Requirements for Generators

- a way to secure a stable and robust power system

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What is RfG?

- COMMISSION REGULATION (EU) 2016/631 - establishing a network code on requirements for grid connection of generators
- Usually called Requirements for Generators (RfG)
- Harmonised rules in order to:
  - Provide a clear legal framework for grid connections
  - Facilitate Union-wide trade in electricity
  - Ensure system security
  - Facilitate the integration of renewable electricity sources
  - Increase competition
  - Allow more efficient use of the network and resources

What is RfG?

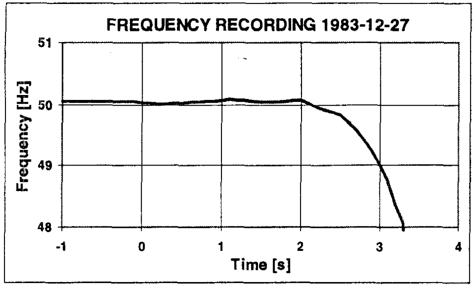
- RfG applies to all new power generating modules
- Fulfilment of the requirements shall be verified
  - Theoretical verification
  - Verification via tests
- RfG replaces the preceding requirements SvK FS 2005
  - Most existing power generating modules still follow SvK FS 2005 but during modernization they will step by step enter into RfG
- RfG has a national complement in EIFS 2018:2

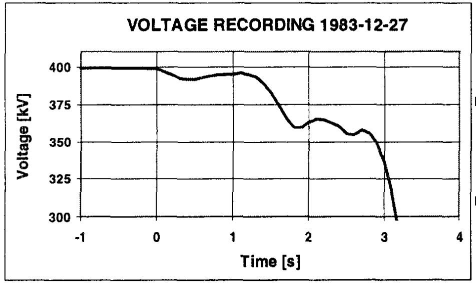
Requirements for system stability

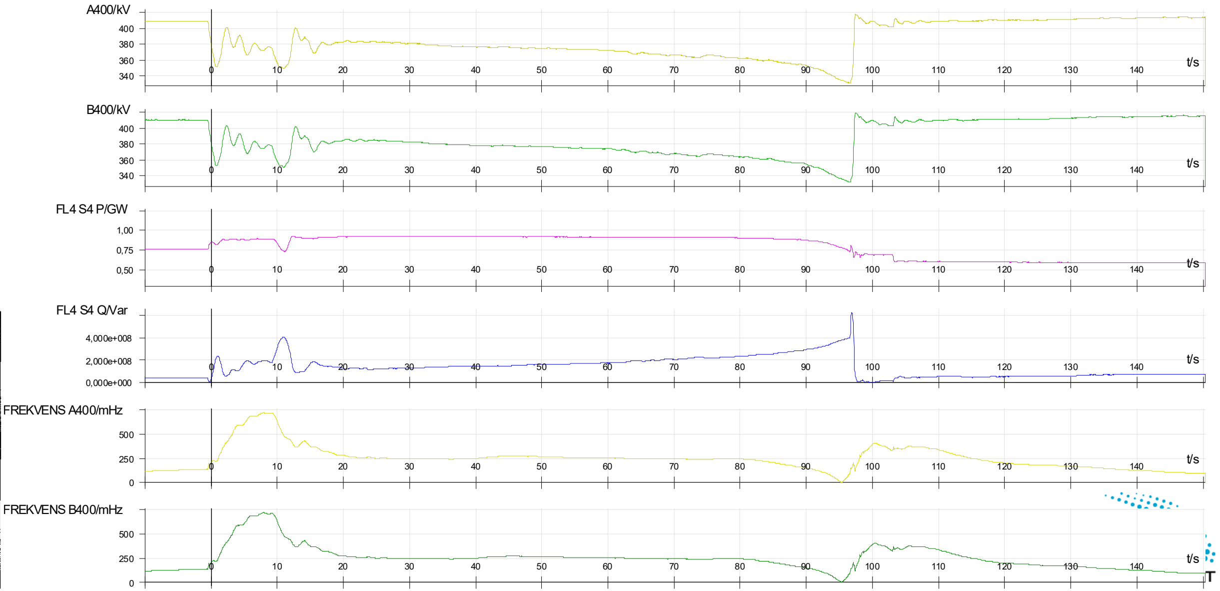
- Requirements in RfG to ensure system stability, such as:
  - Robustness to frequency- and voltage variations, power oscillations
  - Frequency control, FSM and LFSM-O/U
  - Maintain active power in case of frequency variations
  - Adjustment of active power
  - Capability of reactive power production
  - Control of reactive power / voltage
  - For power park modules: fault current injection and synthetic inertia
  - Fault-ride-through capability
  - Quick re-synchronisation or houseload operation

