Discrete droop

TELLEF JUELL LARSEN, STATKRAFT
CHRISTIAN ØYN NAVERSEN, SINTEF

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Background

- SHOP can optimize FCR* deliveries and the droop settings given an obligation or a market price
- The droop is required to be a discrete value (and in Norway an integer), but is modelled in SHOP as a continuous variable
- A simple solution to create discrete results could be to set all droop results down to the nearest legal value after optimization
  - This will cause excess deliveries of FCR, and the corresponding FCR deliveries needs to be recalculated
- Statkraft has initiated a bilateral project to calculate discrete droop with SHOP

*FCR = Frequency Containment Reserves (primary reserveres)

Proposed solution

- Discrete droop can be modelled by using Mixed Integer Programming (MIP)
  - But using MIP will complicate the optimization (increase calculation time), is expensive to implement, and probably not beneficial for this use
- Instead, we proposed a simple heuristic solution:
  1. Create a new input attribute for giving a predetermined list of discrete droop values for units
     - If no list is given assume integer droop values
  2. Create a new command that discretizes the droop results that are below a limit given by the command (for all timesteps)
     - The command is intended to be used between incremental iterations, with an increasing droop limit for each iteration, with the intention to gradually lock the droop and redistribute the remaining FCR obligation
     - The discretization must reduce the droop down to the nearest legal value, comply with the min/max droop constraints, and keep the droop locked in all succeeding iterations

Solution

Note!
SHOP calculates the *allocated* FCR on each unit, not the *physical* delivery

- New Command:
  - set droop_dicretization_limit <number>

- New Input data:

```
GENERATOR   discrete_droop_values   Plant2      1
1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0
```

- Licence: **SHOP_DISCRETE_DROOP**
- From SHOP version 14.0.0.9
- Documentation in the form of an example on the SHOP Portal

