The emerging role of fast frequency reserves (FFR) in balancing markets

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Content

- **Purpose:** Understanding of fast frequency reserve and current practice in Norway
- **Time**: 45 min
- **Target:** Public Audience
- **How:**

Inertia: Physics of the power system
checkpoint I
TSO (Statnett): Pilot Project 2018
checkpoint II
Concluding Remarks

The Electricity System

Characteristics of power system

- power system with suppliers and consumers
- power generated cannot be stored largely, so it must be consumed
- the entire system is in a frequency balance of 50 Hz and needs to be maintained

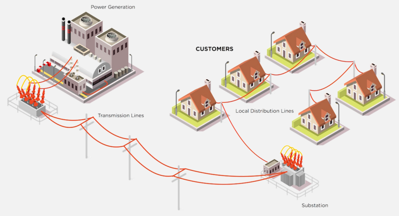

Figure 1: A Typical Power System [Rochester Gas & Electricity]

Steady-State: Balance Model

Supply = Demand

Simplest model of a power system can be written as a balance model

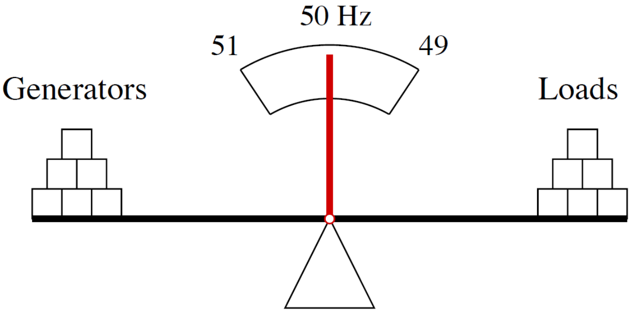

Figure 2: Steady-state balance model of power systems [figure adapted from "Power system dynamics visualization . . . " by F. Milano '18]

Inertia and Electromechanical Oscillations

Let us assume for now that the system includes synchronous machines but no control.

$$Ma - F = 0$$

$$M\ddot{\theta} - K\theta = 0$$

$$M\ddot{\theta} - [P_{gen} - P_{load}] = 0$$

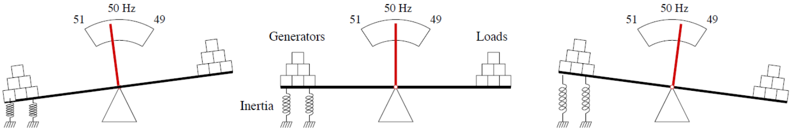

Figure 3: Mechanical springs represent the synchronous machine inertia

[figure adapted from "Power system dynamics visualization . . . " by F. Milano '18]

Primary Frequency Control

Notation

To represent the primary frequency control, we connect a mass to the fulcrum of the beam to lower the center of mass of the scale. Moreover, we add mechanical dampers. Whenever an unbalanced condition occurs, the scale will start to oscillate but the effect of the damper will prevent a sustained oscillation around the equilibrium point. Then the new equilibrium is given by the sum of the momenta of the three masses, generators, loads and primary frequency control.

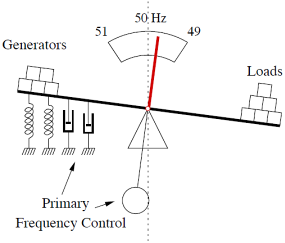

Figure 4: [figure adapted from "Power system dynamics visualization . . . " by F. Milano '18]

Secondary Frequency Control

Notation

This is basically just a rescheduling of the active power set point of the turbines of the synchronous machines. The AGC is much slower than the primary frequency control and in the mechanical model its effect is mainly visible at the equilibrium. The representation in the figure is simplistic, however. In practice all generators will increase their power production to compensate a generator outage or a load increase.

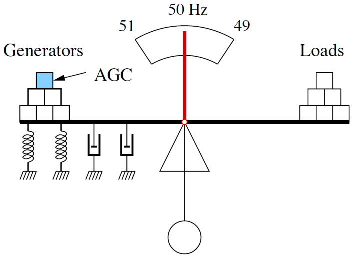

Figure 5: [figure adapted from "Power system dynamics visualization . . . " by F. Milano '18]

Effect of renewable generations

Notation

Renewable sources have several effects on the system: they add randomness and reduce inertia, spinning reserve and damping.

