

Workshop 2:

- Mitigation possibilities for power quality and operational issues in relation to RE integration in distribution networks.
- Inputs to system operating guidelines.

05.10.2020 - 19.10.2020

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Energy Partnership Programme between South Africa and Denmark



Danish Energy
Agency

COWI

About the Programme

- DE2 OUTPUT 3 - CONSULTANT SUPPORT FOR IMPLEMENTING WORKING ACTIVITIES ON RE INTEGRATION AT DISTRIBUTION LEVEL
- Training of distribution network operators – Year 2 (2020)
 - Activity 1: Calculating losses in networks with very high levels of RE generation embedded into the grid
 - Workshop 1 - Training and workshop with Eskom staff focusing on theory and practical calculation of technical losses in power networks with very high levels of RE generation
 - Activity 2: Mitigating solutions for distribution network power quality issues in relation to RE generation and penetration to the distribution network
 - Activity 3: Inputs to system operating guidelines
 - Workshop 2 - Theoretical and practical training activities as specified for Activity 2 & 3.

Workshop 2 – Part 2

Monday 12.10.2020 – Friday 16.10.2020

- Session 4
- Session 5
 - Inputs to system operating guidelines
- Session 6
 - Inputs to system operating guidelines

Pre-recorded sessions released on Monday 12.10.2020

QA session: Monday 19.10.2020

About the Programme

- DE2 OUTPUT 3 - CONSULTANT SUPPORT FOR IMPLEMENTING WORKING ACTIVITIES ON RE INTEGRATION AT DISTRIBUTION LEVEL
- Training of distribution network operators – Year 2 (2020)
 - Activity 3: Inputs to system operating guidelines
 - Task 1: Creation of a practical application guide which can serve as a training manual to train network operators in the Control room. It will focus on:
 - Changing reactive power control modes
 - Operating RE generators during n-1 conditions
 - Curtailment of RE generators due to high frequency
 - Impact of day-ahead power forecasts at DSO level
 - Provide inputs to the practical application guide and preparing the first draft. Eskom to be responsible for final document.

Changing reactive power control modes



Reactive power control modes

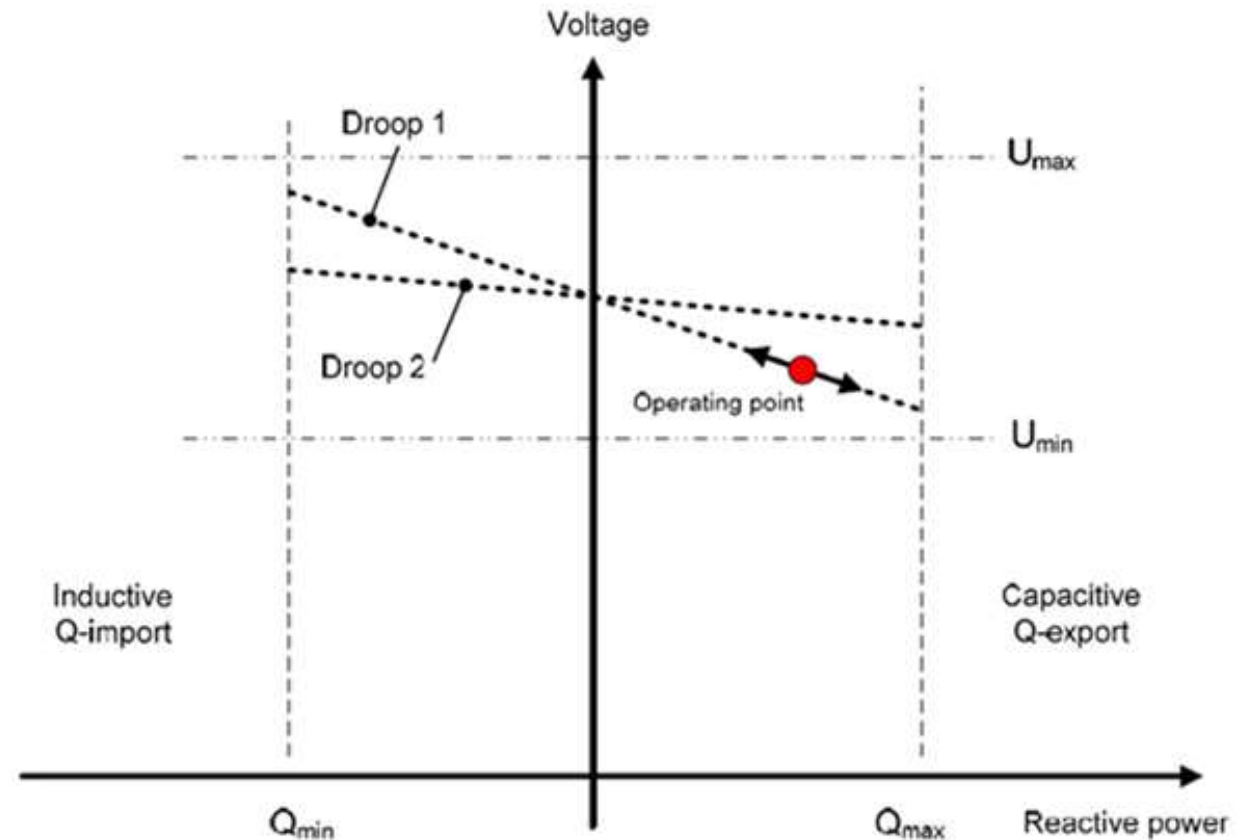
- To ensure that distribution voltage, reactive power flows and losses are managed appropriately, it is common that national/regional grid codes require generators greater than a certain size ($\sim 5\text{MW}$) to be able to deliver three reactive power control modes:
 - Voltage control
 - Power Factor control
 - Constant Q control
- The application of these control modes and selection of set points is essential to ensure that the distribution system operates effectively.

Reactive power control modes

- Voltage control – keeps the voltage constant with a droop setting
- Power Factor control – keeps the power factor constant
- Constant Q control – keeps the reactive power (MVar) constant

Voltage control

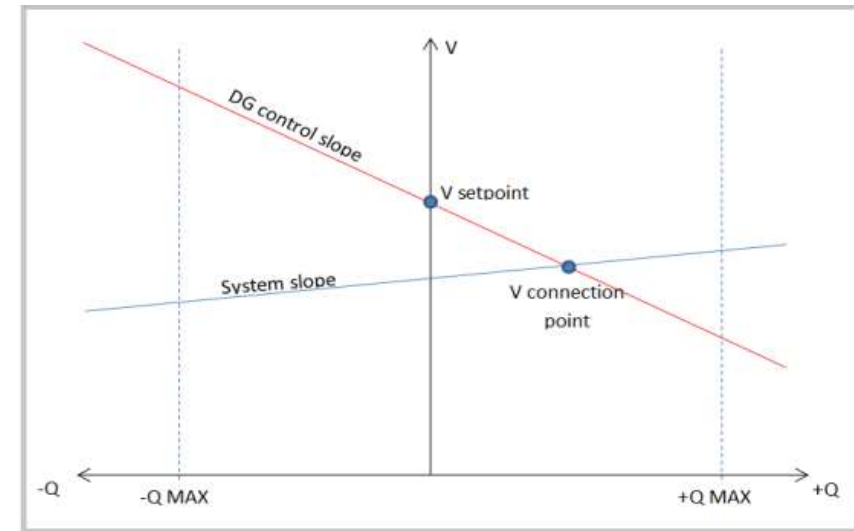
- Keeps the voltage with the droop setting.
- Voltage control is a control function controlling the voltage at the POC.
- Droop/on slope of 4 % means
 - Voltage drop of 4% before full Q-export
 - or, Voltage rise of 4% before full Q-import