Disturbances in Sweden 1983 and 2003

- Caused by voltage collapse
  - High load on the transmission lines
  - Not enough reactive power capacity to maintain the voltage level





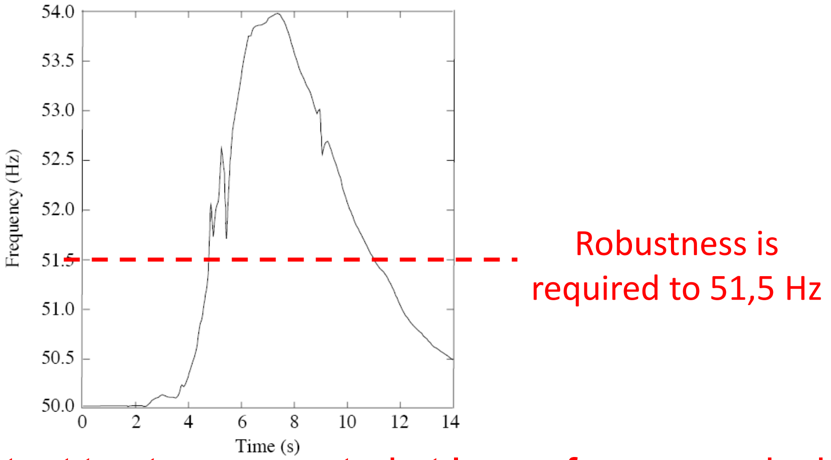


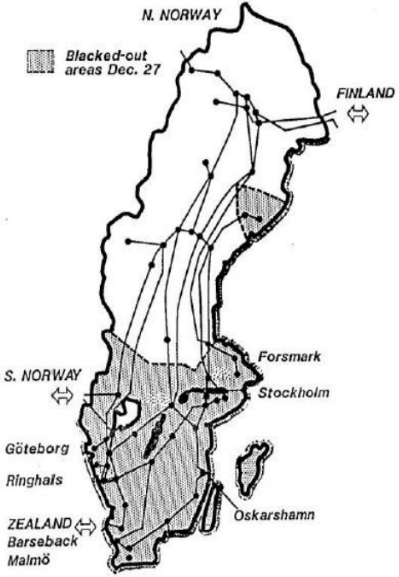
Requirements for voltage stability

- Voltage range for operation 90-110 %
- Reactive power capability given in EIFS 2018:2
  - Synchronous power-generating module: +1/3 and -1/6 of P_{prod}
  - Power park module: +1/3 and -1/3 of P_{prod}
- Modes for reactive power control
  - Reactive power/Mvar control
  - Voltage control
  - Power factor control
- Automatic transition to voltage control (EIFS 2018:2)
  - In case of a voltage drop below 0.95 pu, power park modules should switch to voltage control if they are in Mvar or power factor control

Disturbance in Sweden 1983

- Disconnection of the southern part caused overfrequency in the remaining northern part of the grid
  - Important with robustness towards frequency deviations and frequency derivative

