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Droop Optimization in SHOP

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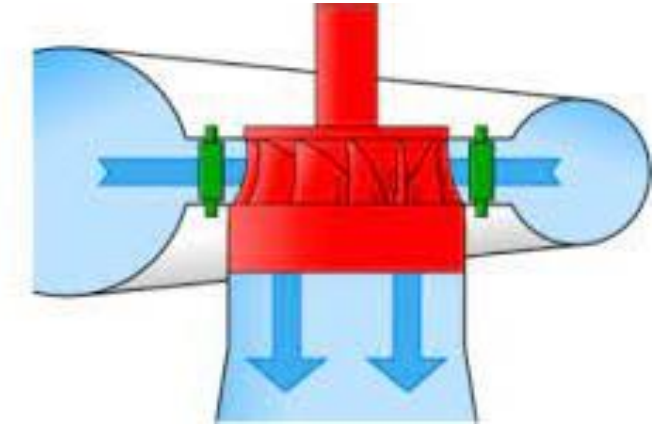
SINTEF USER MEETING, 28.11.2023

What is droop?



- The droop (‘statikk’ in Norwegian) decides the deliveries of FCR (Frequency Containment Reserves) for the generators
  - FCR-N Normal FCR, same/symmetrical delivery/market for up and down
  - FCR-D Disturbed FCR, separate deliveries/markets for up and down
  - FCR = 2 *Δf * $P_{nominal}$ / Droop
    - Δf = frequency band (0,1 for FCR-N and 0,4 for FCR-D)
- The droop is normally set in discrete steps between 2% and 12%
  - Integer droop levels in Norway
  - Discrete FCR-delivery steps in Sweden (EP-läge)
- Modern turbine regulators can
  - Set the droop separately for each FCR-type
  - Turn off the deliveries of each FCR-type separately

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Functionality developed in SHOP for modelling droop

1. One common continuous droop for all FCR-types
   - First basic implementation
   - Implemented in 2014
2. Discrete droop modelling
   - Goal: Get feasible results
   - Implemented and presented in 2021
3. Separate droop modelling
   - Goal: Adapt to new turbine regulators
   - This functionality is developed this year
4. Stoppable droop modelling
   - Goal: Adapt to new turbine regulators
   - This functionality is developed this year

1. Basic droop modelling in SHOP (2014)

- Can model obligations and markets for each FCR-type
- Droop can be modelled for both generators and pumps
- One common droop for all FCR-types

Generator input

- droop_min
- droop_max
- fixed_droop
- droop_cost

Generator results

- droop_result

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2. Discrete droop (2021)

- New generator input
  - discrete_droop_values A list of feasible droop values
- New command
  - set droop_dicretization_limit <value>
    - The command is used between iterations
    - Discretizes the droop results from the previous iteration that are below the limit given by the command (no MIP - mixed integer programming)

3. Separate droop (new)

- Modelling separate droop is done in the same way as the basic common FCR
- New generator input data types
  - Same datatypes as before, but with prefix for the 3 FCR-types, e.g.
    - fcr_n_droop_min, fcr_n_droop_max
    - fcr_n_fixed_droop, fcr_n_droop_cost
    - fcr_n_discrete_droop_values
- New result data types
  - Droop result as before, but with prefix for each FCR-type, e.g.
    - fcr_n_droop_result
  - Physical deliveries for each of the 3 FCR-types, e.g.
    - fcr_n_ delivery_physical

4. Stoppable droop (new)

- No new input data or result data types
  - Apply input value 0 in the discrete_droop list for an FCR-type to make it stoppable

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Analysis

Analysis setup

- 5 calculations with gradually improved modelling of FCR
  1. Base case: Continuous, common, must-run droop, but no FCR-obligations
  2. + FCR-obligations
  3. + Discrete droop
  4. + Separate droop
  5. + Stoppable droop
- Focus on monitoring excess deliveries of FCR

Case 1

- One week horizon
- Obligation given for spot sales, FCR-N and FCR-D-up
- One plant, 2 generators
  - G1
    - Discrete droop FCR-N 0 1.25 2.5 3.797 5.556
    - Discrete droop FCR-D-up 0 3,947
  - G2
    - Discrete droop FCR-N 0 1.056 2.239 3.947 6.25
    - Discrete droop FCR-D-up 0 3,555