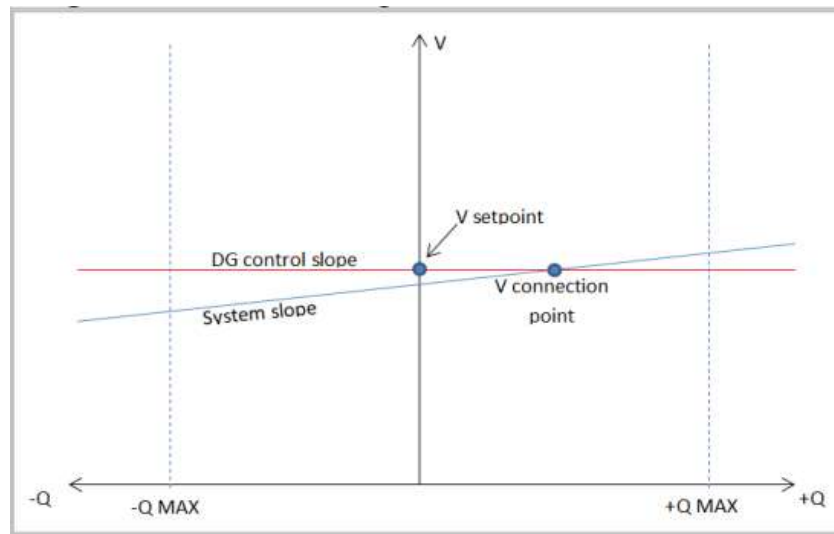
Voltage control

- Several variants of voltage control modes

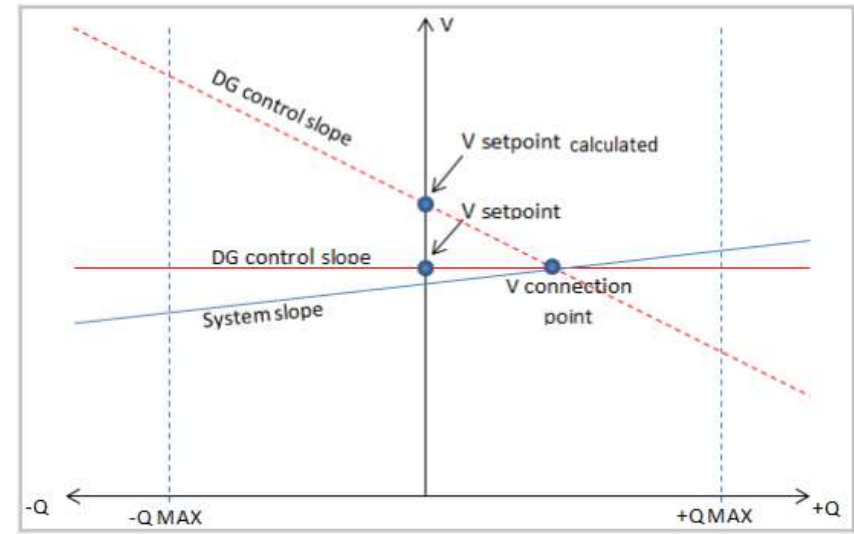
Voltage control on slope



Direct voltage control with feedback

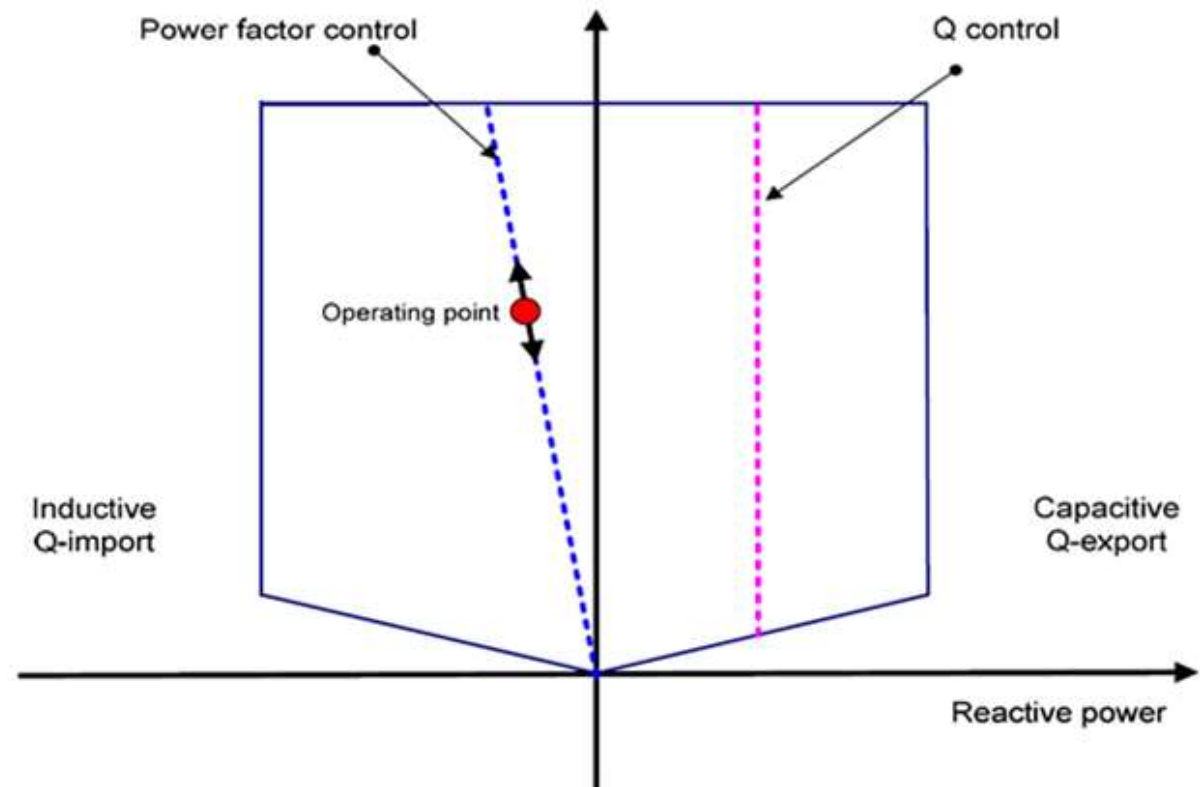


Direct voltage control with slope



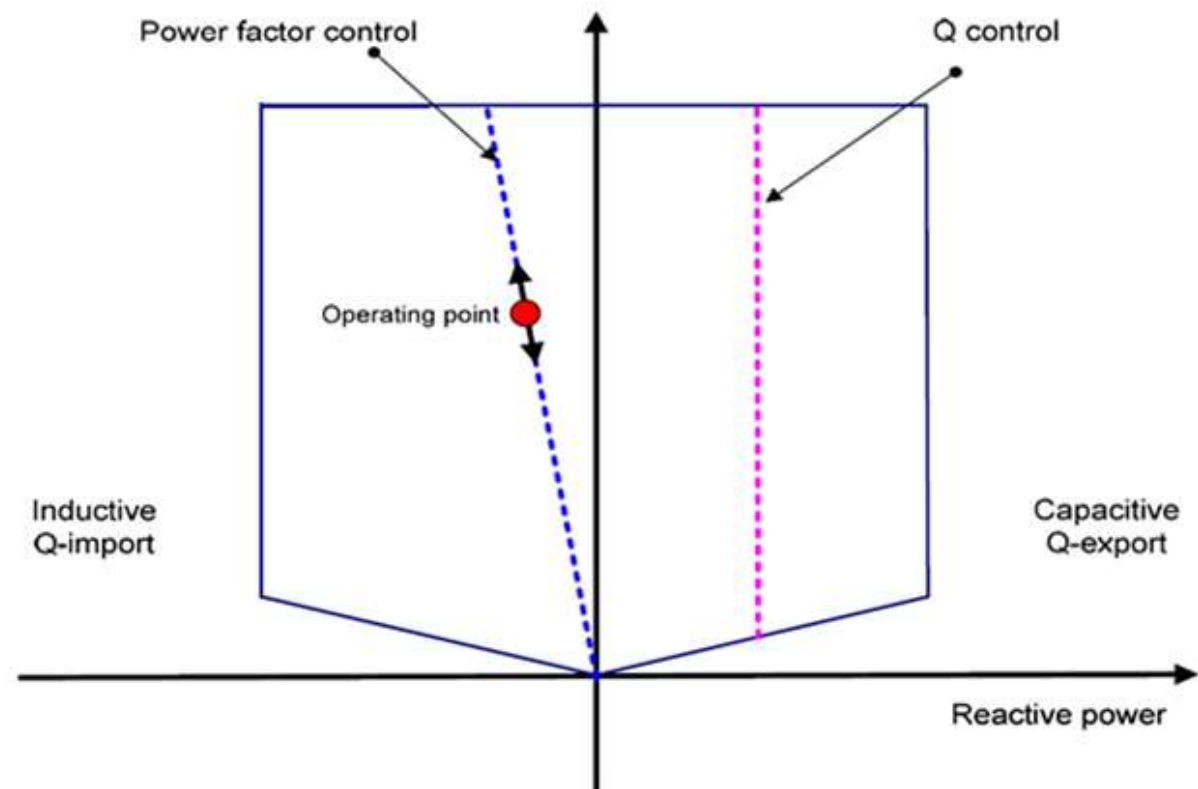
Power Factor control

- Keeps the power factor constant
- Power Factor Control is a control function controlling the reactive power proportionally to the active power at the POC.
- This is illustrated in the figure by a line with a constant gradient.



