ADVANCED CONTROLLABILITY OF HVDC

practical examples

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DIFFERENT MARKETS, DIFFERENT CONTROLS

Today a number of different market solutions are either already operational, or will be in the near future:

- **Day ahead** (DA) and **Intraday markets** (ID): today they are hourly based markets, but in the future both will be based on 15 min market periods
- mFRR, manual Frequency Restoration Reserve, also a reserve type with a resolution of 15-60 minutes, in the future the european **MARI** platform will allow exchange of mFRR reserves across HVDC tielines
- aFRR, automatic Frequency Restoration Reserves, more complex reserve type, will be activated based on observations (measurements) and can change values every 4 sec. In the future the european **Picasso** platform will be responsible for calculting and sending setpoints to HVDC links
- **IGCC**, International Grid Control Cooperation, imbalance netting function running today, but will be expanded to include HVDC in future, also with new setpoints every 4 sec.

HVDC CONTROL, LCC OR VSC SPECIALS

By nature it is rather simple to control VSC converters, they do not have any restrictions related to change of direction, no minimum power, no block/deblock sequences, no filter switching e.g.

LCC converters are more complex, this type of converter can not operate below a certain limit (typically approx 3%), do not like frequent block/deblock sequences (change of direction) and for some manufacturers operation within certain ranges can require use of converter transformer tap changers, so operating within this range is not desired.

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HVDC CONTROLS, TYPES OF CONTROLS

Normal Power control orders

- Absolute Power control, A-reg
- ~~Delta regulation, D-reg~~
- Absolute Delta regulation, AD-reg (not available everywhere)

Power controls based on Local criterias

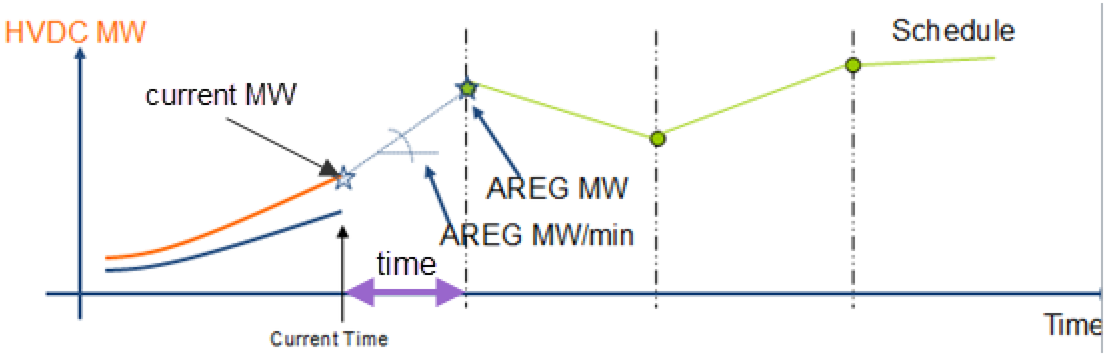
- Frequency Control Regulation, FCR
- Emergency power, used in protection schemes
- Runback, used in protection schemes

Reactive power controls

- RPC, Reactive Power Control
- EPQ, Emergency power-reactive

ABSOLUTE POWER CONTROL, TYPICAL USE

Absolute regulation is a type of regulation primarily used to allow the HVDC connection to follow a predefined power schedule. The A-reg controls consist of a final value, a ramp rate and "initialize"



Final value is defined as next power breakpoint "AREG MW" in the power schedule

Ramp rate is defined as: $\frac{(\text{AREG MW} - \text{current MW})}{time}$

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ABSOLUTE POWER CONTROL, CONTINUED

Automatic creation of power schedules

- If the regulation of an HVDC connection is to be performed automatically, either by using an internal scheduler function in the HVDC connections pole control or coming from an external source (SCADA) hourly exchange schedules needs to be converted to a power schedule.
- Power schedules are normally based on hourly energy schedules coming from Day-ahead and intraday market operators, it could however be any type of schedule. An example could look like this:

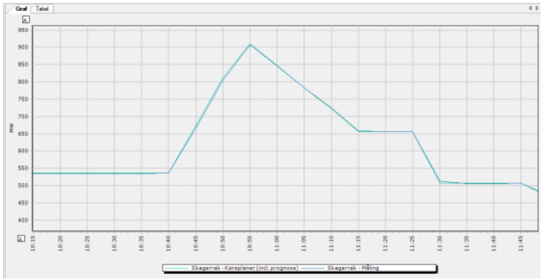
Original energy schedule

Hour	MWh/h
6	552,4
7	350
8	0

Calculated power schedule

Time	MW
05:00	616
05:05	595
05:10	574
05:15	552
05:20	552
05:25	552
05:30	552
05:35	552
05:40	552
05:45	552
05:50	552
05:55	552
06:00	552
06:05	552
06:10	552
06:15	552
06:20	552
06:25	552
06:30	552
06:35	552
06:40	552
06:45	552
06:50	519
06:55	485
07:00	451
07:05	418
07:10	384
07:15	350
07:20	350
07:25	350
07:30	350
07:35	350
07:40	350
07:45	350
07:50	317
07:55	283
08:00	175

In future the MARI platform will also add regulations to the A reg based schedule regulation



ABSOLUTE DELTA REGULATION, AD-REG

The newest control type introduced is the AD-reg, the reason behind this new type of control was to allow the HVDC connection to operate as a ”power plant” in the normal LFC control (Load Frequency Controller)

In addition there was a growing demand for smart balancing functions, such as imbalance netting and sharing of aFRR reserves (Picasso in future)

The concept behind AD-reg is quite different from the A-reg orders, AD-reg orders can be send to both stations at the same time (not necessary to be MASTER)

ABSOLUTE DELTA REGULATION, AD-REG, CONTINUED

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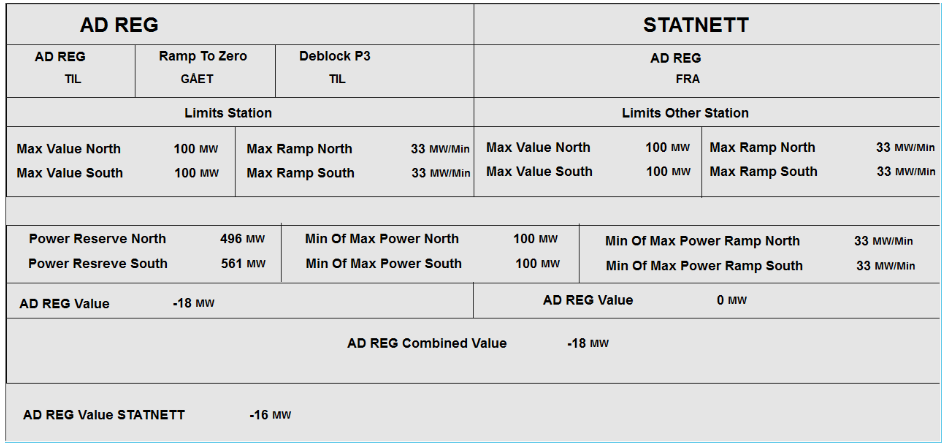
The current implementation of the AD-reg functionality at Energinet.dk is supposed to cover these two usecases:

- Exchanging reserves from one area to another
- Allow both areas to benefit from imbalance netting function without the need to include neighboring area in own LFC control
- Expected to be used for by The International Grid Control Cooperation (IGCC) for imbalance netting in near future
- Direct interface from Picasso in future
- Transparency, controls are kept seperated, it is possible only to change direction if DA or ID markets do so e.g.



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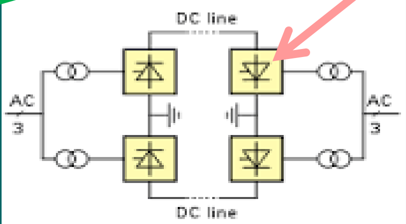
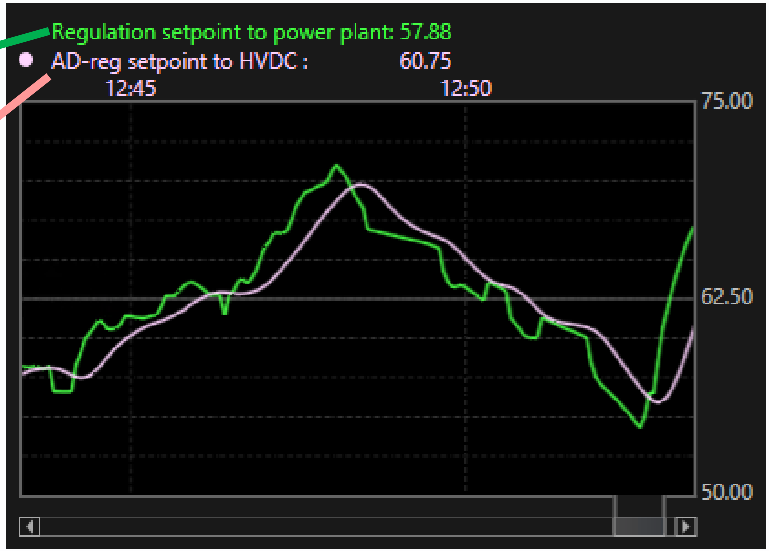
ABSOLUTE DELTA REGULATION, AD-REG, CONTINUED

