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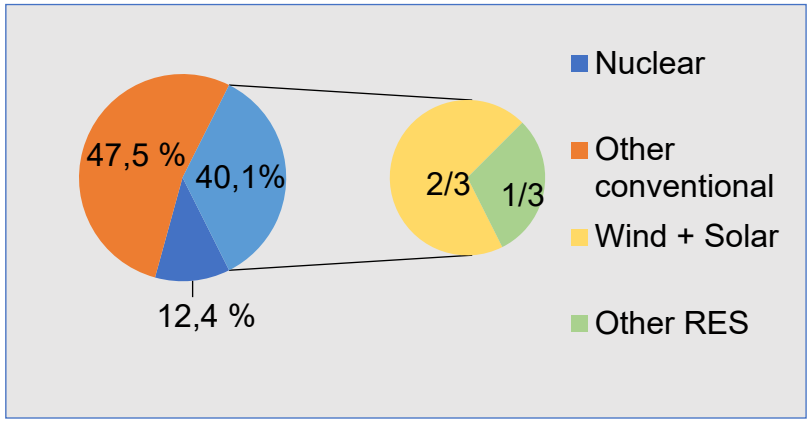
Survey on power system ancillary services
Markets and services technically suitable and applicable to NPPs

Tatiana Salnikova, Framatome GmbH

Energiforsk Webinarium GINO project findings
13 October 2020

Introduction

- France and Germany are leading countries applying flexible operation modes for NPPs.
- The German grid has a very strong penetration of **volatile renewable energy**
- The regions of Germany (in terms of transmission operator jurisdiction), or even Germany as a whole, do not have such a large nuclear fleet as EDF in France, which has 58 NPPs
- Much more flexibility is required for **each particular** plant, both PWRs and BWRs, in Germany.



Germany is probably the best example and reference for the Nordic system

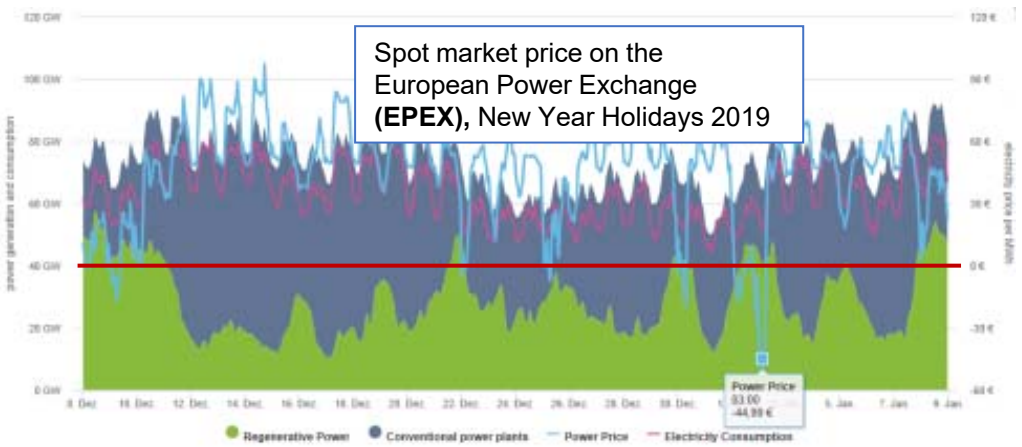
Market development: Negative/Low Prices in Germany

Since 1991 - renewables obligation and feed-in tariff - “non-dispatchable energy”

Since 2008 - market liberalization, European Energy Exchange allows “negative prices” -> start of advanced flexible operation of NPPs in Germany

Since 2017, six-hour rule (EEG-2017)

- **In 2019, peak production of renewables led via ENTSO-E to 211 negative hours**
- **March, 2020 -> led alone to 130 negative hours due to COVID-19 pandemic impact!**



www.agora-energiewende.de

Advanced flexibility gives more opportunities for fleet optimization and avoids NPP production for negative and low prices at energy market!