Constant Q control

- Keeps the reactive power (MVAR) constant
- Q control is a control function controlling the reactive power supply and absorption at the POC independently of the active power and the voltage.
- This control function is illustrated in the figure as a vertical line.

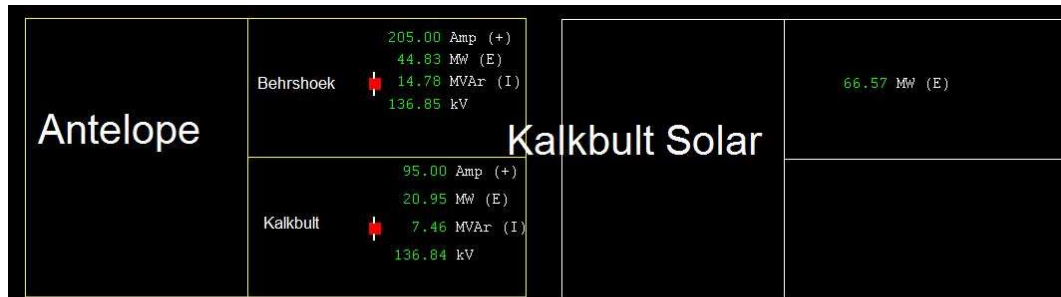


RPP Dashboards

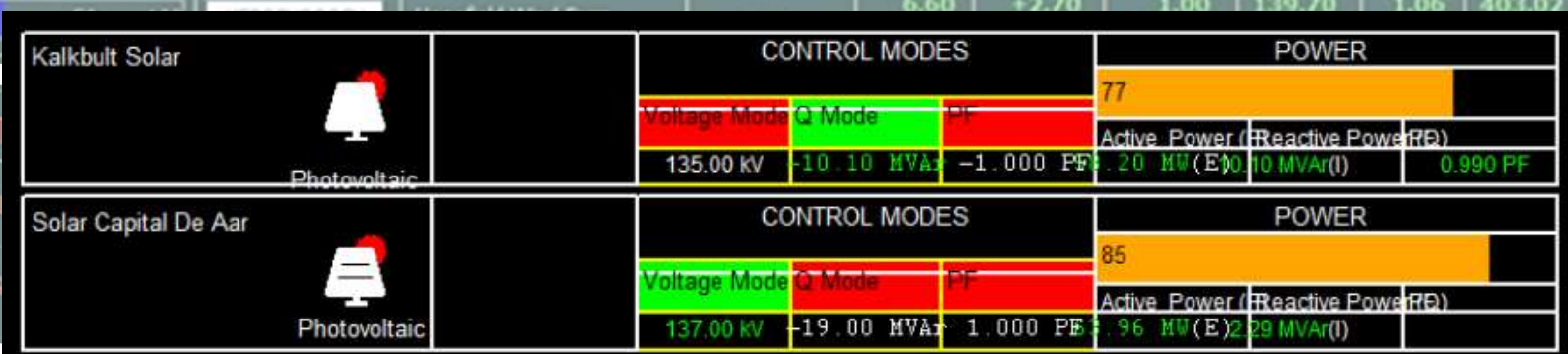
RPP INFORMATION				POWER			VOLTAGE		MTS	BREAKER STATUS	Control Mode			Setpoint Reference		
POWER OUTPUT %	SUBSTATION	PROJECT NAME	TECHNOLOGY	MW	MVAR	PF	kV	PU	kV		V	PF	Q	V.PU	PF	Q
<div><div></div><div>050100</div></div>	BULTE	Vredendal Solar Power	Solar (PV)	4.17 8.8	-0.15 -2.01 : 2.01	1.00 -0.975 : 0.975	11.20 9.9 : 12.1	1.02 0.9 : 1.1	397.94 June	PV1 <div><div></div><div></div></div>	On	Off	Off	1.03	0.975	1.5
<div><div></div><div>050100</div></div>	VREDELUS	Aurora-Rietvlei Solar Power	Solar (PV)	5.04 9	-0.02 -2.05 : 2.05	1.00 -0.975 : 0.975	22.71 19.8 : 24.2	1.03 0.9 : 1.1	403.02 Aurora	S1 <div><div></div><div></div></div>	Off	On	Off	N/A	1	N/A
<div><div></div><div>050100</div></div>	KERSCHBOSCH	Hopefield Wind Farm	Wind	6.60 65.4	+2.70 -21.6 : 21.6	1.00 -0.95 : 0.95	139.70 118.2 : 145.2	1.06 0.9 : 1.1	403.02 Aurora	W1 W2 <div><div></div><div></div></div>	On	Off	Off	1.05	0.95	12

IPP SITES	STATUS		VOLTAGE	VOLTAGE (PU)	MVAR	ACTUAL MW	POWER FACTOR	CONTROL MODE		SETPOINT	
KERSCHBOSCH	W1 <div><div></div><div></div></div>	W2 <div><div></div><div></div></div>	139.30 kV	1.06	+3.00 MVAR	16.40 MW	1.00	Voltage PF Q	On Off Off	Voltage PF Q	1.05 p.u 0.95 12 Mvar
SWARTBAS	PV1 <div><div></div><div></div></div>		22.48 kV	1.02	-2.00 MVAR	0.00 MW	0.18	Voltage PF Q	On Off Off	Voltage PF Q	1.02 p.u 0.975 2.2 Mvar

RPP Dashboards

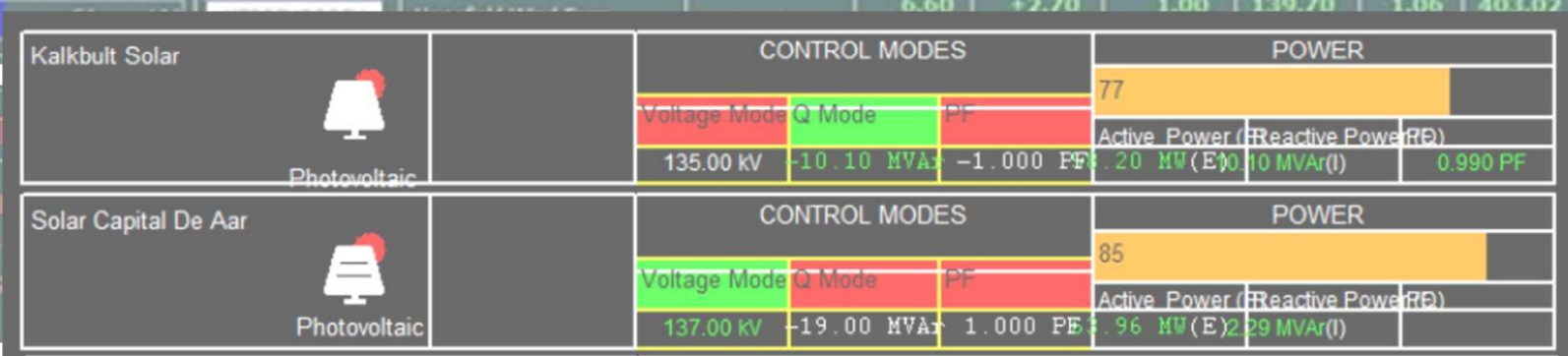
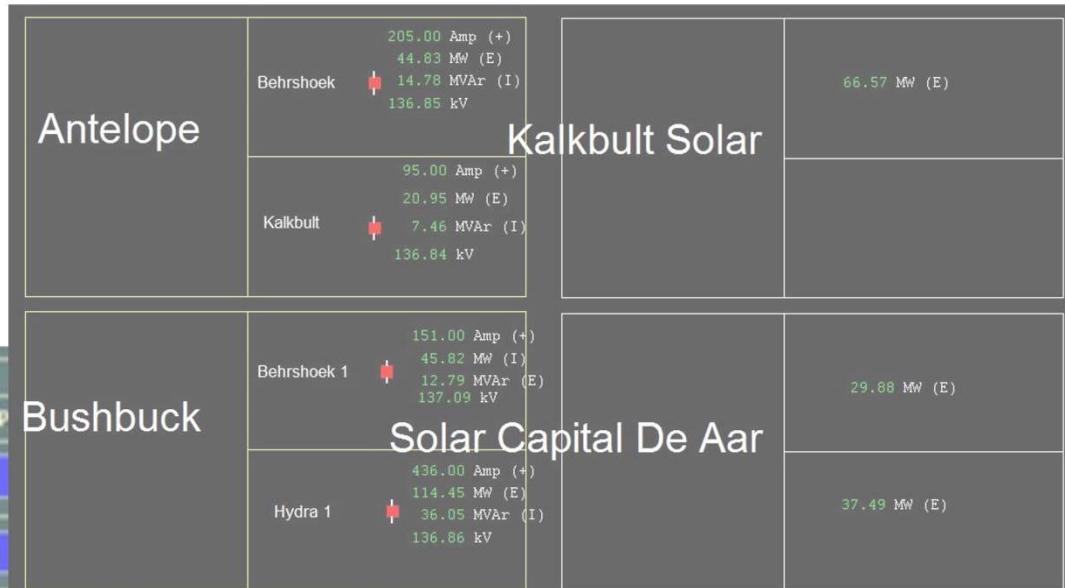