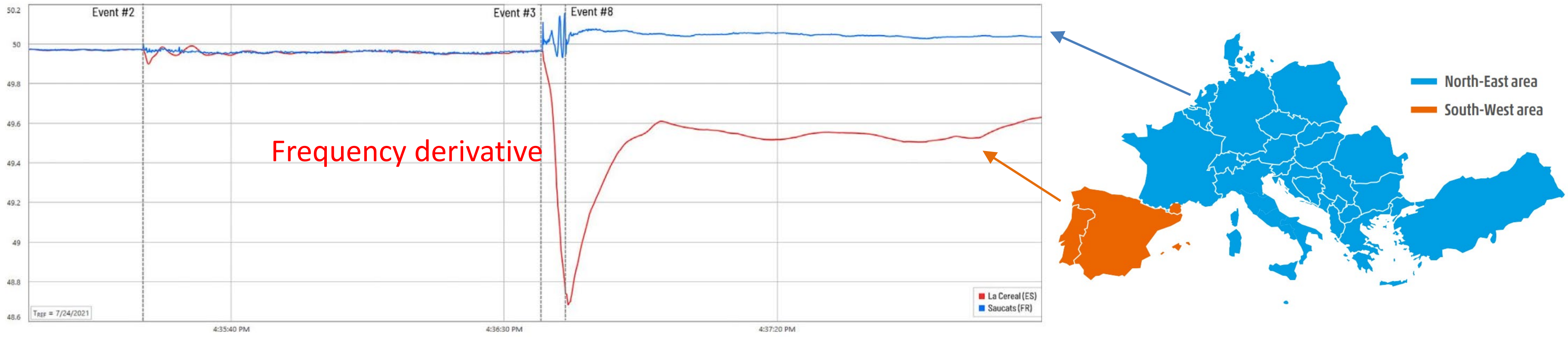




Important to stay connected at larger frequency deviations if possible

System split 2021 Portugal/Spain

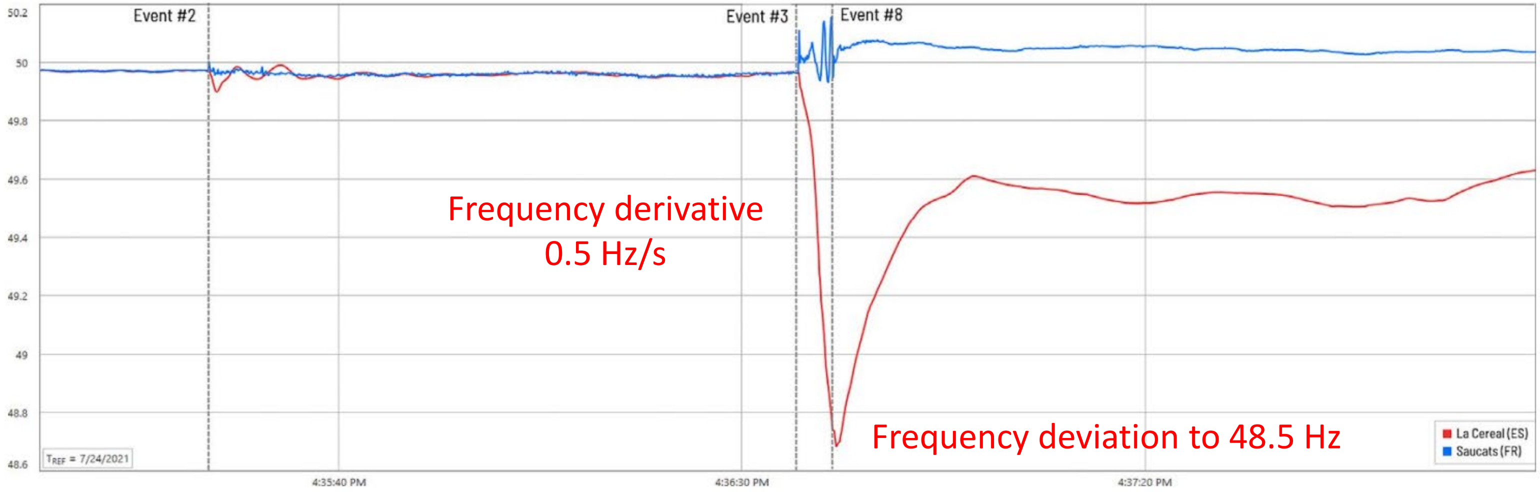
- System split due to two subsequent faults and following overload
  - Resulting overfrequency / underfrequency in the disconnected systems
  - Frequency restored by frequency control and underfrequency loadshedding