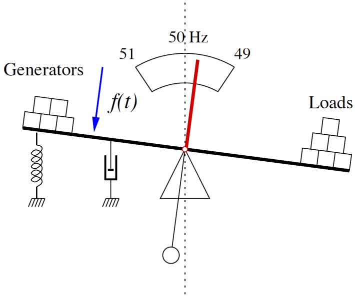

Figure 6: [figure adapted from "Power system dynamics visualization . . . " by F. Milano '18]

Effect of renewable generations

Notation

$$M\ddot{\theta} = P_{generation}(t) - P_{demand}(t)$$

change of kinetic energy = instantaneous power balance

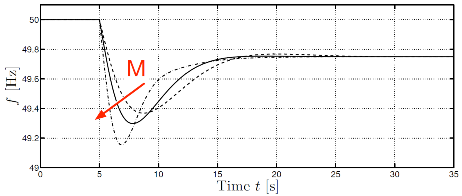

Figure 7: [figure adapted from "Low-Inertia Power Systems . . . " by Florian Dörfler, ETH Zurich]

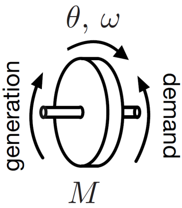

Figure 8: [figure adapted from "Low-Inertia Power Systems . . . " by Florian Dörfler, ETH Zurich]

RoCoF

Rate of Change of Frequency = RoCoF

- $M \uparrow \quad \text{RoCoF} \downarrow$

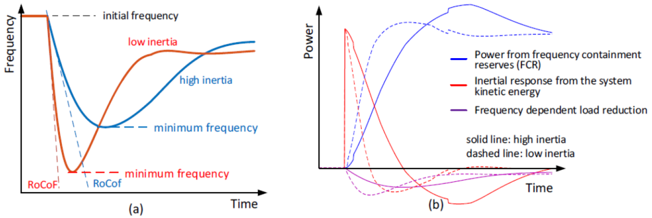

Figure 9: [figure adapted from "Fast Frequency Reserve – Solution to the Nordic inertia challenge " by entsoe]

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- M $\downarrow$ RoCoF $\uparrow$

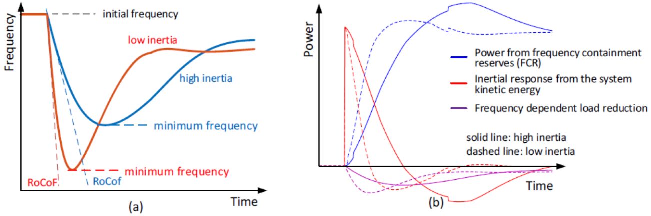

Figure 9: [figure adapted from "Fast Frequency Reserve – Solution to the Nordic inertia challenge " by entsoe]

Inertia in Power Systems

- It is expected that electricity will be produced more and more by wind and solar power plants.

Figure 10: Wind and Solar [Source: Getty Images]

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- Thermal power plants will spend less time synchronised to the power system.

Figure 11: Thermal Power Plant [business-standard.com]

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- High import on HVDC connections to other synchronous systems is also expected to replace traditional production more often.

Figure 12: HVDC [etap.com]

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- High import on HVDC connections to other synchronous systems is also expected to replace traditional production more often.
- Decommissioning of nuclear power plants.

Checkpoint I

TSO (Statnett): Pilot Project 2018

System Structure: Market and System Operators

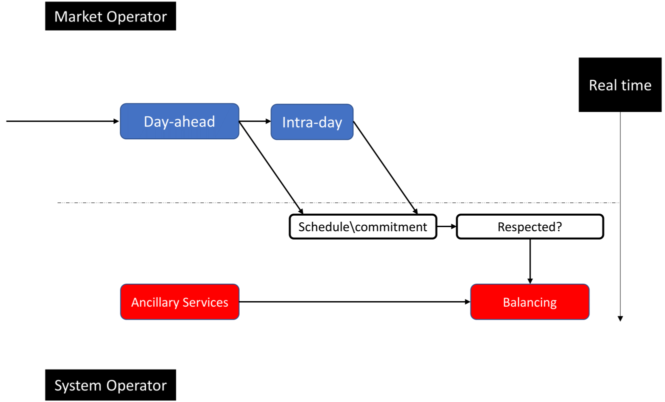

Figure 13: Structure of Market and System Operator

The role of TSO-Operational Security

Statnett duties:

1. Balance production and consumption.

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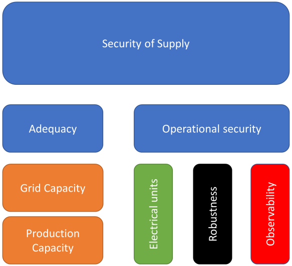
6. Adapt the control system over time.