Exchanging reserves from one area to another:

Supplier in area B

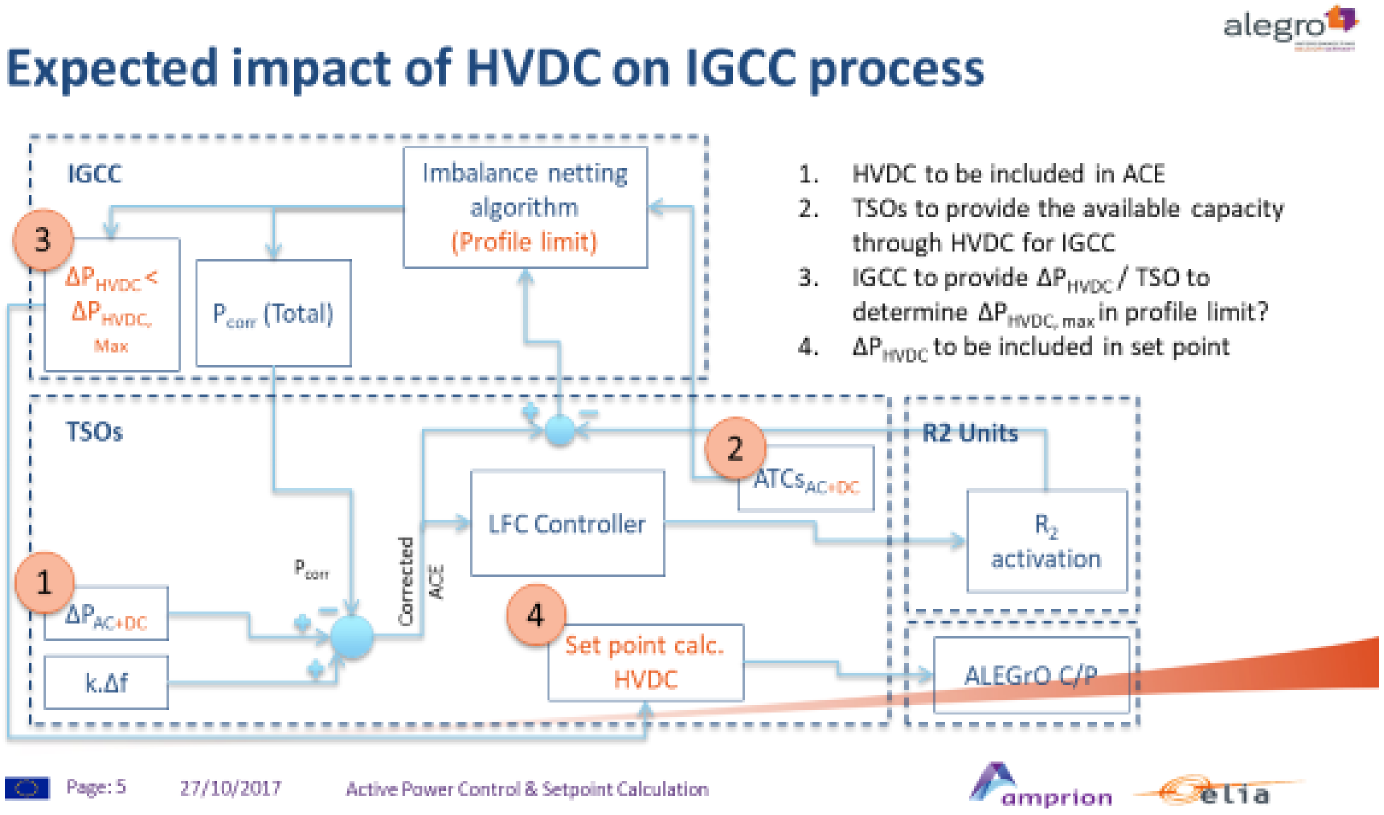




Purchase in area A

The difference between regulation setpoint to power plant and AD-reg signal to HVDC reflects delays in communication and control of the power plant.