Frequency deviation

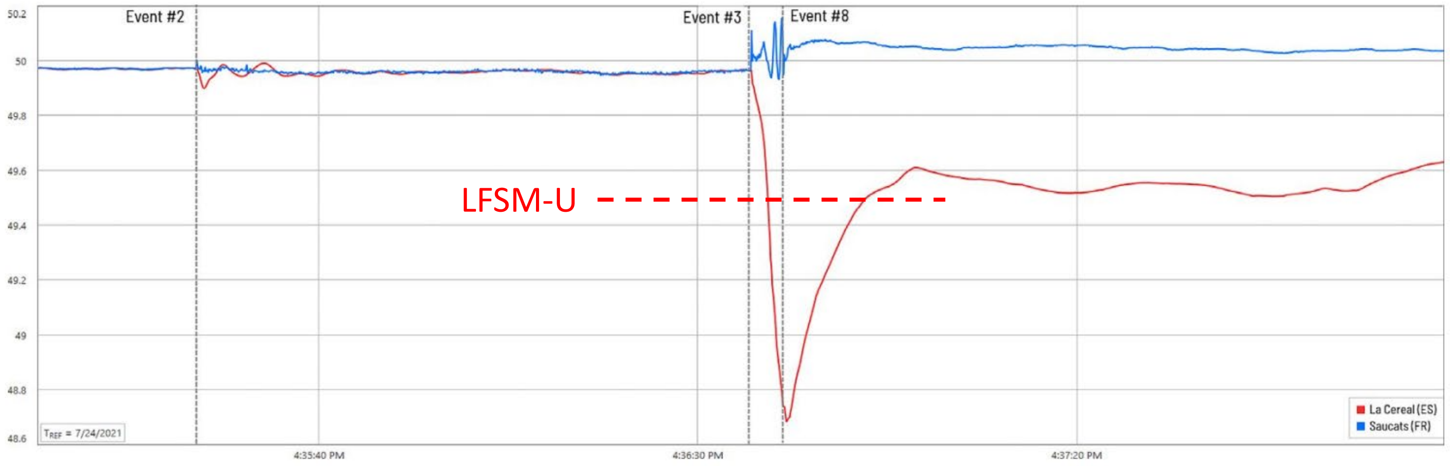
Requirements for frequency stability

- Important that the power-generating modules do not trip
  - Robustness to frequency deviations within 47.5-51.5 Hz (EIFS 2018:2)
  - Robustness to frequency derivative up to 2.0 Hz/s (EIFS 2018:2)
  - Limited reduction in power production at low frequencies (EIFS 2018:2)



Requirements for frequency stability

- Frequency control
  - The inertia in the grid limits the frequency derivative
  - In addition to FCR and FSM, LFSM-U starts at a certain frequency (49.5 Hz)
  - Underfrequency loadshedding also important for severe frequency deviations



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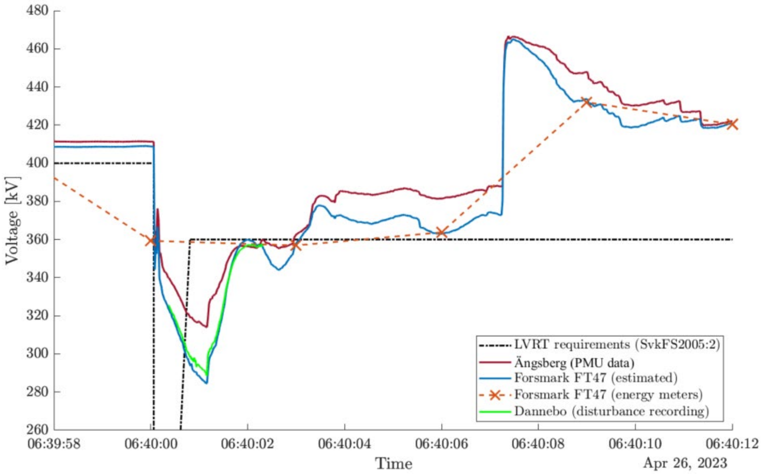
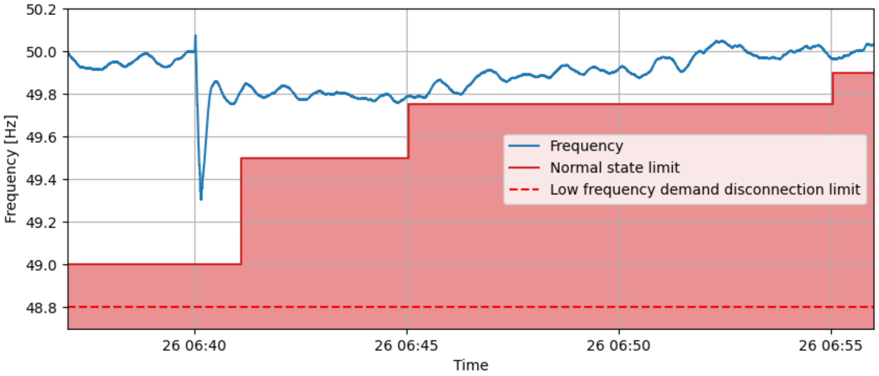
Hagby incident 2023

