs derived, the FB parameters are available. The FB parameters that have been computed indicate what net positions, given the Critical Branches that are specified by the TSOs, can be facilitated under the Market Coupling without endangering the grid security.

## Exchange of 1 MW from zone A to zone B; how about the hub?



An exchange of 1 MW from zone A to zone B is equivalent to:  
 an exchange of 1 MW from zone A to the hub – an exchange of 1 MW from zone B to the hub



It is important to note that we compute “zone-to-hub” PTDFs: the flows induced when we scale up a zone with 1 MW, while we extract the 1 MW from a hub. A more common way of looking to PTDFs, are the zone-to-zone PTDFs. Indeed, 1 MW injected in zone A will be taken out in other zones / another zone. The use of the “hub” is just a computational trick. The advantage of this trick is that the FB parameters are concentrated in a small number of values (zone-to-hub PTDFs). Computing and providing separately all combinations of hub-to-hub PTDF would be impractical, especially if the number of zones increases.

Please note that the choice of the “hub” (as long as the choice of the hub is unique within the overall computation) does not impact the relevant numbers:

An exchange of 1 MW from zone A to zone B = (an exchange of 1 MW from zone A to the hub) - (an exchange of 1 MW from zone B to the hub).

This property holds due to the linearity of the PTDF computation (DC load flow computation). “Zone-to-zone” PTDFs are therefore easily derived by subtracting the “zone-to-hub” PTDFs that we have computed so far.

This property is demonstrated on this and the following slide.

Exchange of 1 MW from zone A to zone B; how about the hub?

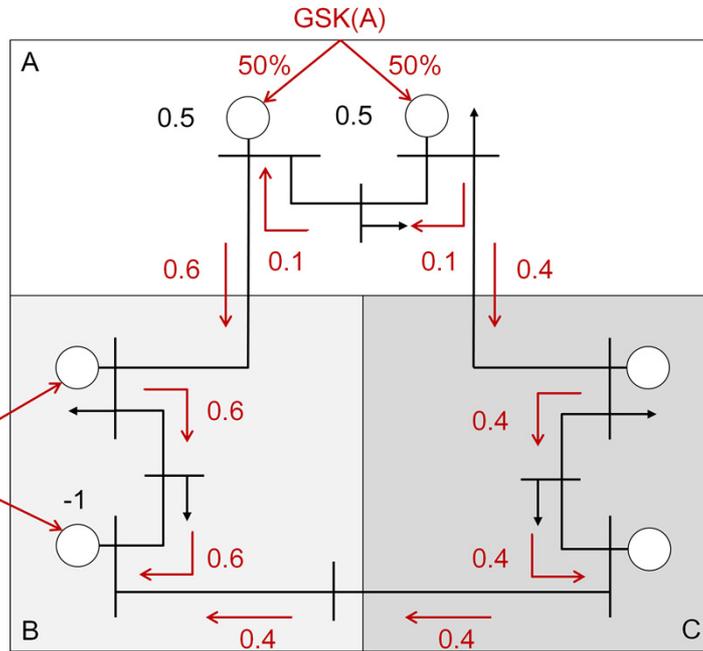


An exchange of 1 MW from zone A to zone B is equivalent to: an exchange of 1 MW from zone A to the hub – an exchange of 1 MW from zone B to the hub

GSK(B)

0%  
100%

Import = 1



Export = 1