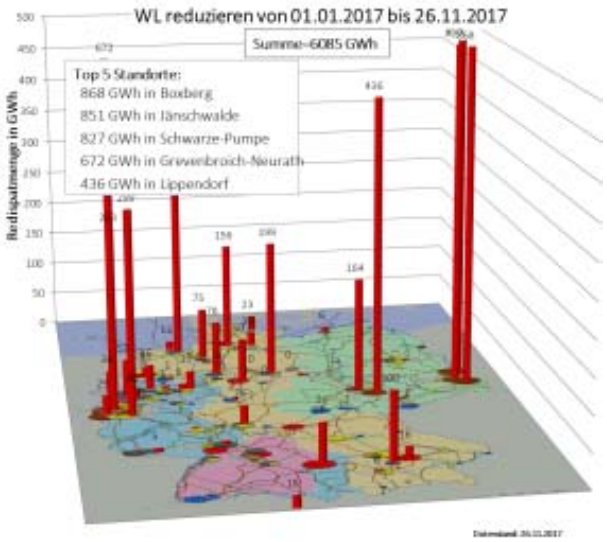
Reserve and Balancing Markets on German Example

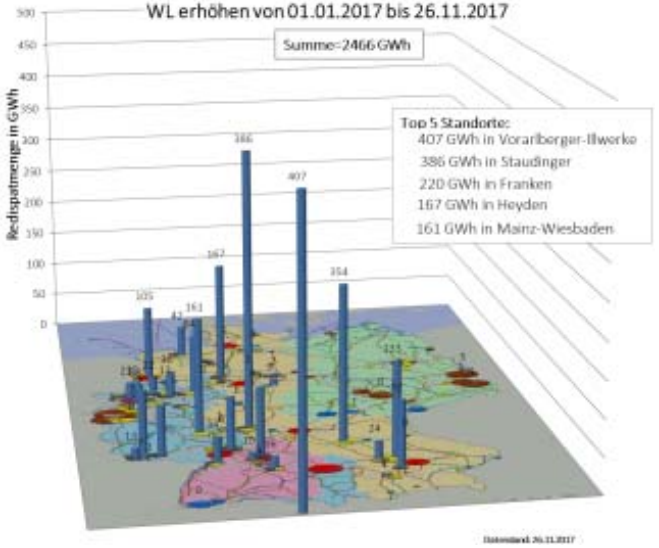
The intermittency of renewables increases the price levels on the reserve and balancing markets

	Activation time	Duration	Pro-cured	Refund Pay-as-bid
Primary balancing, FCR	30 s	< 15 min	daily	capacity
Secondary balancing, aFRR	5 min	< 15 min	daily	capacity+ energy
Minute reserve, mFRR	15 min	> 15 min, up to few h	daily	capacity+ energy

» **Reserve and balancing markets together with additional intra-day trading provide increased opportunities!**

Grid Stability & Redispatch measures

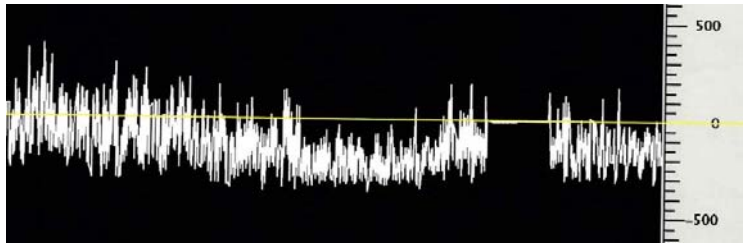




https://archiv.bundesregierung.de/archiv-de/netzausbau-kommt-voran-411276 Ref. (Salnikova T., Panzer, 2019)

NPPs in Germany support introduction of the RES, beneficially participating on overload management!

Grid Stability & Voltage control



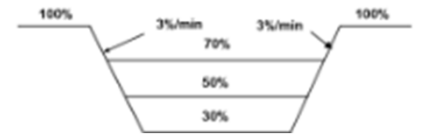
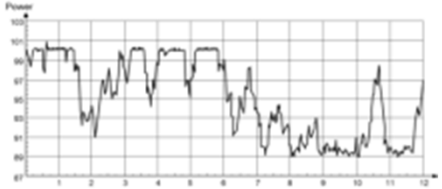
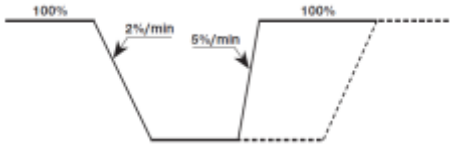
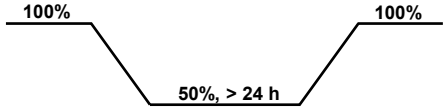
Example of PWR of 1500 MWel:
Annual participation in voltage regulation in Mvar

- is a local service and in Germany has prices approved by the regulator
- under excited mode of NPP is not rewarded
- adequate payment, e.g., via own market is needed from utility point of view
- Operation example
  - ✓ typical **over excited mode (inductive)** of approximately 150 Mvar (up to approx. 450 Mvar)
  - ✓ mostly in **under excited mode (capacitive)**, typical activation of about approx. 200 Mvar (up to approx. 350 Mvar)