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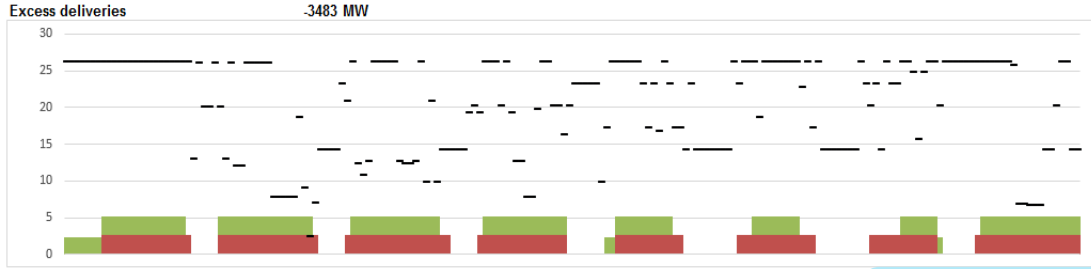
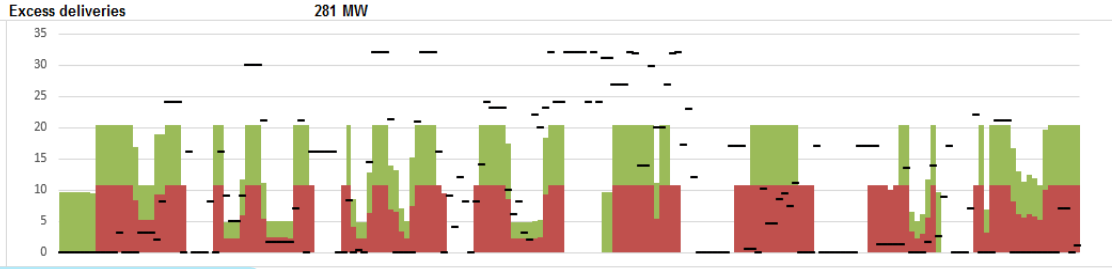
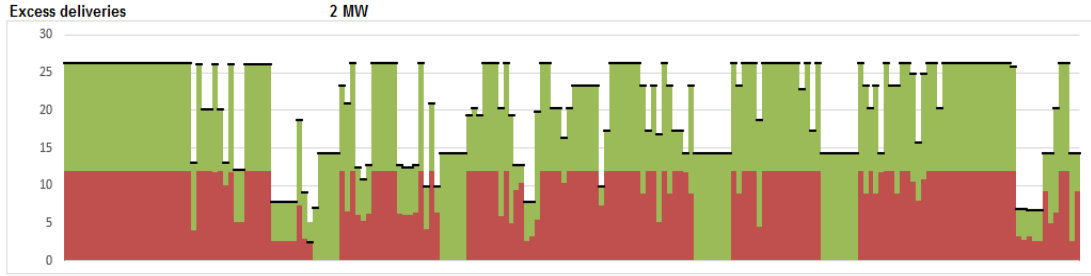
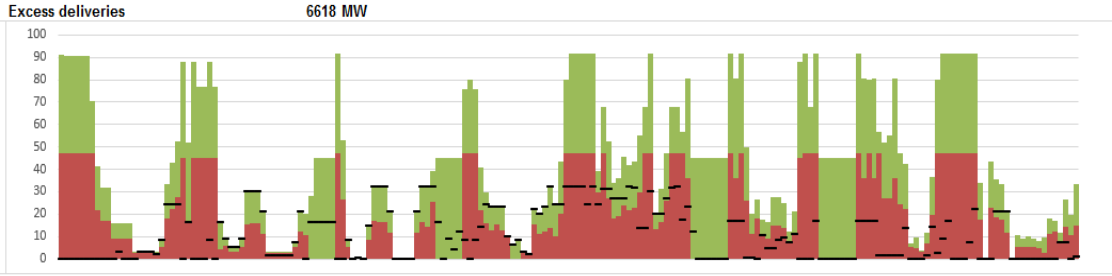