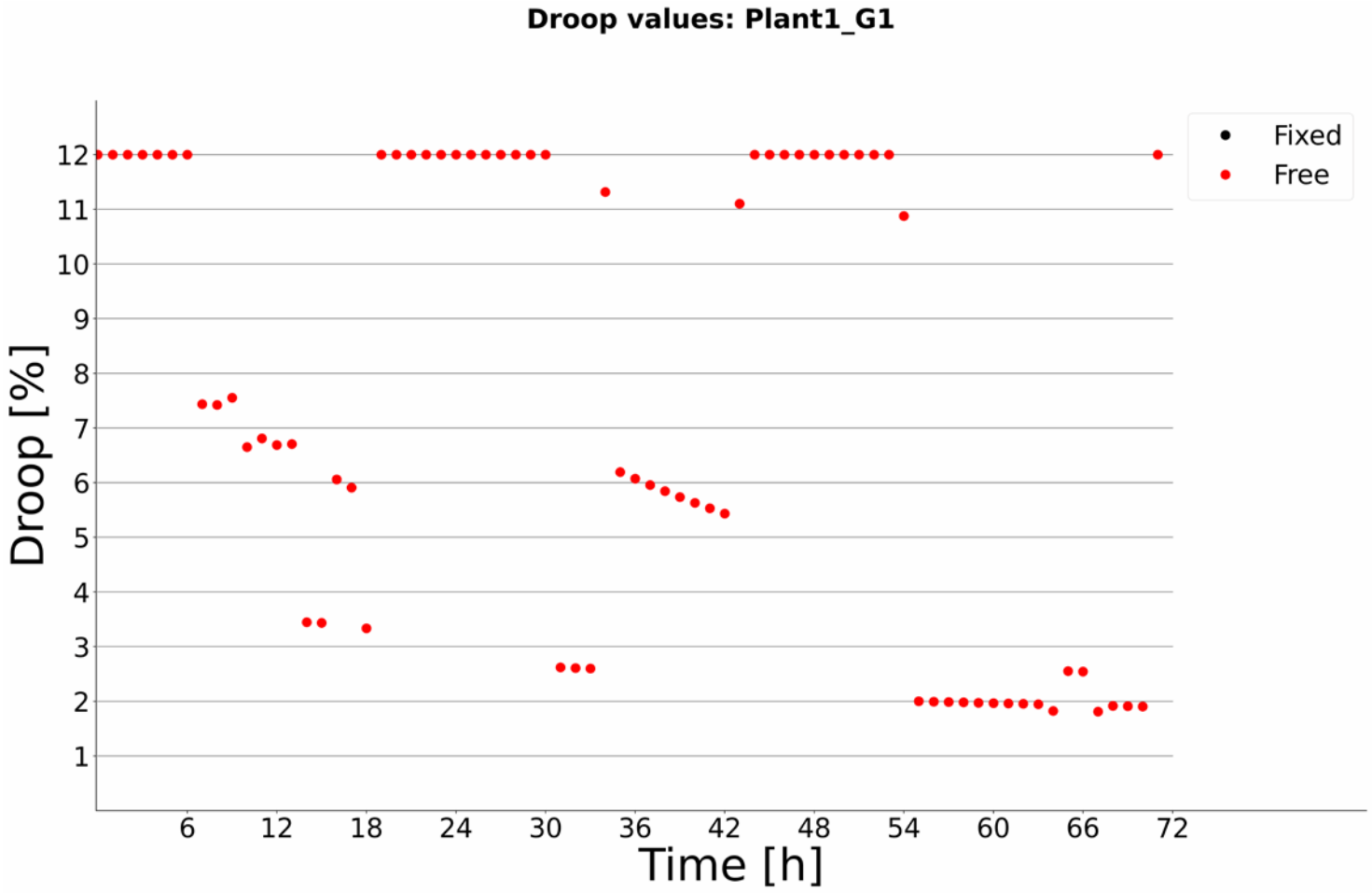
How it works

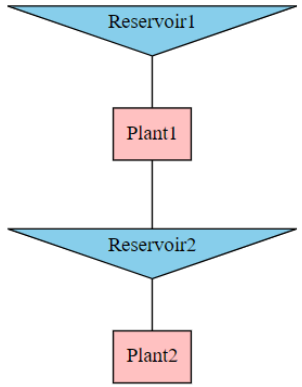
1. Run a standard optimization with FCR reserves

2. Add several new incremental iterations where the droop is fixed to increasingly higher values:

```
set droop_discretization_limit 2
start sim 1
set droop_discretization_limit 3
start sim 1
…
```