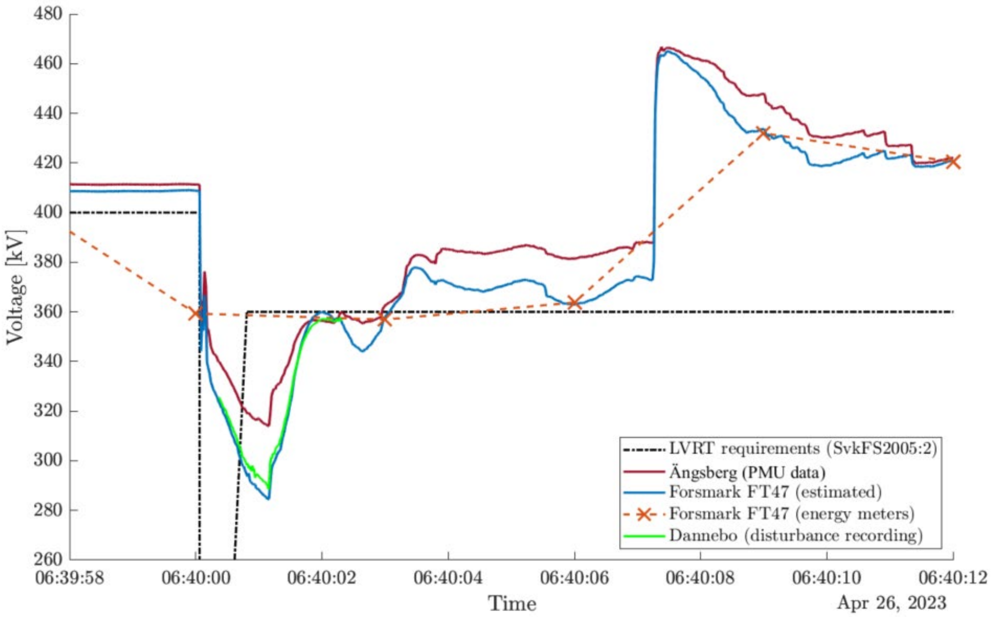
- Fault applied for 7 s with resulting voltage dip
- Disconnection of generation leads to a frequency dip





Hagby incident 2023

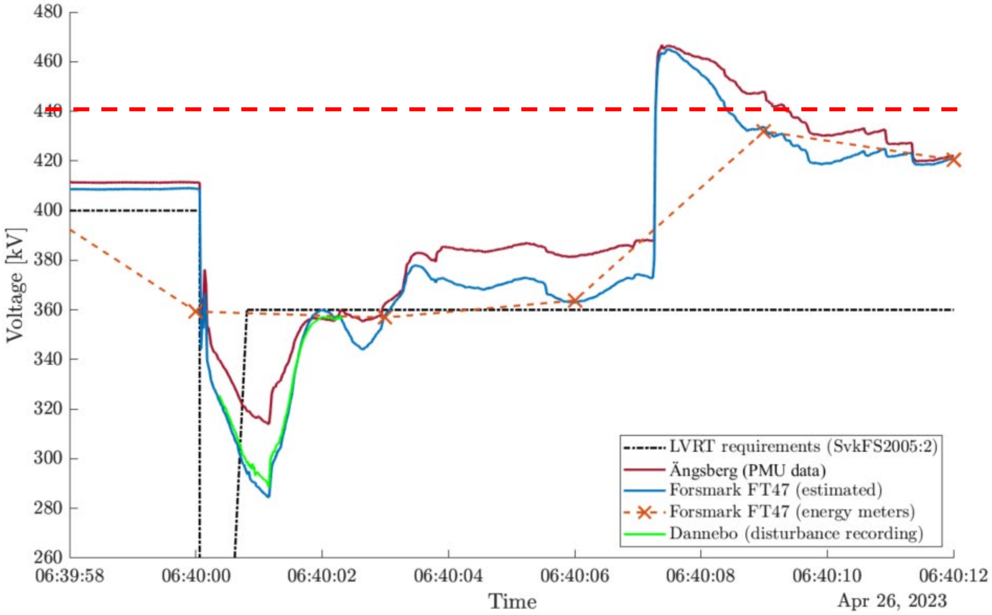
- Reactive power support:
  - Generation
  - HVDC
  - STATCOM
  - Load reduction
- Fault current injection
- Robustness to voltage variations 90 % to 110 %
- Fault-ride-through
  - Forsmark 1 and 2 tripped
  - Forsmark 3 did not trip