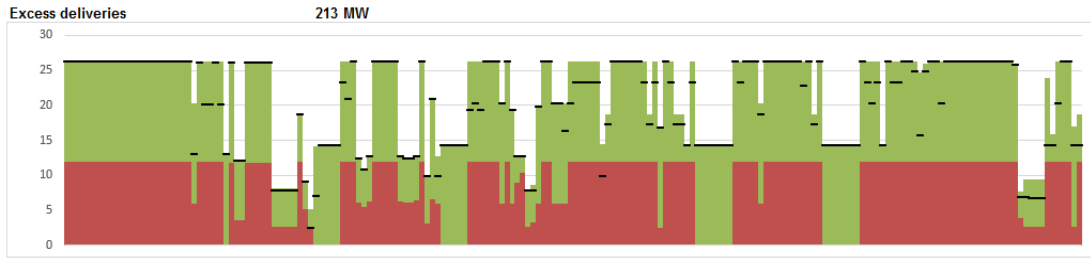
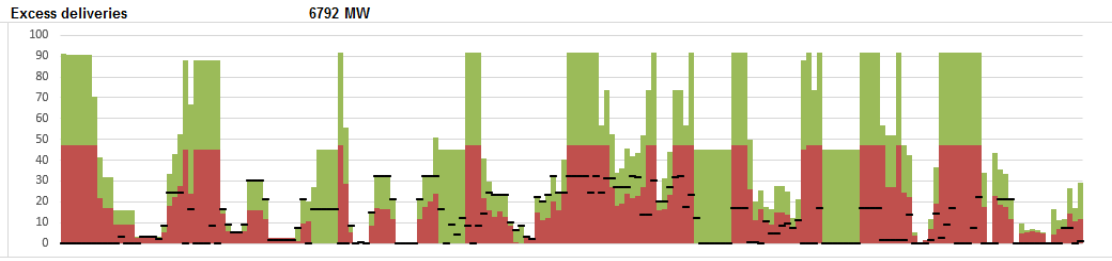
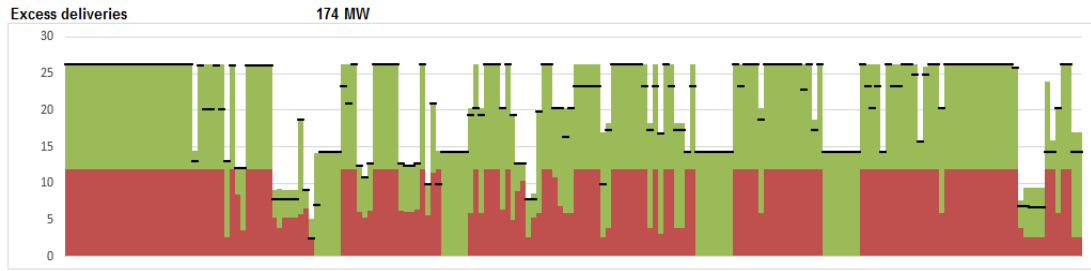
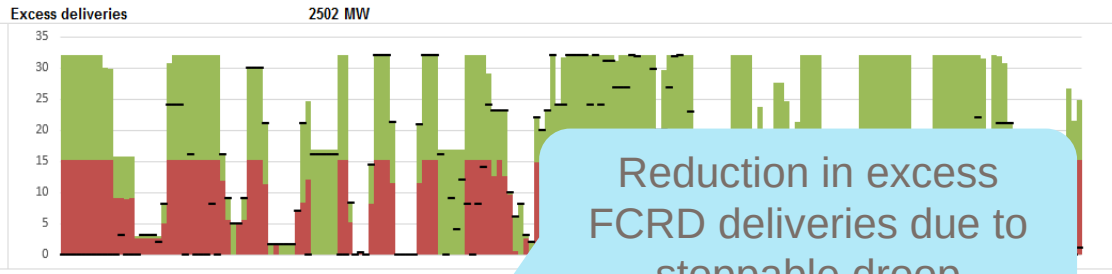
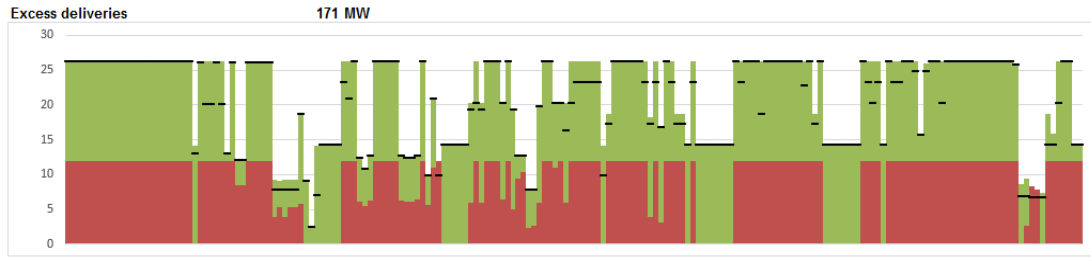
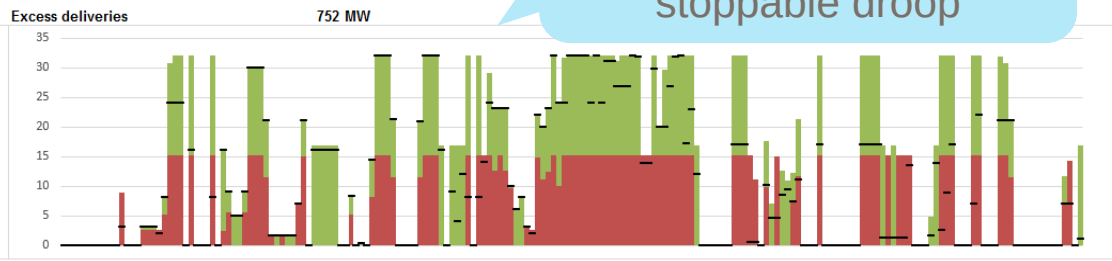
RESULTS