A simple test case – before discretization





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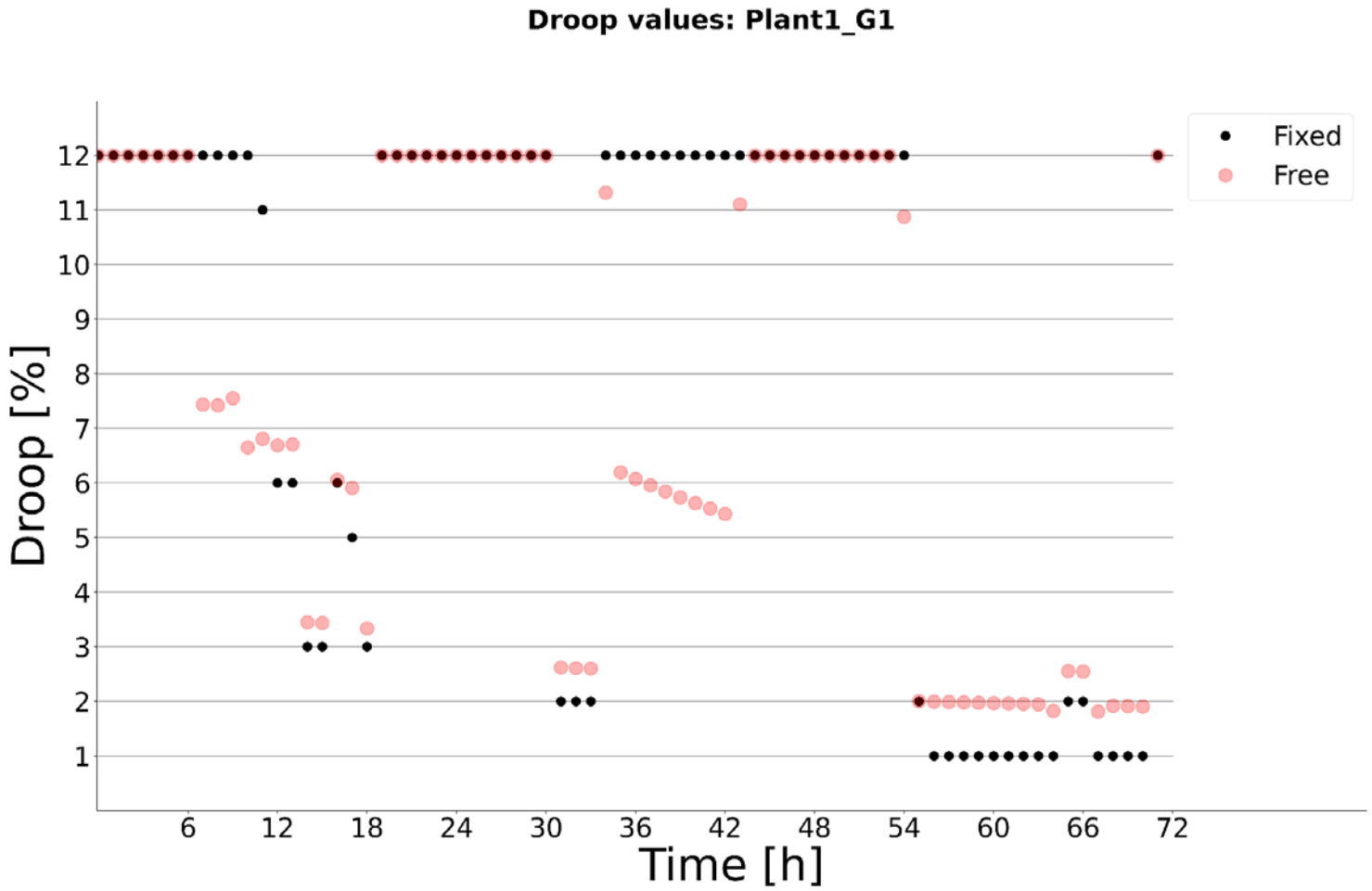
A simple test case – after discretization



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Evaluation

- How much is the excess FCR-N-up reduced by using different discretization approaches?
  - Note that the profit is impossible to compare as the real costs of FCRN are not modelled and SHOP don't calculate the physical deliveries

Approach	Discretization limit used in the incremental iterations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
No discretization	-	-	-	-										
One final discretization	-	-	-	-	**12**									
2-step discretization	-	-	-	-	**6**	**12**								
3-step discretization	-	-	-	-	**4**	**8**	**12**							
5-step discretization	-	-	-	-	**4**	**6**	**8**	**10**	**12**					
10-step discretization	-	-	-	-	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**

Test setup

- Price optimization
- No maintenance or schedules
- 3 days horizon
- Increasing FCR-N obligation
- Min/max droop is 2/12 for all units
- Integer discretization

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Results

Total excess FCR-N [MW] compared to no discretization	NO2 40 units
One final discretization	61
2-step discretization	45
3-step discretization	37
5-step discretization	37
10-step discretization	32

- Why doesn’t the excess FCR-N drop steadily with improved discretization?
  - SHOP do not always cover the FCR-N obligation, and sometimes deliver too much
- Why doesn’t the excess FCR-N drop closer to zero with maximum discretization?
  - Too many units are set and locked to the minimum droop limit (probably because the cost of regulating the droop is independent of the droop setting)

Recommendations

Improvement of FCR-N

- Implement cost curve for droop
- Improve optimization to cover the obligation better
  - The allocated FCR-N should only deviate from the physical FCR-N when the base deliveries (grunnleveransen) is higher than the obligation
- Implement own production constraints for FCR
  - Allocated deliveries are now restricted by generator max and plant max constraints, but the turbine regulator do not consider them
- Calculate the physical deliveries for each unit (in addition to the allocated)

Improvement of droop discretization

- Try alternative heuristics if other improvements doesn't help, e.g.:
  - Lock a percentage of the units, or
  - Lock units with droop above the limit instead of below, or
  - Lock the units closest to their droop limits

Use of droop discretization

- Apply one discretization step with current SHOP version

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statkraft.com