ABSOLUTE DELTA REGULATION, PICASSO



EMERGENCY POWER, EPC

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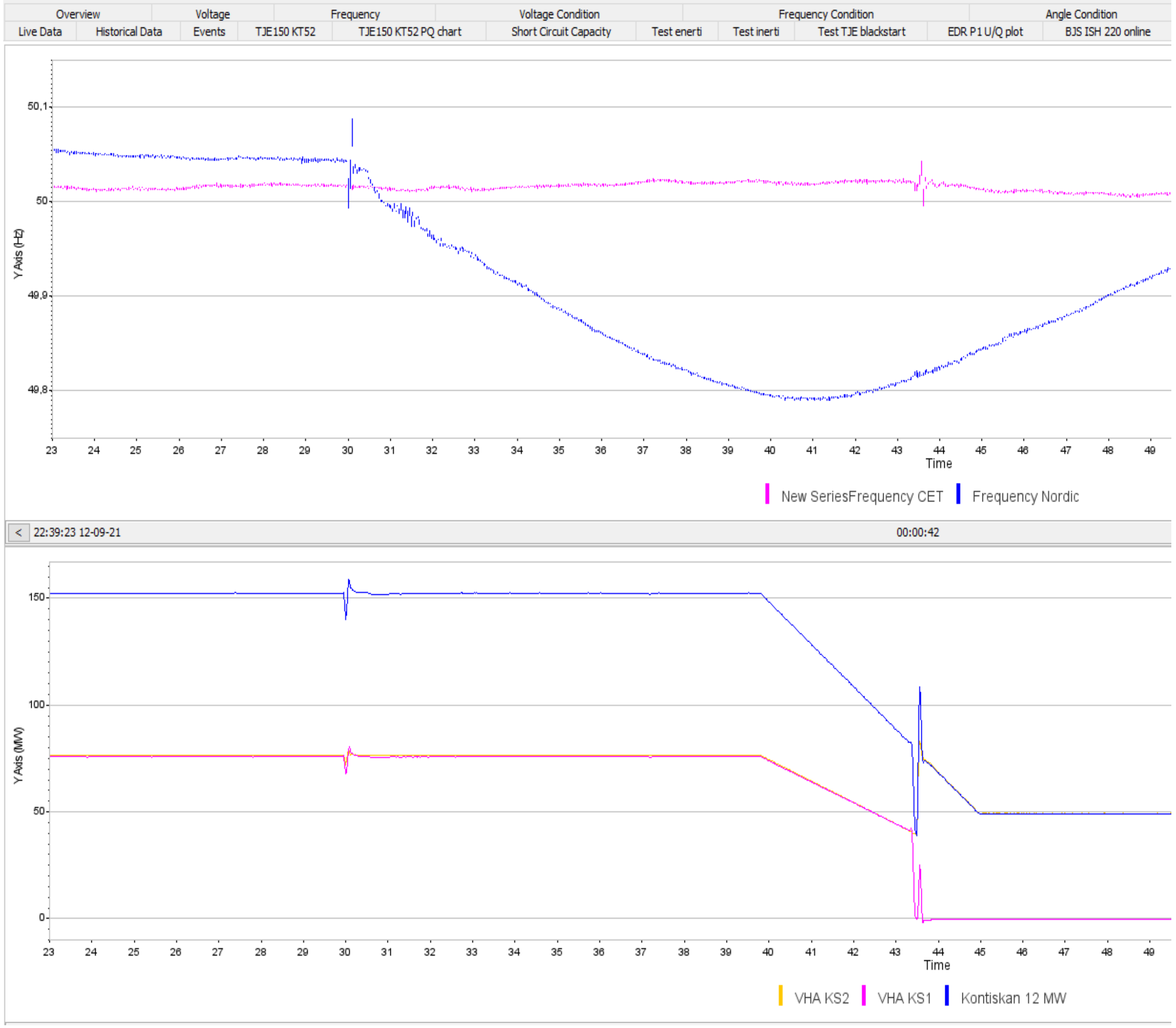
In the example here the frequency drops below a predefinet threeshold value in Sweden, resulting in triggering of 100 MW power change on the Kontiskan HVDC connection.



EPC IN THE FUTURE ?

It is expected that EPC will gradually change nature over the next years, from a rather static type of support to a more dynamic support. LFSM, limited Frequency Sensitivity Mode will be the typical EPC (like a droop control), with the added functionality of the supporting area being able to freeze the delivery

Public information

European Network of Transmission System Operators for Electricity entsoe

Steering Group Operations – Project

Operational Limits and Conditions for Frequency support over HVDC due to inertia erosion

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1 Executive summary

This paper recommends to the System Operation Committee (SOC) the setting of limits for mutual frequency support over HVDC between Synchronous Areas (SAs).