» **Currently various generators are operating mostly in the not rewarded under excited mode**

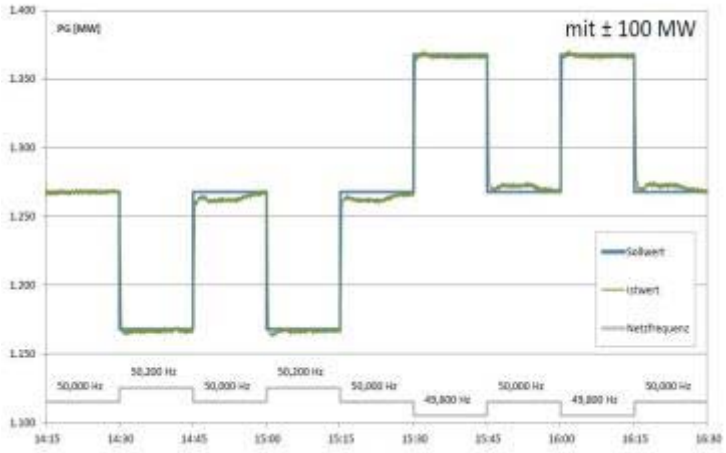
Flexible Operations from NPP pont of view

NPP Operation Modes

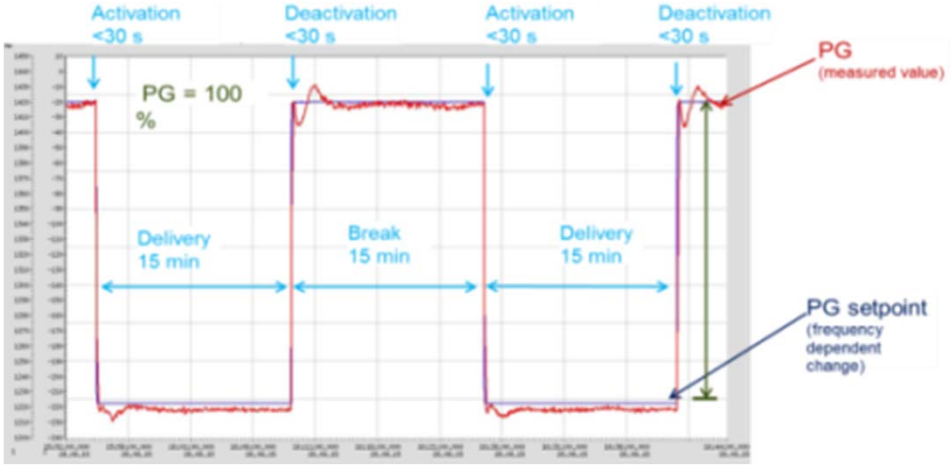
Potential Grid Requirements	Example	Potential NPP Operation Modes
Adaptation to daily demand variation		**Load Follow (LF)- Energy market (EM) service** • Low power period: power level, duration • Power range rate (slope): slow, fast • Load Schedule
Adaptation to real-time frequency variation		**Frequency Control (FCR, aFRR, mFRR)** • Primary (FCR): automatic (amplitude, slope) • Secondary (aFRR): remote control (amplitude slope); Minute Reserve mFRR manual/automatic (amplitude, slope)
Adaptation to Grid disturbances		**Emergency access** • Low power period: power level, duration • Power range rate (slope): fast
Adaptation to longer term forecasted demand		**Extended Low Power Operation (ELPO) - EM** • Reduce the power level during significant periods (number of occurrences, duration)

Operational experience with Advance Load Following Control

Primary frequency control providing FCR, 30 s - response



Prequalification test for FCR - symmetric, approx. 100 MWel (Müller C., 2020)