	FCR-N	FCR-D UP
BASE CASE No FCR-obligations. Continuous, common, must-run droop		
+ FCR-obligations		
+ Discrete droop		
+ Separate droop		
+ Stoppable droop		

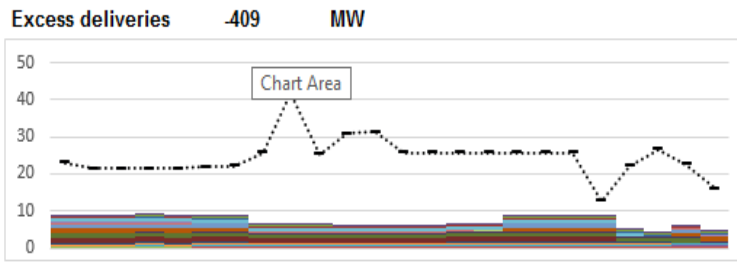
Reduction in excess FCRD deliveries due to stoppable droop

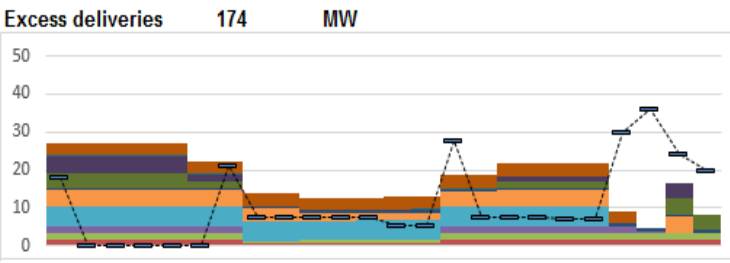
Case 2

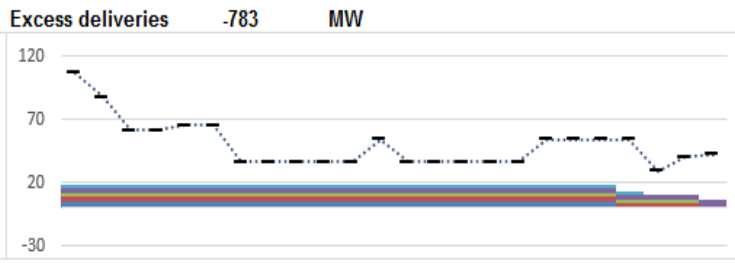
- One week horizon
- Demand for spot sales and all 3 FCR-types
- 29 generators
  - 21 can deliver FCRN
  - 12 can deliver FCRD-up
  - 6 can deliver FCRD-down
- Focus on next day