Important that the capability follows, but is not limited to, the requirements given in the grid codes

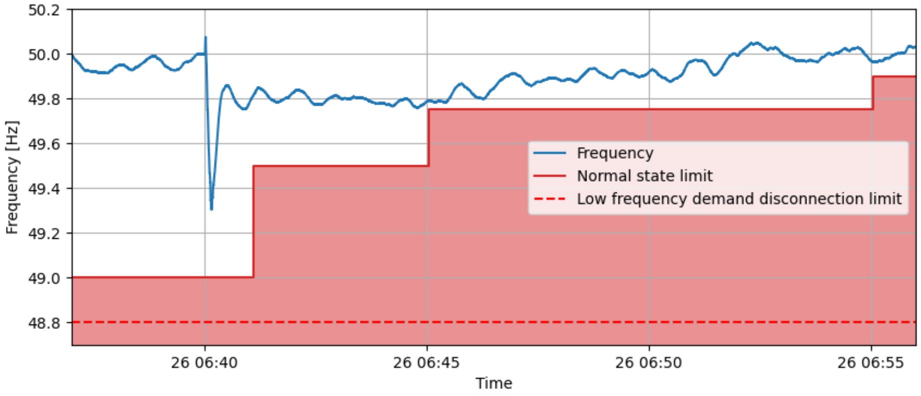
Hagby incident 2023

- Low-voltage ride through capability is required and well known
- Robustness to 110 % overvoltage is required, here 440 kV
- Also requirements for over-voltage ride through are needed