ER		VOLTAGE		MTS	BREAKER STATUS	Control Mode			Setpoint Reference		
	PF	kV	PU	kV		V	PF	Q	V.PU	PF	Q
5	1.00	11.20	1.02	397.94	PV1	On	Off	Off	1.03	0.975	1.5
01	-0.975 : 0.975	9.9 : 12.1	0.9 : 1.1	None							
12	1.00	22.71	1.03	403.02	S1	Off	On	Off	N/A	1	N/A
05	-0.975 : 0.975	19.8 : 24.2	0.9 : 1.1	Aurora							
					W1 W2	On	Off	Off	1.05	0.95	12



FOR	CONTROL MODE		SETPOINT	
Voltage	On		Voltage	1.05 p.u
PF	Off		PF	0.95
Q	Off		Q	12 Mvar
Voltage	On		Voltage	1.02 p.u
PF	Off		PF	0.975
Q	Off		Q	2.2 Mvar

RPP Dashboards



Substation
Site name
Breaker status
Technology
Voltage kV
Voltage pu
MVAR
MW
Ampere
PF
Flow directions
Data per line
Data per site
Control mode
Set point

Power output %-meter
Performance graph
Zone division
Technology division

Control possibilities
Step to page/navigation
List layout
Cluster layout
Alarms/flags

Operating RE generators during voltage violations and/or n-1 conditions



Operational cases with DG involved

Before planned outages and when seeing operational/voltage violations or at contingencies

Ideal first response/action from controllers:

Planned outages

1. Study the outage plan and related earlier fault reports before letting the work start, consult back-office analysis staff.
 1. Taking reactive recourses in/out of operations and set in manual mode for the entire period of the work
 2. Contact neighboring/overlaying networks (National Control) for their reactive recourses to be taken in/out of operations for the work
 3. Change the voltage setpoint at substations or set tap changes in manual modes at specific steps.
 4. Speak to large load centers (mines) / RPPs – adjust generation / load on forehand
 5. Inform RPPs of the weakened network and increased tripping risk

Operational cases with DG involved

Before planned outages and when seeing operational/voltage violations or at contingencies

Ideal first response/action from controllers:

Operational/voltage violations or contingencies

1. Assess the situation
2. Consult a colleague
3. Are there any ongoing planned outages that might have affected the situation for example by making the network weaker and more prone to voltage deviations? Outages that have not been previously identified as a conflicting outages?
4. Is the situation showing signs of mal-operation of the protection?
5. Are there any circumstances that adds to the problem (unbalance/tractions loads)
6. Consult earlier fault reports / outage studies
7. Go to the following list of ideal response/action
8. After each action wait for updated analogues to see the response before taking another action

Operational cases with DG involved

HGLL – high voltages

High Generation Low Load may result in high voltages especially during N-1 contingencies/planned outages

Ideal response/action from controllers:

- 1. Tap changer positions – starting with the main feeding transformer closest to the area
 - Check if automatic tap changer response has been acting on the high voltages
 - Manually adjust (lower) tap changer positions
 - Or change the voltage setpoint at the busbar
- 2. Reactive recourses – starting with the closest and/or smallest to/in the area
 - Check if capacitor banks have disconnected automatically. If not manually disconnect capacitor banks.
 - Check if reactors have connected automatically. If not connect reactors.
- 3. Contact neighboring/overlying networks for tap changer or capacitor/reactor actions

Operational cases with DG involved

HGLL – high voltages

- 4. Reactive power control modes of the DG/RPP
 - If the RPP is in default Voltage control mode - Change setpoint by lowering it
 - (Contact the RPP to exclude possibilities for direct voltage control with feedback/slope and/or change the drop/slope setting – rather an action during post evaluation).
 - Change the control mode to PF or Q. Fixed Q mode maybe the best – absorb as much Q as possible.
 - Change setpoint – reduce the active power setpoint
 - If no response from the control modes actions with the RPP – communication / implementation problem – call the RPP and ask them to support/perform the actions.
 - Trip the breaker/ Curtail

RPP INFORMATION				POWER			VOLTAGE		MTS		Control Mode			Setpoint Reference		
POWER OUTPUT %	SUBSTATION	PROJECT NAME	TECHNOLOGY	MW	MVAR	PF	kV	PU	kV	BREAKER STATUS	V	PF	Q	V.PU	PF	Q
0 50 100	BULTE	Vredendal Solar Power	Solar (PV)	4.17 8.8	-0.15 -2.01 : 2.01	1.00 -0.975 : 0.975	11.20 9.9 : 12.1	1.02 0.9 : 1.1	397.94 Tunde	PV1 ■▲	On	Off	Off	1.03	0.975	1.5
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Operational cases with DG involved HGLL – high voltages

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Operational cases with DG involved LGHL – under voltages

Low Generation High Load may result in under voltages especially during N-1 contingencies/planned outages.

Ideal response/action from controllers:

- 1. Tap changer positions – starting with the main feeding transformer closest to the area
 - Check if automatic tap changer response has been acting on the low voltages
 - Are the tap changes stuck – send technician
 - Manually adjust (lower) tap changer positions
 - Or change the voltage setpoint at the busbar
- 2. Reactive recourses – starting with the closest and/or smallest to/in the area
 - Check if reactors have disconnected automatically. If not manually disconnect reactors.
 - Check if capacitor banks have connected automatically. If not connect capacitor banks.
 - If they don't connect - due to too low voltage? Another action needed to help the voltage temporarily before it can be connected.
- 3. Contact neighboring/overlying networks for tap changer or capacitor/reactor actions
- 4. Network switching states that acts as reactive sources or strengthens the network
 - Connect possible idle lines acting as capacitor banks
 - Create loops/meshed operation for increased network strength

Operational cases with DG involved LGHL – under voltages

Low Generation High Load may result in under voltages especially during N-1 contingencies/planned outages.

Ideal response/action from controllers:

- 5. Reactive power control modes of the DG/RPP
 - If the RPP is in default Voltage control mode - Change setpoint by raising it
 - Change the control mode to Q – inject as much Q as possible.
(The PF mode is less useful in this case as it controls the reactive power proportionally to the active power which is low)
- 6. Contact loads (mine/municipalities etc.) – reduce the load

Curtailment of RE generators due to high frequency



Curtailment

Curtailment is a reduction in the output of a generator from what it could otherwise produce given available resources, typically on an involuntary basis.

Curtailment of generation has been a normal occurrence since the beginning of the electric power industry. However, owners of wind and solar generation, which have no fuel costs, are concerned about the impacts of curtailment on project economics.

Operator-induced curtailment typically occurs because of transmission congestion or lack of transmission access, but it can occur for a variety of other reasons, such as excess generation during low load periods, voltage, or interconnection issues.

Reasons for curtailment

- Transmission Constraints
 - Most curtailment has occurred when the construction of necessary transmission lags behind the pace of RPP development, resulting in infrastructure that is insufficient for the amount of RE generation.
- System/Frequency balancing
 - Some RE curtailment has been attributed to challenges in balancing the system with higher penetrations of RE due to oversupply of generation, typically during low load periods. Some utilities or grid operators have curtailed generation from wind plants when minimum generation levels on fossil-fuel / thermal plants are reached, because stopping and restarting fossil units within a few hours can be significantly more expensive than paying for a few hours of RE curtailment. This type of situation can occur at night when there are substantial amounts of wind generation, but loads are low.
- Voltage reasons
 - In weak areas of the grid and in areas where older RPPs are unable to provide necessary grid support.