The establishment of a project team, “Inertia management and supporting reserve services over HVDC”, was approved by the System Operations Committee on 10 October 2018, reporting to Steering Group Operations. Its scope is designed to complement the current internal SA work on inertia[1] and to be compliant with the (EU) 2016/1447[2] Article 13 (3), Article 39 (4) & (7).

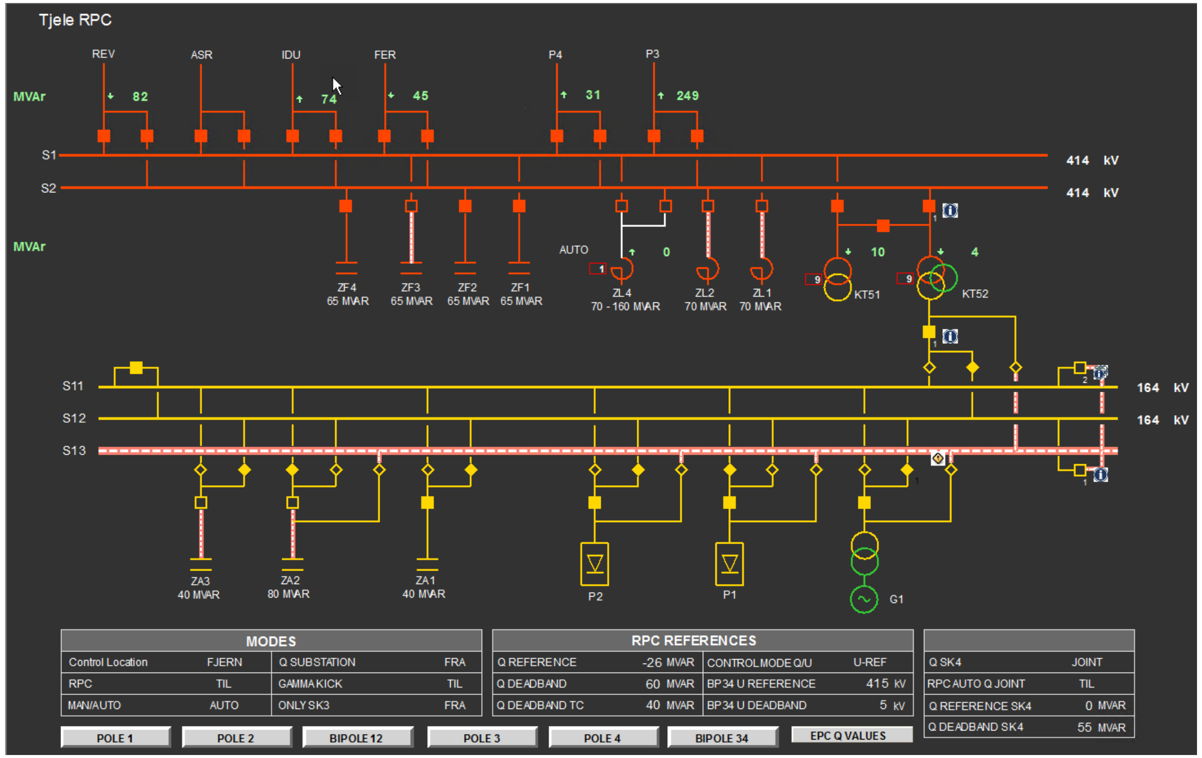
This project has modelled the CE, Nordic and GB synchronous areas[3] to recomend a safe, secure and standardised European framework to enable system defense using HVDC links between SAs. The maximum level of mandatory frequency support that a SA will provide to the other SAs are set out in table 1 below are recommended for inclusion in the in the Synchronous Area Operational Agreements (SAOA) and in accordance with COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (SOGL).