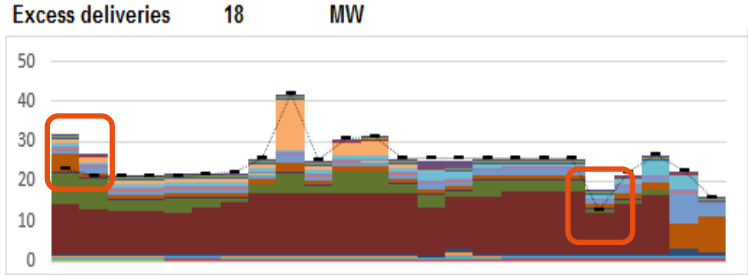
RESULTS

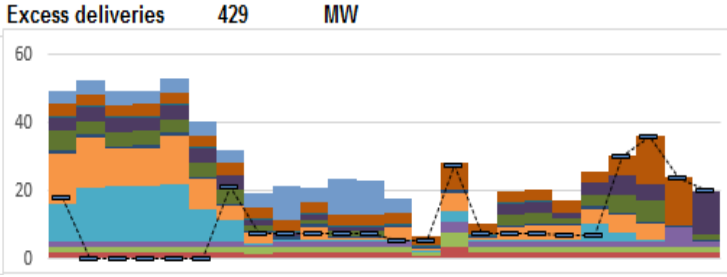
	FCR-N	FCR-D UP	FCR-D DOWN
BASE CASE No FCR-obligations. Continuous, common, must-run droop	Excess deliveries -409 MW	Excess deliveries 174 MW	Excess deliveries -783 MW
+ FCR-obligations	Excess deliveries 18 MW	Excess deliveries 429 MW	Excess deliveries 512 MW
+ Discrete droop	Excess deliveries 40 MW	Excess deliveries 476 MW	Excess deliveries 528 MW
+ Separate droop	Excess deliveries 0 MW	Excess deliveries 658 MW	Excess deliveries 28 MW
+ Stoppable droop	Excess deliveries 17 MW	Excess deliveries 40 MW	Excess deliveries 34 MW