Curtailment international perspectives

“Curtailment” today does not necessarily mean what it did in the early 2000s. Two major changes in the electric sector have shaped curtailment practices since that time:

- the utility-scale deployment of RE generation, which has no fuel cost
- the evolution of wholesale power markets

These simultaneous changes have led to new operational challenges but have also expanded the array of market-based tools for addressing them.

Practices vary significantly by region and market design. In places with centrally-organized wholesale power markets and experience with RE, manual RE curtailment processes are increasingly being replaced by transparent offer-based market mechanisms that base dispatch on economics. In opposite to balancing authority areas operated by a vertically integrated utility.

Curtailment international perspectives

A primary strategy to mitigate curtailments is improved use of forecasting.

The market redesign also helps reduce curtailments. The market redesign includes shifting from dispatch intervals from the hour to 15-minutes or lower, more centralized scheduling, and changes to how forecasting is integrated into market operations.

In countries or regions, as the European capacity calculation regions, with well developed energy markets, curtailment in its original sense is rare. The word itself is not commonly heard, rather related marked terms as “downward dispatch” or “congestion management”.

Next chapter on “Impact of day-ahead power forecasts at DSO level” continues this subject.

Signaling of Curtailment

- Automatic signaling

Automatic signaling is used to curtail RPPs in many areas

SCADA systems are used to send signals and curtailment limits in real time to RPPs

In some markets, regular market operator signals can be used to signal curtailments.

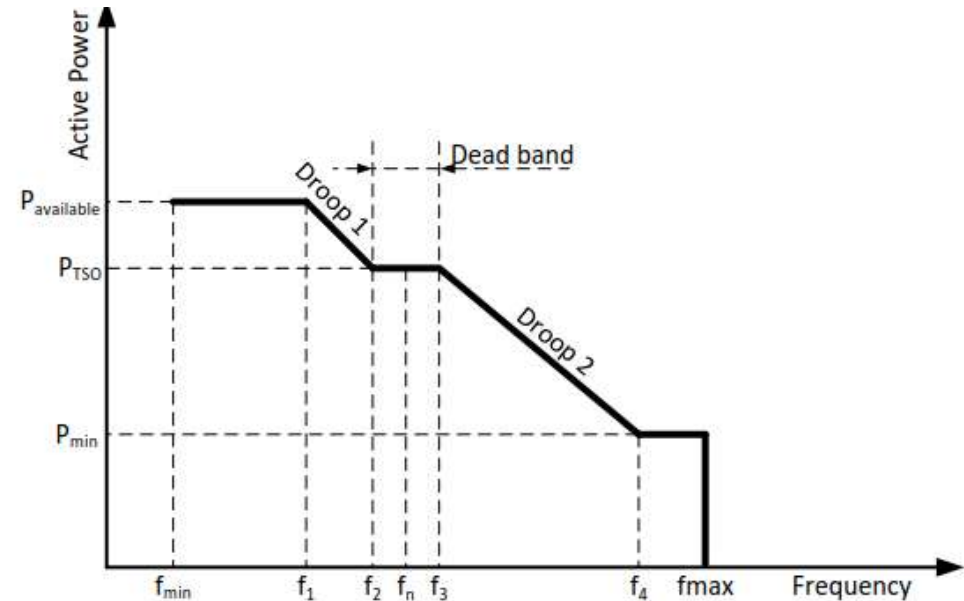
- Manual signaling

In many areas, curtailments are implemented manually whereby grid operators call the RPPs to issue curtailment directives or alternatively have access to set-point instruction via SCADA.

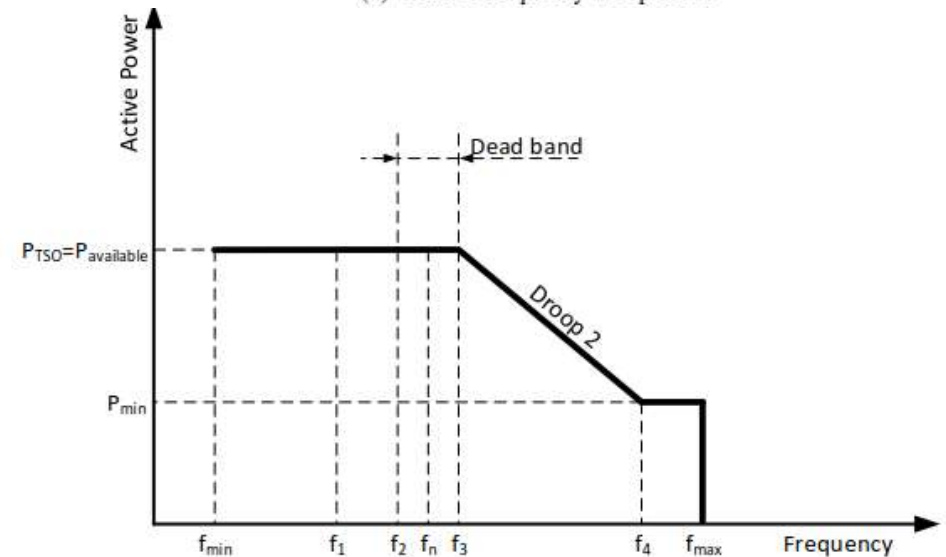
Because the operators have the ability to adjust the curtailment as often as they wish via set-point control, the curtailments can be fine-tuned to a more precise level than block curtailments done by phone

Curtailment

- To ensure system balance and frequency stability, it is common that national/regional grid codes require generators greater than a certain size to be able to take part in frequency regulation actions:
 - Active power curtailment: the TSO sends an active power setpoint to be injected.
 - Frequency regulation by droop curve: The TSO specifies a curve which predefines an increase or decrease of the active power delivered as a function of the measured frequency.
 - For over frequencies outside the curve it is permitted to disconnect.



(a) Generic frequency droop curve



(b) Frequency droop curve in absence of curtailment event

Order of Curtailment

The methods for determining the order in which resources are curtailed can vary. Criteria often depend at least in part on the reason for curtailment.

Curtailment order can be influenced market design, contracts, and plant economics, as well as whether the curtailment relates to local transmission congestion or is caused by balancing-related challenges

Typically congestion-related curtailments are based on the effectiveness of generators in alleviating constraints.

A number of utilities and grid operators base curtailments on contracts and plant economics cutting the most expensive energy first.

Compensation to wind generators for curtailment varies across balancing authorities and typically depends upon the cause of the curtailment.

In some wholesale power markets, there is no compensation for economic curtailment outside of the market settlement mechanisms. Within the market, the decision to generate is based on the economics of dispatch. If a plant bids higher than the market clearing price, which for wind could occur if prices are negative, the plant is not dispatched and does not generate revenue.

Ideal response/actions for Curtailment

An order to curtail due to high frequency must come from, or be coordinated, with the right balancing authority

1. Identify and document the reason for curtailment
2. Identify which contractual agreement / protocol it falls under
3. Decide the order of curtailment according to contractual agreement / protocol / economics / compensation
4. Perform the curtailment
 1. Can the curtailment be handled through your SCADA?
 2. Is there automated curtailment and the SCADA has initiated a signal to the RPP?
 3. Call the RPP to issue curtailment directives
5. Survey the effects of the curtailment and document for follow-up purposes