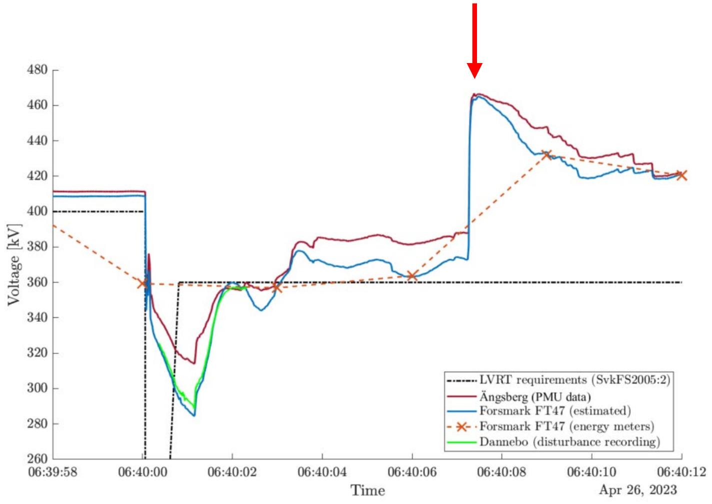
Hagby incident 2023

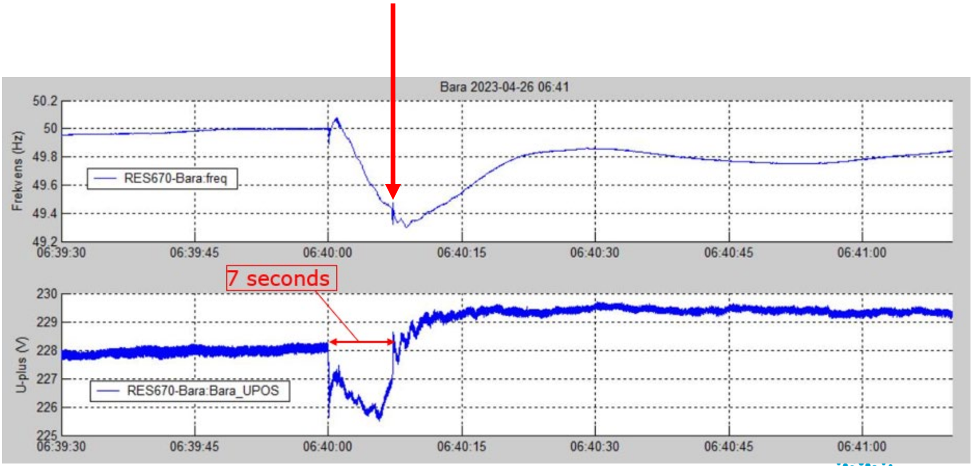
- Loss of 2100 MW from Forsmark plus additional smaller units
- High inertia limited the frequency derivative
  - Requirement for synthetic inertia for power park modules
- Frequency dip to 49,3 Hz
  - LFSM-U activated



Hagby incident 2023

- Voltage dip with resulting disconnection of generation
  - Under-frequency as a result of the disconnection
  - Over-voltage when the fault is cleared
  - Simultaneous under-frequency and over-voltage => high V/Hz





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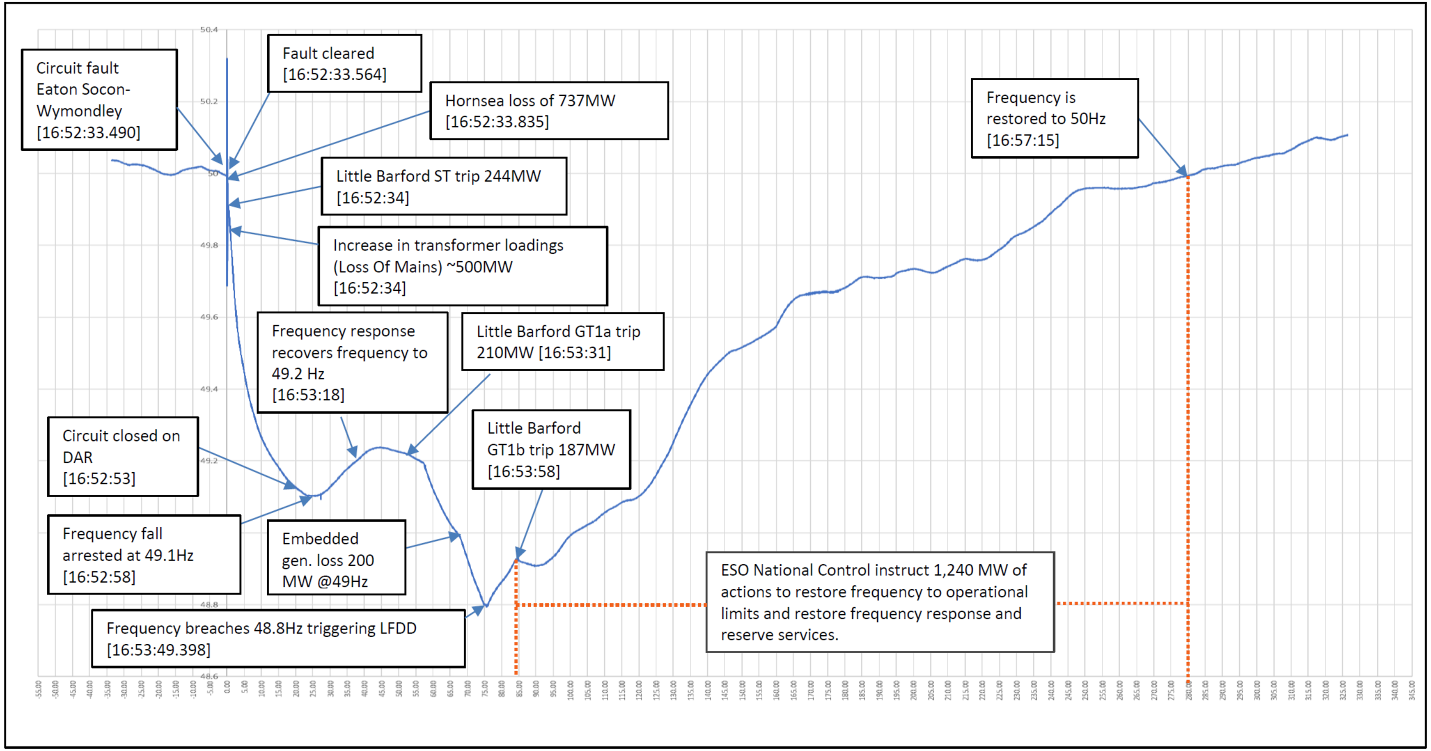
Underfrequency Event London 2019