Power system is more than 100 years old and changing a lot



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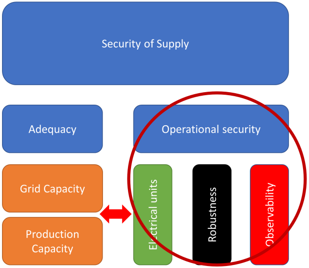

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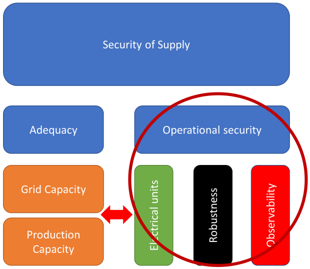
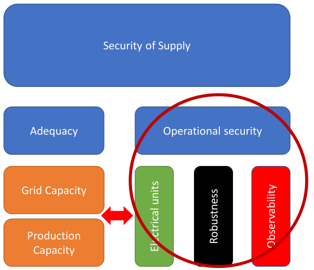


System Operation shall be done to the lowest achievable costs!

Operational Security

- System challenges in the Nordic power system are changing the technical characteristics.

Increase need of flexibility: | Frequency | Voltage | Power



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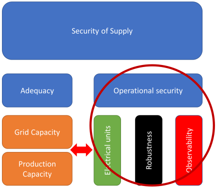
New system Characteristics

- Low inertia system
- Balancing - More weather dependent power production

Electricity Market



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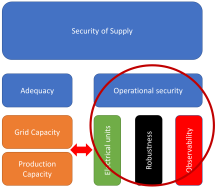

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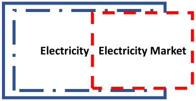
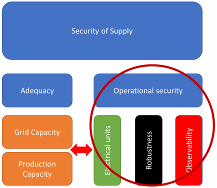
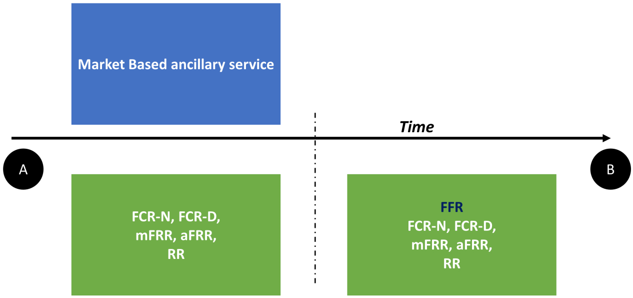


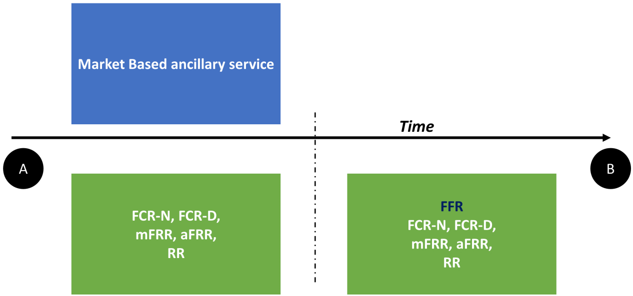


From A to B



why do we want market based solution?

From A to B



why do we want market based solution?

Because we want to make sure who knows each power plant the best, put in a bid when suits them.

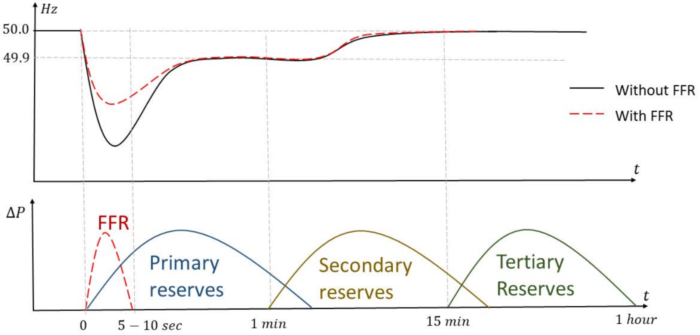


Figure 14: Power system frequency response to a power deficit [Kjetil Uhlen and Olav Bjarte Fosso. Power system operation and Frequency control (lecture notes).]