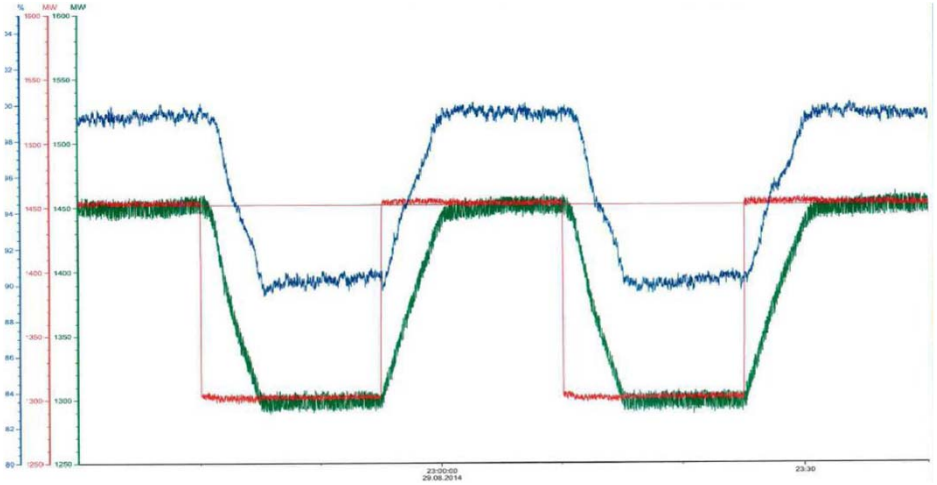


World record for FCR with NPPs: Successful qualification test of downwards 200 MWel

In German NPPs typical performed range for FCR would be ± 50 MWel. The qualified values are between ± 2 % to ± 10 % Rated Electrical Output (REO).
Thereby the minimum power level is typically defined at 50% - 60% REO

Operational experience with Advance Load Following Control

Secondary frequency control providing aFRR, 5 min - response



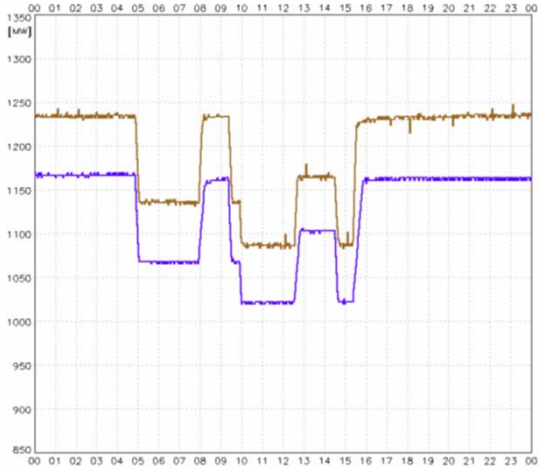
Prequalification test for aFRR - symmetric, approx. 150 MWel (Müller C., 2020)

Ramp rate (rate of change in power) is set by the reactor operator and is typically in the range between 10 and 30 MW/min in Germany

aFRR can be performed within a specified power level range, thereby the minimum power level is typically defined at 50% - 60% REO

Operational experience

Minute Reserve providing mFRR, 15 min – response, over a 24-hours period

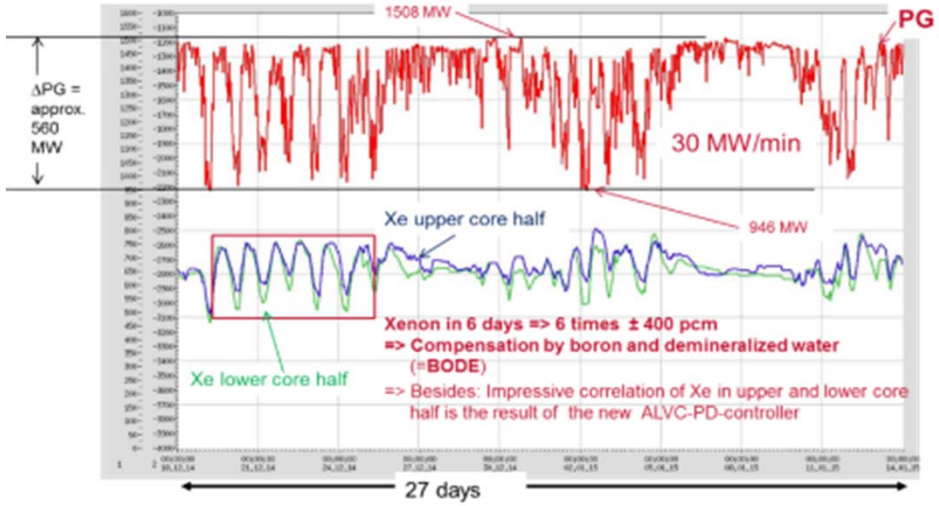


Electrical output in MWel, two NPPs, providing downwards mFRR,
X-axis = Time, Y-axis = Power (MW) (Fuchs, M. and Timpf, W., 2011)