- August 9th 2019 correctly cleared lightning strike
  - Loss of 150 MW embedded generation
  - Correctly cleared fault after about 60 ms
- Additional loss of generation in contradiction to the requirements in the grid codes giving a total loss of 1878 MW
  - Frequency decreased gradually with the disconnections to 48,8 Hz
- Frequency was eventually restored by load shedding, backup power and frequency control
  - Approximately 1.1 million customers were without power for 15-45 minutes

Underfrequency Event London 2019



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Underfrequency Event London 2019

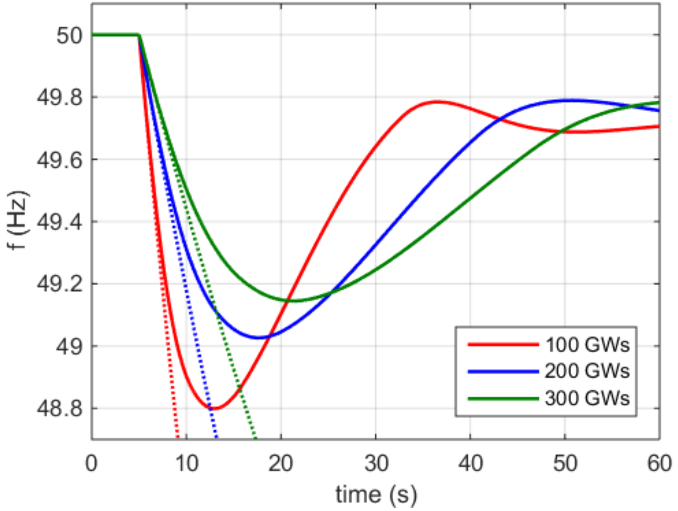
- Important that the fault ride-through requirements are met
  - Verify the fault-ride-through capability for the whole power park module, including connection and internal grid
  - Verify the response to the transient voltages such as a fault
- Verify the robustness for the whole power plant to avoid tripping
  - Duration of the fault only about 60 ms
  - Frequency drop to 48,8 Hz
- The controller is an important part of a power park module
  - Verify the capability of the power park with the actual controller and settings
  - Repeat verification when updating the controller
- Simulations are important to verify robustness in the grid

In case of a blackout

- In case of a blackout, it is important to energize the grid as fast as possible
- Power-generating modules shall be able to re-synchronize within 15 minutes after the voltage has been restored
  - Quick restart followed by resynchronization or
  - Houseload operation followed by synchronization
- Good to support the system as long as possible but do not risk the capability to houseload operation by staying connected too long in case of a voltage dip
- During previous disturbances, nuclear power plants had problems with entering houseload operation

Outlook for the future grid

- In the future the generation mix will have a larger share of renewable generation
- The characteristics of the power park modules will be more important for the system stability
- Fault current injection
  - Limit the distribution of a voltage dip
  - Maintain the possibility for fault detection and correct disconnection of faults
- Synthetic inertia
  - Limit the initial frequency derivative in case of loss of generation or load
  - Improve the frequency stability



Concluding remarks

- Important that all stakeholders contribute to a stable power system
- The requirements in RfG are important to avoid and/or limit disturbances in the system
- Verify the characteristics/capability of the whole power generating module, including the internal grid as well as the present control system and settings
- All new power generating modules must be verified according to RfG
- In case of upgrades of existing power generating modules, the relevant regulatory authority (Energimarknadsinspektionen) decides which requirements that should be fulfilled and verified