Q&A

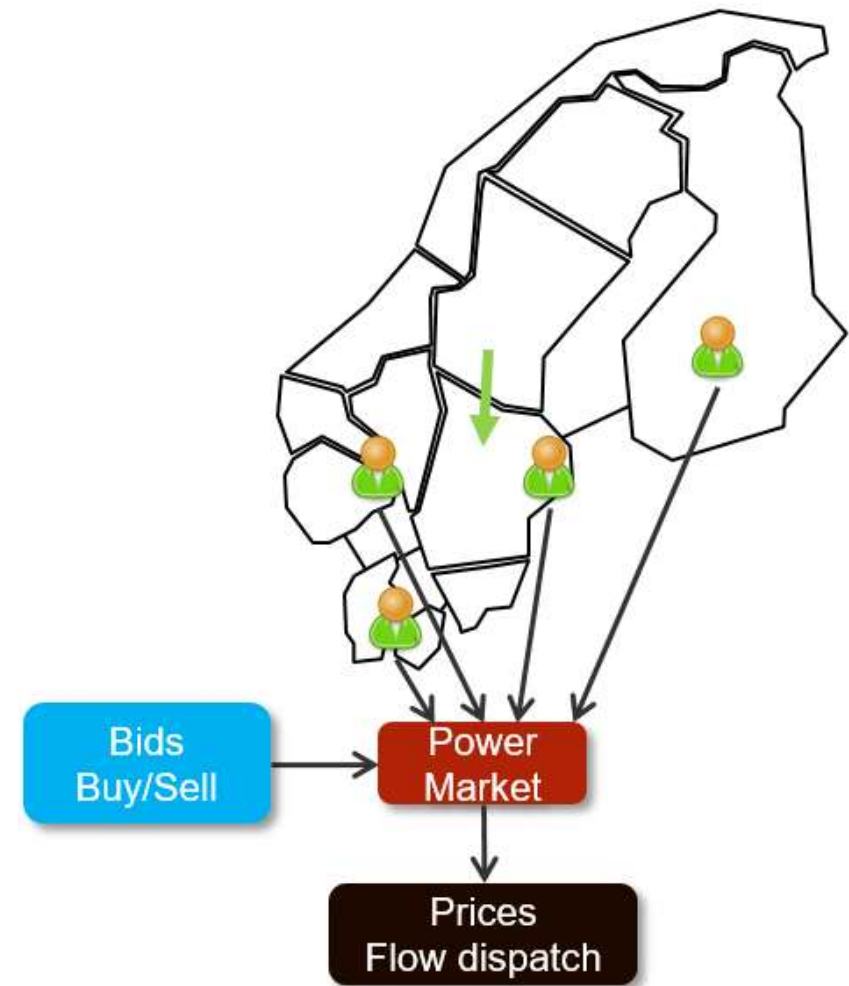
For the Q&A session – which aspects should be included in a system operating guidelines “practical application guide which can serve as a training manual to train network operators in the Control room” when it comes to Curtailment of RE generators due to frequency?

Impact of day-ahead power forecasts at DSO level



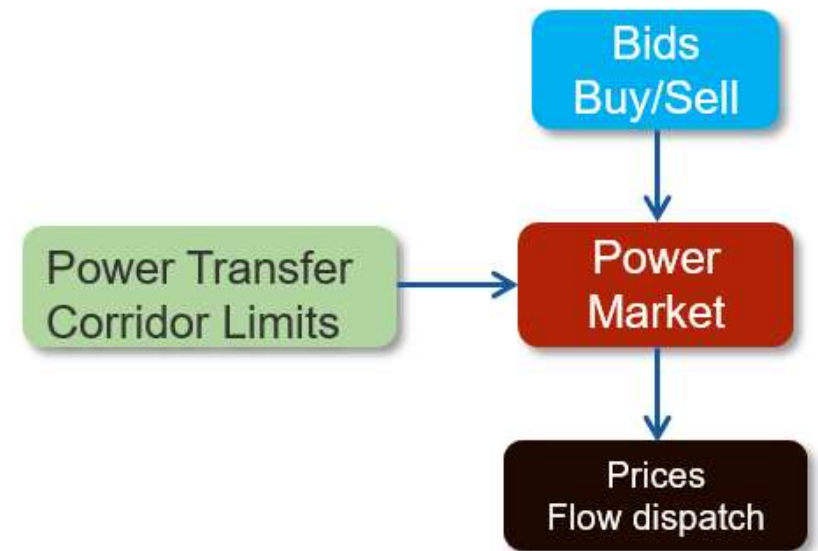
Day-ahead power market and forecasts

- In places with centrally organized wholesale power markets and experience with RE, manual curtailment processes have increasingly been replaced by transparent offer-based market mechanisms that base dispatch on economics.
- The Nordics
Short term markets; day-ahead, intraday and balancing.



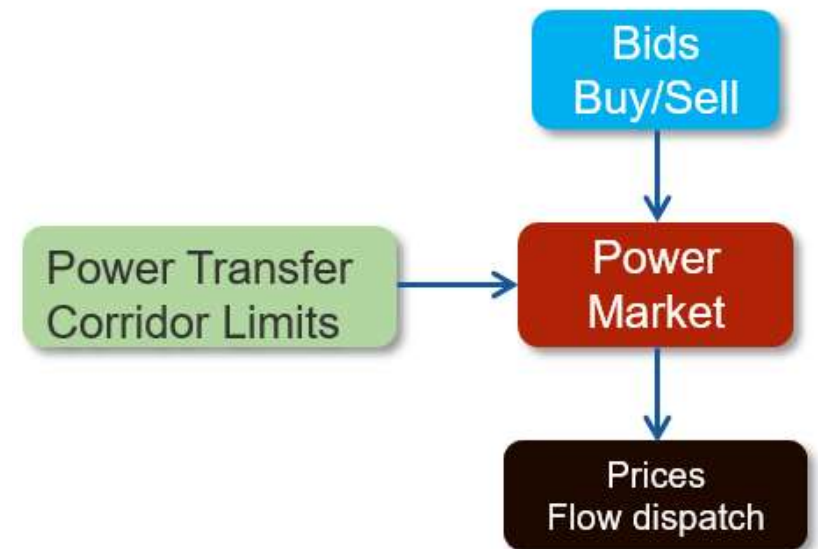
Day-ahead power market and forecasts

- Capacity restrictions for the power market to ensure operational security
- Constitutes a secure domain where the market bids are allowed to clear within
- Restrictions must be calculated by the grid owner just before the day-ahead market starts



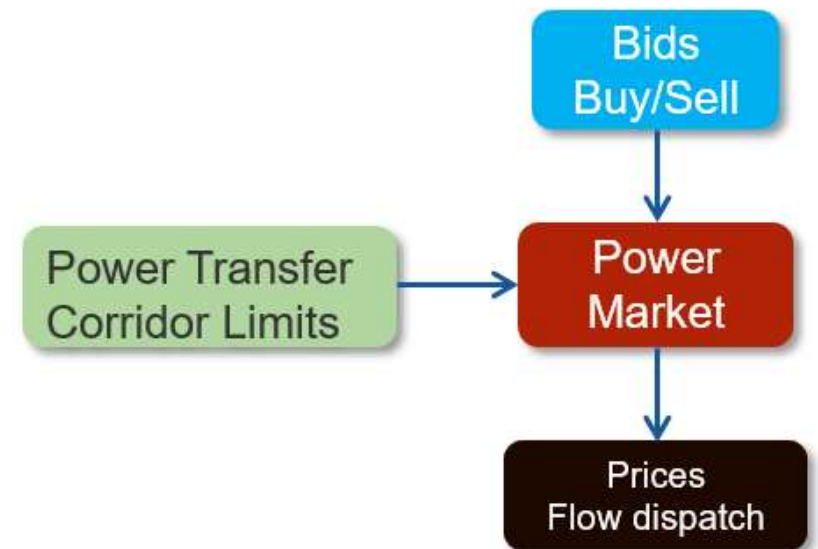
Day-ahead power market and forecasts

- Impact at grid owner level
- Process impact
 - Load flows and dynamic analysis to capture the transfer limits per hour day-ahead
 - Thermal limits
 - Dynamic/voltage collapse limits
 - Estimated states day-ahead in Power Factory
 - Scenario data; generation and load forecasts
 - Temperature, sun, wind
 - Planned outages
 - Contingency list
 - Real time monitoring of transfer limits and dispatched market flows