Justification-Why do we need FFR?

Frequency stability in Nordic system

Frequency stability here mainly referred to the ability of securing the frequency above a threshold

1. The current response of the primary frequency reserve in the Nordic synchronous area does not ensure frequency stability in low inertia situation. [1]

[1] [entsoe, "Fast frequency reserve-solution to the Nordic inertia challenge" 2019]

[2] [Ørum et al., Future system inertia 2, 2017]

[3] [M. Kuivaniemi and E. A. Jansson, "FFR feasibility study," Unpublished report, 2019]

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2. The volume needed to affect the minimum frequency by 0.1 in an 80 GWs system is 20 GWs [2]. The availability of different possible techniques are varies but the cost will be high.
3. FFR is deemed the most promising mitigation solution for low inertia situation since several techniques can provide fast power response estimated at low socio-economic costs, either as a disconnection of load or fast increase from inverter-based generation and storage [3]

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Nordic TSOs: Inertia Forecasting

> **Inertia Monitoring:** Real time kinetic energy estimation tool is implemented for all Nordic TSOs, in their supervisory control and data acquisition SCADA/Energy Managment System (EMS).

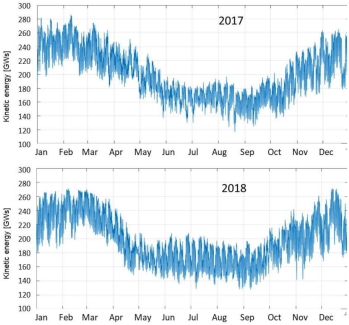

Figure 15: Estimated kinetic values (Nordic synchronous system)

Nordic TSOs: Inertia Forecasting

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> **Inertia Forecasting:** The aim of forecasting the system inertia is to estimate the instantaneous frequency minimum for the online reference incident.

> **FFR estimate need:** see ["Fast Frequency Reserve – Solution to the Nordic inertia challenge " by entsoe]

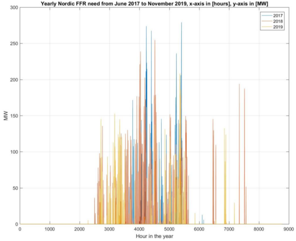

Figure 15: Historical need for FFR in the Nordic SA based upon estimated inertia levels from June 2017 to Nov. 2019)

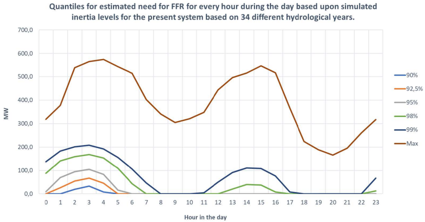

Figure 16: 90, 92.5, 95, 98, 99 and 100 % quantiles for the estimated need for FFR for the Nordic SA for every hour during the day based upon simulated inertia levels for the present system based on 34 different hydrological years.

Statnett Pilot for FFR, 2018

Aim to gain knowledge

- about availability of such a new reserve product.
- challenge and possibility related to technical and market aspect.
- provide the Norwegian stakeholders with a heads-up on the future possible system needs.

Statnett Pilot for FFR, 2018

Product requirements

- Activation for a frequency triggering point of 49.6 Hz
- Time of full activation from 49,6 Hz: 2 seconds
- Duration: 30 seconds (i. e. FFR shall be able to be activated for a minimum of 30 seconds)
- Resting time: 15 min

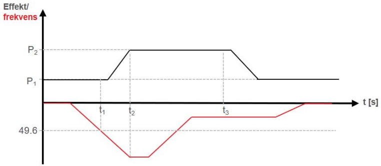

Figure 17: Illustration of power response as a result of frequency change. The figure illustrates a case where netpower input to the grid is increased. [Fast Frequency Reserves 2018-pilot for raske frekvensreserver, Statnett]

Statnett Pilot for FFR, 2018

Received Tenders

- SFE[a]: Fast response form hydro power in generation mode
- BKK: Fast load disconnection via pump power disconnection
- Fast load reduction in a smelter (electrolysis process)
- Fast load disconnection by an aggregated portfolio in industrial costumers.
- Tibber: Fast load disconnection by an temporary stopping the charging in an aggregated pool of electric vehicles
- Fortum/Basefarm: Fast switch in power supply from grid to battery power (UPS) to a data center.