Proportional support scheme	GB ->CE	Nordic ->CE	CE ->GB	Nordic ->GB	CE ->Nordic	GB ->Nordic
Maximum support (MW)	600	600	1000	600	1000	600
Frequency trigger for starting delivery (Hz)	CE : 49.8	CE : 49.8	GB : 49.5	GB : 49.5	NO : 49.5	NO : 49.5
Frequency for full delivery (Hz)	CE : 49.2	CE : 49.2	GB : 49.0	GB : 49.0	NO : 49.0	NO : 49.0
Frequency level for freezing of delivery (Hz)	GB : 49.75	NO : 49.75	CE: 49.9	NO : 49.75	CE: 49.9	GB : 49.75
Support scheme droop (MW/Hz)	1000	1000	2000	1200	2000	1200
Ramp rate (MW/s)	200	200	1400	840	1400	840

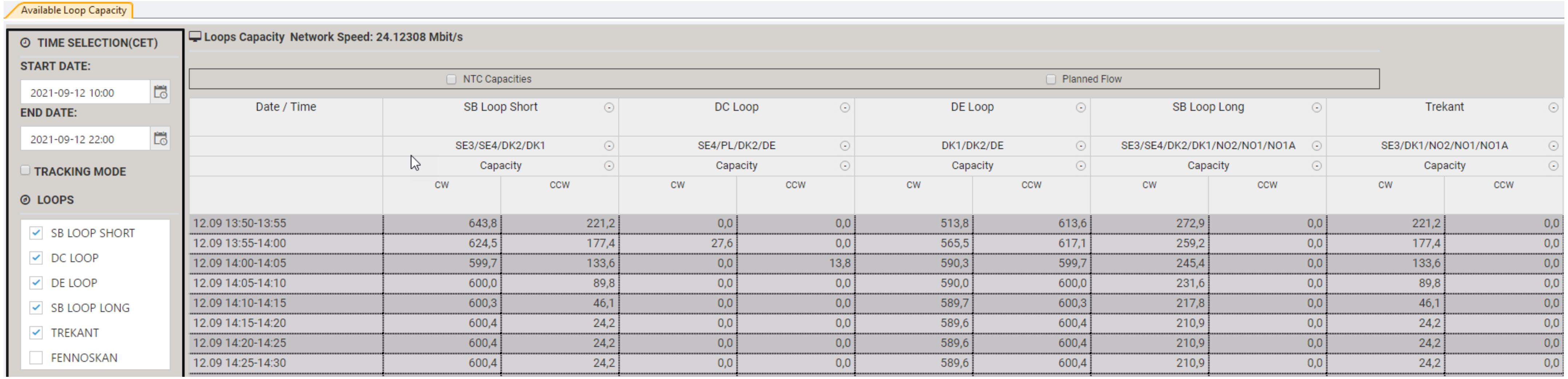
Table 1- Recommended mandatory frequency support between Synchronous Areas

RPC, REACTIVE POWER CONTROL

RPC controls can be quite different by nature, depending on converter types, LCC or VSC.
The RPC can typically control either voltage or reactive flows (LCC´s will primarely have to fulfill filter requirements from converter).
If required RPC controllers can be an integrated controller where all reactive components in a substation are controlled together, like the examples shown here



LOOP FLOWS



Date / Time	SB Loop Short		DC Loop		DE Loop		SB Loop Long		Trekant	
	SE3/SE4/DK2/DK1		SE4/PL/DK2/DE		DK1/DK2/DE		SE3/SE4/DK2/DK1/NO2/NO1/NO1A		SE3/DK1/NO2/NO1/NO1A	
	Capacity		Capacity		Capacity		Capacity		Capacity	
	CW	CCW	CW	CCW	CW	CCW	CW	CCW	CW	CCW
12.09 13:50-13:55	643,8	221,2	0,0	0,0	513,8	613,6	272,9	0,0	221,2	0,0
12.09 13:55-14:00	624,5	177,4	27,6	0,0	565,5	617,1	259,2	0,0	177,4	0,0
12.09 14:00-14:05	599,7	133,6	0,0	13,8	590,3	599,7	245,4	0,0	133,6	0,0
12.09 14:05-14:10	600,0	89,8	0,0	0,0	590,0	600,0	231,6	0,0	89,8	0,0
12.09 14:10-14:15	600,3	46,1	0,0	0,0	589,7	600,3	217,8	0,0	46,1	0,0
12.09 14:15-14:20	600,4	24,2	0,0	0,0	589,6	600,4	210,9	0,0	24,2	0,0
12.09 14:20-14:25	600,4	24,2	0,0	0,0	589,6	600,4	210,9	0,0	24,2	0,0
12.09 14:25-14:30	600,4	24,2	0,0	0,0	589,6	600,4	210,9	0,0	24,2	0,0

Loop Flows can be used to mitigate congestions in the grid, reduce voltage problems in the grid and much more. It is however not a specific HVDC feature but more related to market, agreements and overview.