Day-ahead power market and forecasts

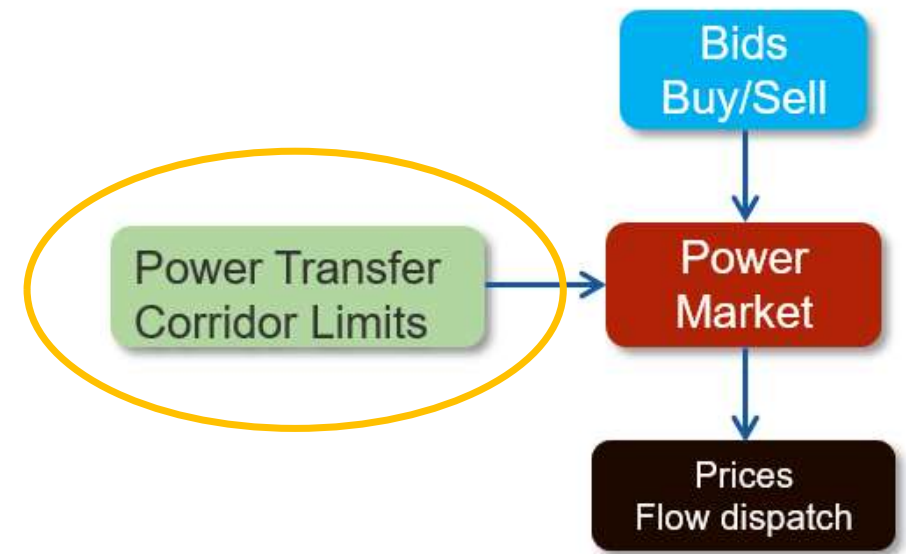
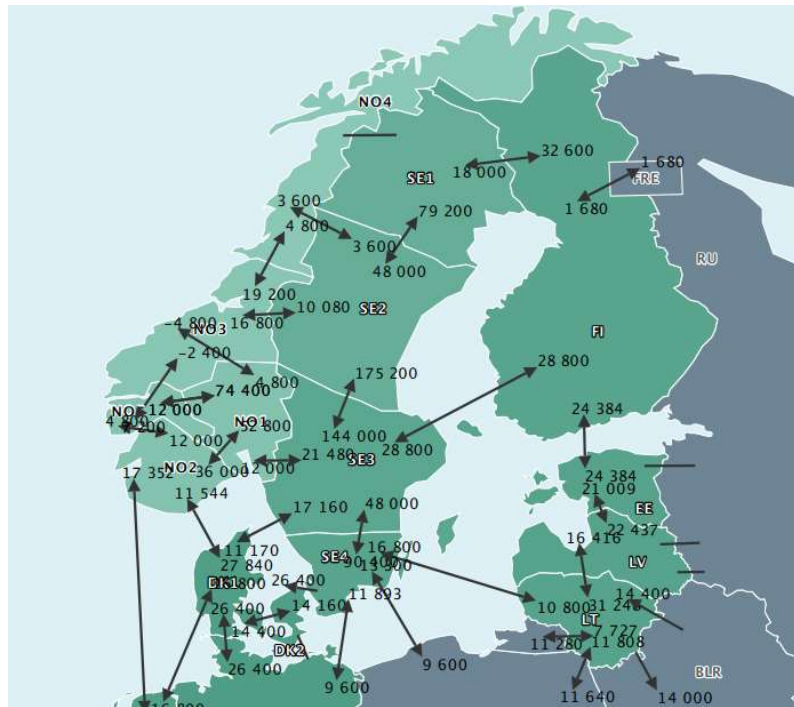
- Impact at grid owner level
- IT-impact
 - Network model generator (for Power Factory?)
 - Integrations to outage planning/coordinating tools
 - Integrations to scenario data
 - Weather forecast access
 - Integrations to power market platforms
 - Development of exchange standards



Q&A

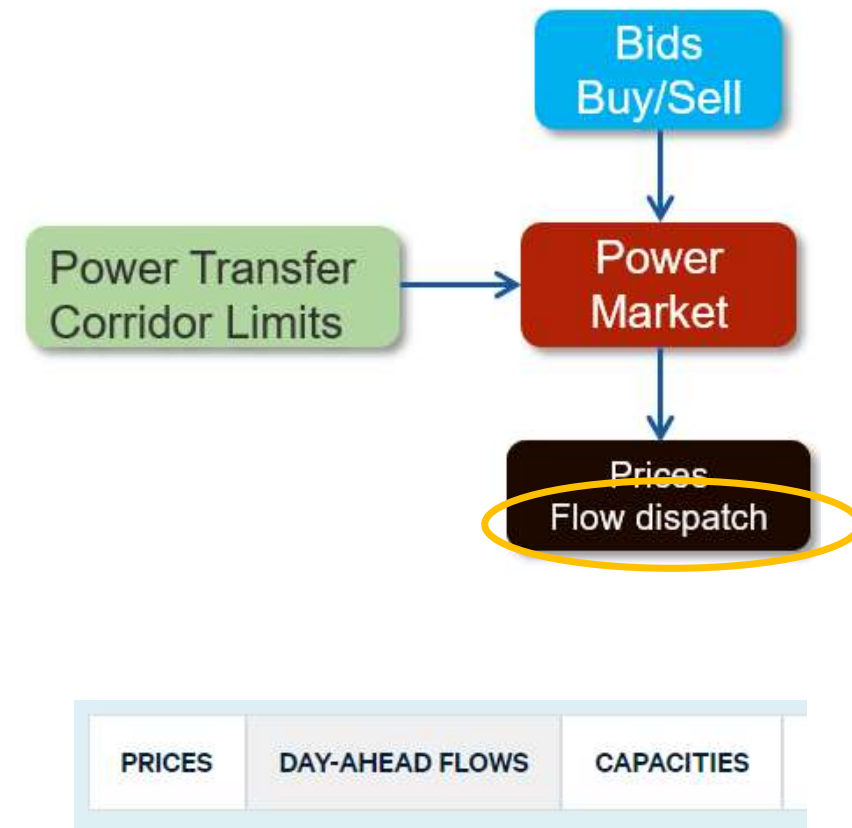
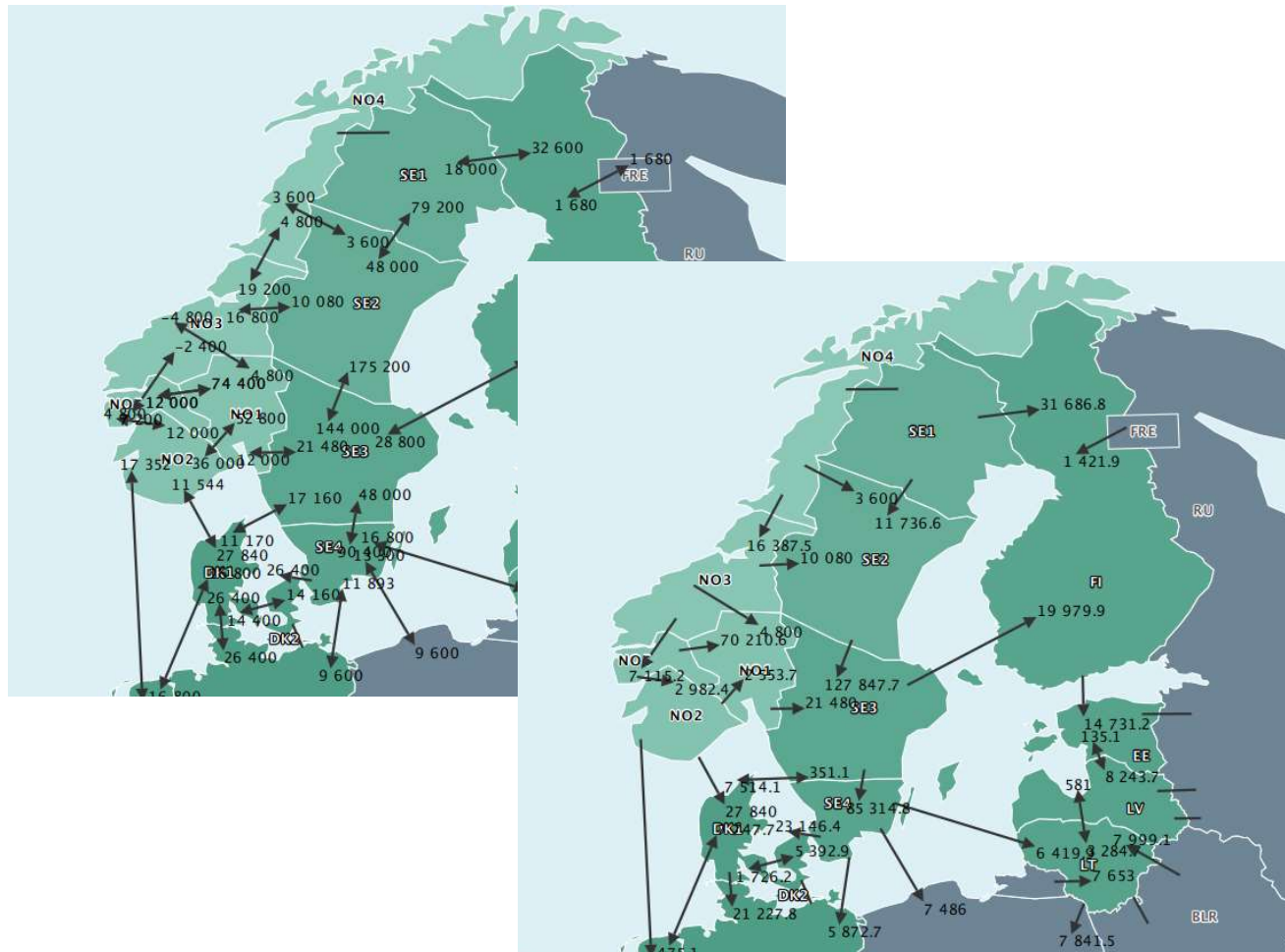
For the Q&A session – which aspects should be included in a system operating guidelines “practical application guide which can serve as a training manual to train network operators in the Control room” when it comes to Impact of day-ahead power forecasts at DSO level?