[a] Song og Fjordane Energi

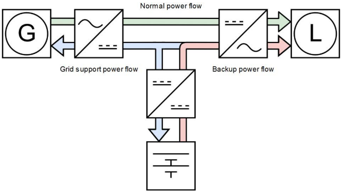

Figure 18: Power flow for UPS for normal use and for backup solution and FFR (Fortum 2018).

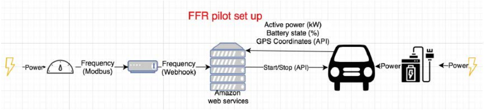

Figure 19: Delivery of FFR from electric cars (Tibber 2018)

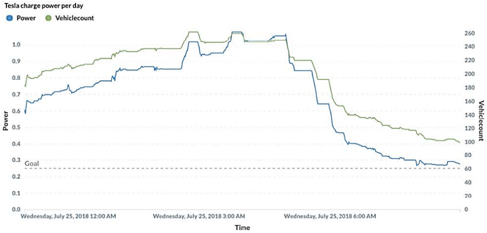

Figure 20: Example of how a portfolio of electric cars is charged through the night measured in MW (Tibber 2018).

Statnett Pilot for FFR, 2018

Summary of technology and fulfillment if criteria

Technology	Response time	Endurance	Ramping back	Rest time
Hydropower SFE	Not Ok	Ok	Ok	Ok
Pumped-storage hydroelectricity	Ok	Ok	Not Ok	Not Ok
Industry, Electrolysis process	Ok	Ok	Ok	Ok
Tibber, Aggregator, EV	Ok	Ok	Ok	Ok
Fortum, UPS	Ok	Ok	Ok	Ok

FFR-demo 2020

Statnett requested even for more faster response for FFR participants demonstration projects of 2020.

Alternative	Activation level [Hz]	Maximum full activation time [s]
A	49.7	1.3
B	49.6	1.0
C	49.5	0.7

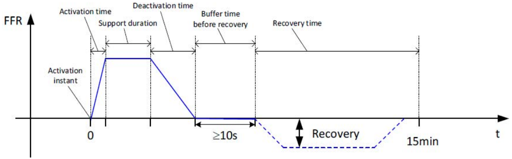

Figure 21: Illustration of power response as a result of frequency change. The figure illustrates a case where netpower input to the grid is increased. Table and figure are taken from [FFR-demo 2020, betingelser for deltagelse i demonstrasjonsprosjekt]

The Nordic product requirements define two equivalent combinations of delivery time (period of fullpower supply) and deactivation of power supply

I Long delivery time, at least 30 seconds

II Short delivery time, at least 5 seconds

Checkpoint II

Summary:

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Highlights

- Amount of inertia in the synchronous power system is proportional to the amount of rotating mass of synchronous generators and machines.

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- Massive integration of renewable energy generations, decommissioning of thermal and nuclear power plants (with synchronous generators), more and more dependence on HVDC import/export, all are parts of the road map toward expected near future.

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- Amount of inertia in the synchronous power system is proportional to the amount of rotating mass of synchronous generators and machines.
- Massive integration of renewable energy generations, decommissioning of thermal and nuclear power plants (with synchronous generators), more and more dependence on HVDC import/export, all are parts of the road map toward expected near future.
- TSO have an important role in shaping new emerging markets, by opening dialogue with market players and introduce flexibility in a socio-economical manner.

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- Amount of inertia in the synchronous power system is proportional to the amount of rotating mass of synchronous generators and machines.
- Massive integration of renewable energy generations, decommissioning of thermal and nuclear power plants (with synchronous generators), more and more dependence on HVDC import/export, all are parts of the road map toward expected near future.
- TSO have an important role in shaping new emerging markets, by opening dialogue with market players and introduce flexibility in a socio-economical manner.
- Pilot Project 2018:
  I FFR is a cost efficient measure for handling of low inertia challenges.
  II Pilot project gave a profound understanding how FFR could be implemented and tested.
  III Pilot project gave an overview of how flexibility could contribute to power system operational security.

Thank you for your attention!

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