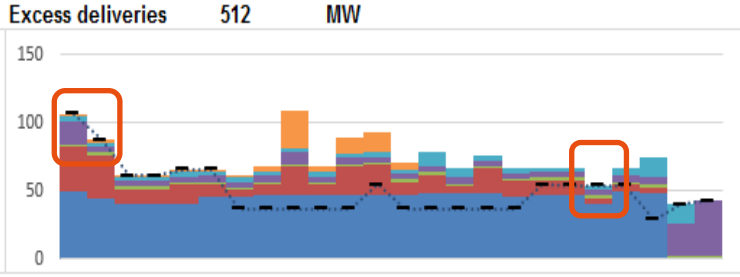


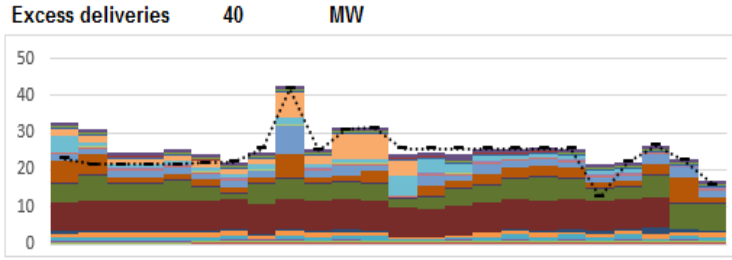


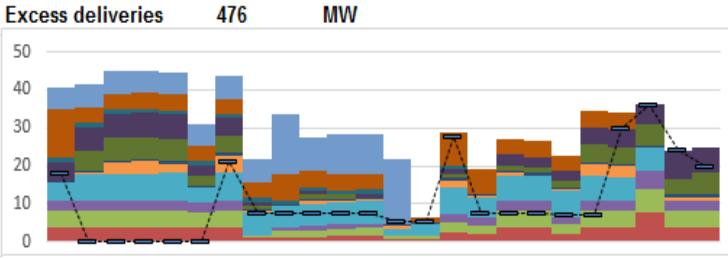


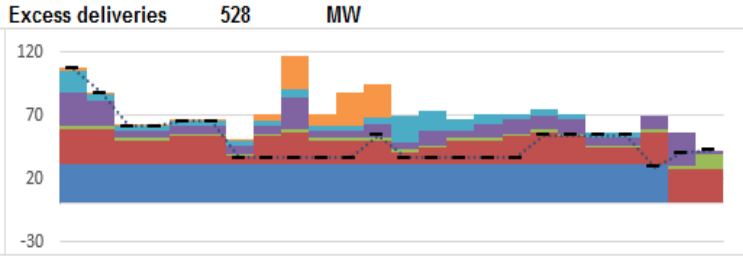


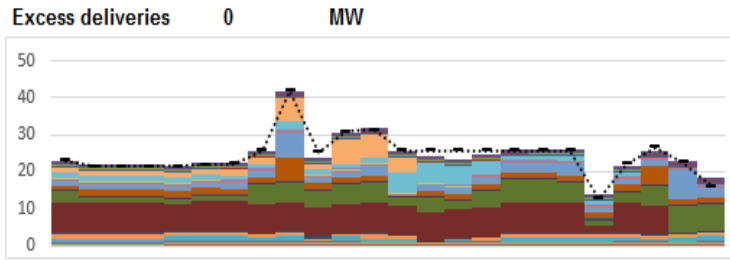


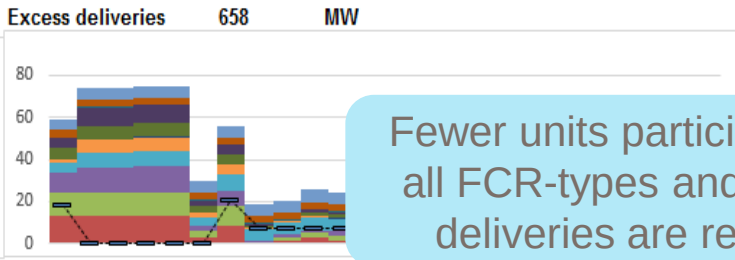


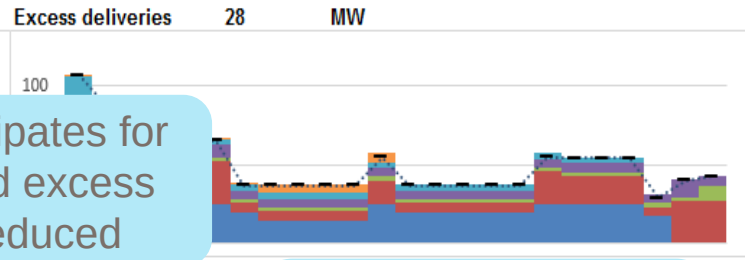




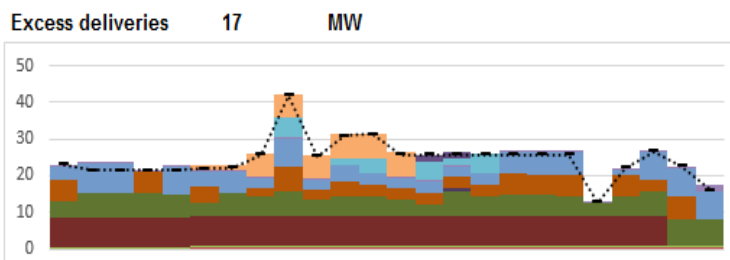


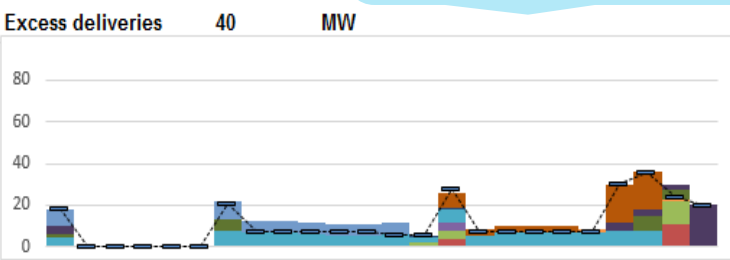


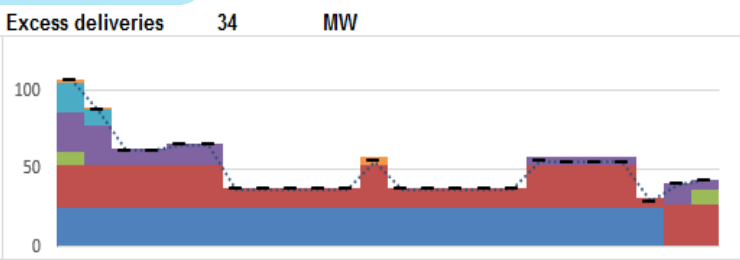




Fewer units participates for all FCR-types and excess deliveries are reduced







Summary

- The functionality for modelling combined separate, discrete and stoppable droop works very fine
- Some minor inconsistency detected in analyses with partial modelling of the droop
- Thanks for a good cooperation!

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