Day-ahead power market and forecasts

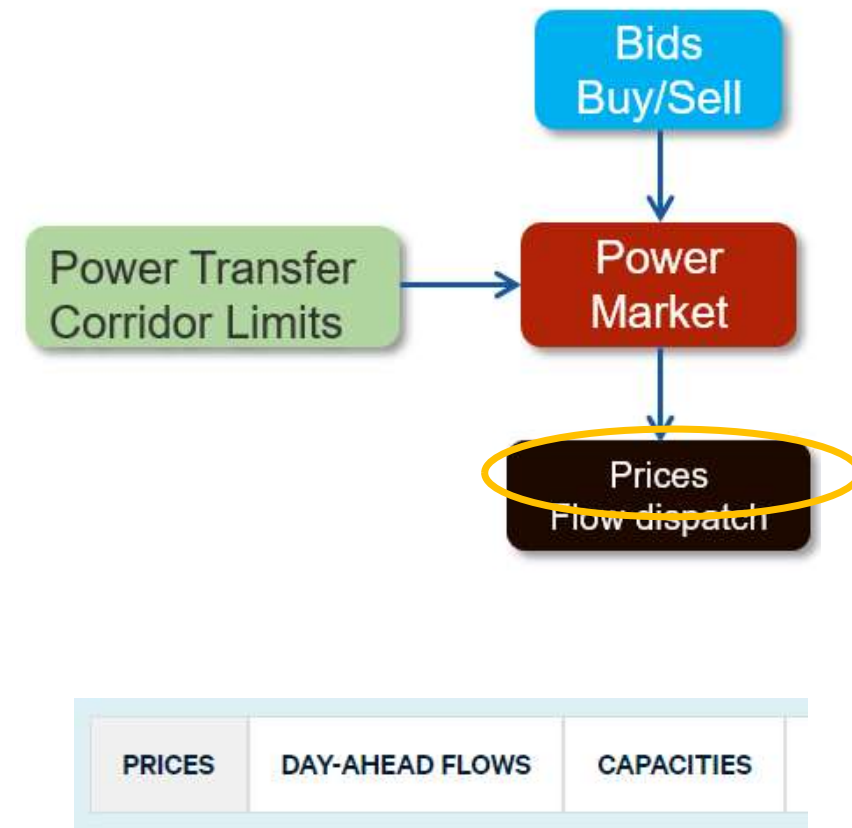
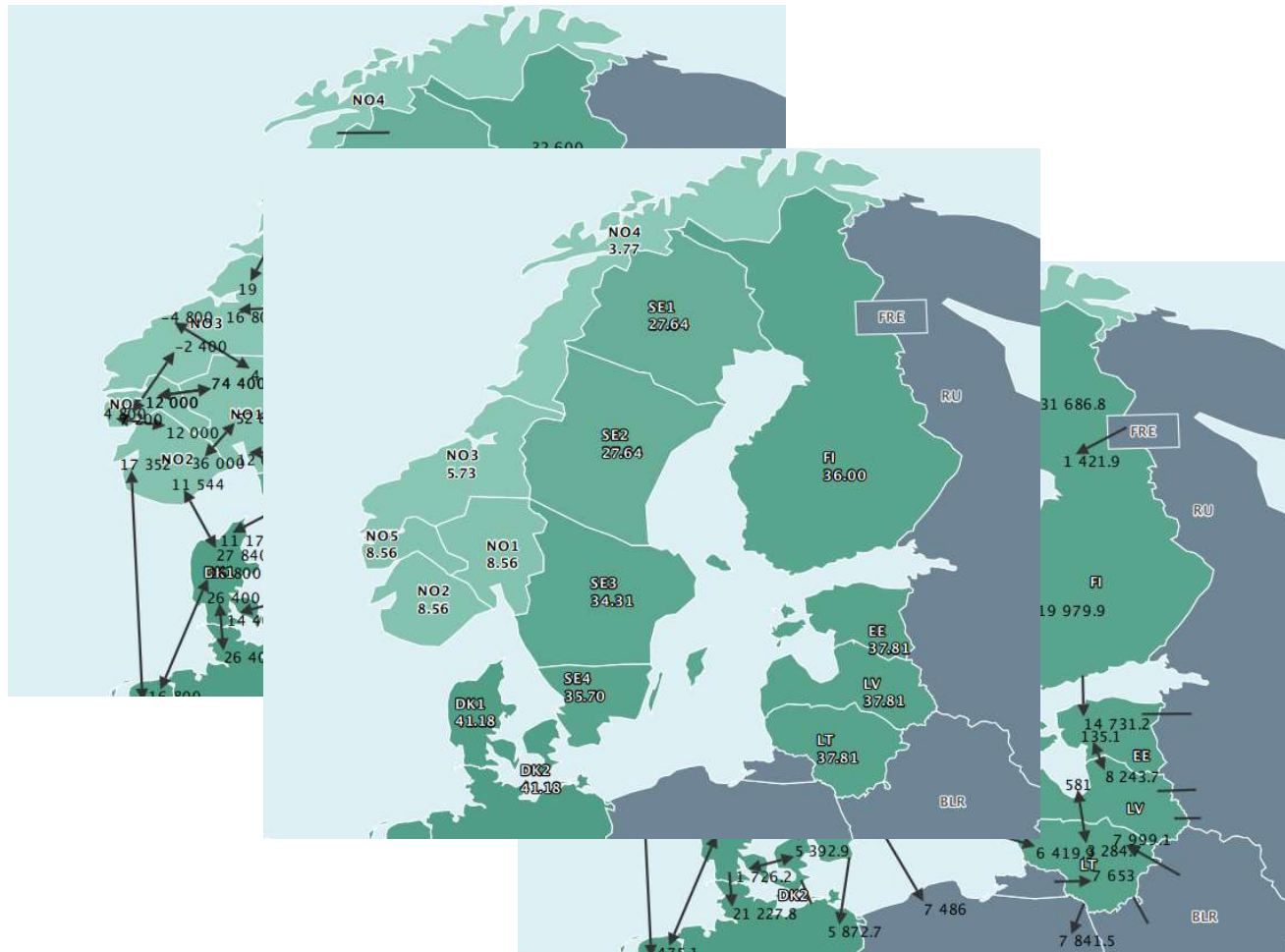


PRICES	DAY-AHEAD FLOWS	CAPACITIES
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Day-ahead power market and forecasts



Day-ahead power market and forecasts



International perspectives

- Nordic TSOs have already agreed several solutions that will evolve the short-term markets in coming years (2020-2022)
 - implementation of 15-minute time resolution
 - establishment of the Nordic Regional Security Coordinator (RSC)
 - common capacity calculation methodology – Flowbased for the day-ahead market
 - modernized Area Control Error (ACE) for balancing with automatic/manual Frequency restoration Reserves (aFRR/mFRR) platforms
- Nordic TSOs expect that trading in short-term markets increases in the future implying that market timeframes such as day-ahead, intraday and balancing timeframe and market time units could be reconsidered to reflect trading needs in shorter timeframes and market time units.
- Furthermore, it could be considered, if there is a need to move gate closure times closer to real-time to facilitate short-term markets and still meet the TSO need to maintain grid security.
- Several EU wide and regional platforms will be established – to comply with legal requirements – requesting access to physical transmission capacity for the same delivery period. These platforms will request tighter coordination in the allocation of transmission capacity.

References

- [1] Application of DG reactive power control modes to increase system stability, Jonathan POLLOCK and David HILL, 2016
- [2] Wind and Solar Energy Curtailment: Experience and Practices in the United States, Lori Bird, Jaquelin Cochran, and Xi Wang, <https://www.nrel.gov/docs/fy14osti/60983.pdf>
- [3] Power Plant Control in Large Scale PV Plants. Design, implementation and validation in a 9.4 MW PV plant, CITCEA-UPC, Electrical Engineering Department, Technical University of Catalonia, GreenPowerMonitor, Barcelona, Spain
- [4] Short-term markets Discussion Paper, Nordic TSOs, April 2019

Workshop 2 – Part 2

Monday 12.10.2020 – Friday 16.10.2020

- Session 4
- Session 5
 - Inputs to system operating guidelines
- Session 6
 - Inputs to system operating guidelines

Pre-recorded sessions released on Monday 12.10.2020

QA session: Monday 19.10.2020