Ramp rate is set by the reactor operator and is typically in the range between 10 and 30 MWel/min in Germany. SFC can be performed within a specified power level range, thereby the minimum power level is typically defined at 50% - 60% REO

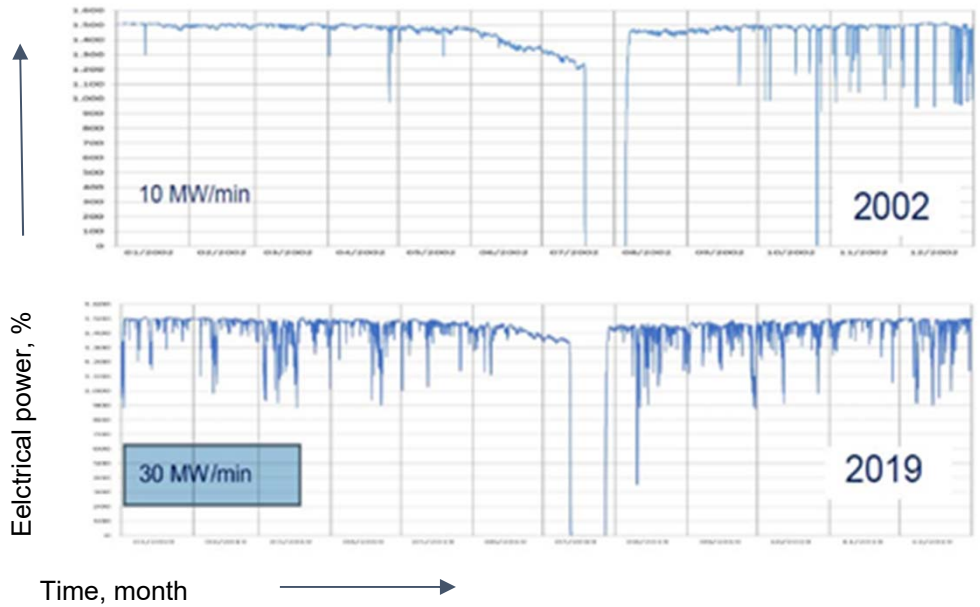
Flexible operation with ALFC in fully automatic mode

1500 MW PWR, Electrical output (gross) in MWel over a 27-days period



Various Grid services: FCR ± 100 MWel, aFRR ± 150 MWel, mFRR ± 300 MWel, load following with a ramp rate of approximately 30 MWel/min incl. economic dispatch incl. possible Redispatch measures with set point defined by load dispatcher; Can be activated in a range of appox. 560 MWel

Increased Grid requirements over the years

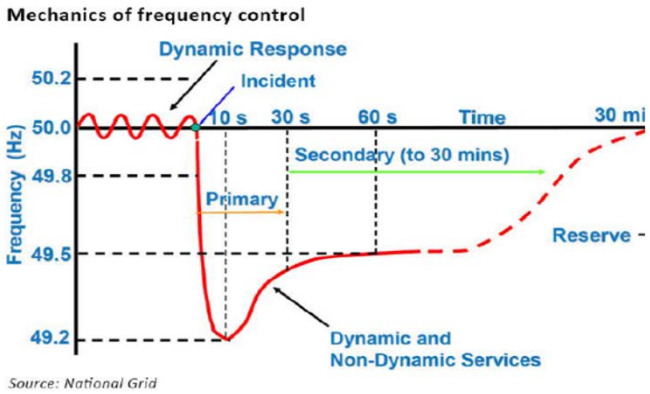


Advance Load Following Control (ALFC) incl. visualization of the predictive Reactivity Management

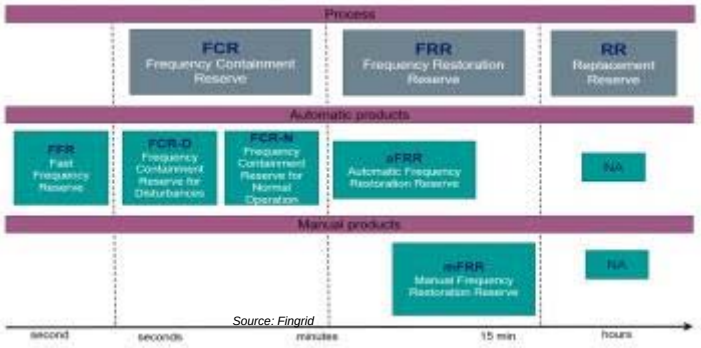
Source: Müller, C., Presentation from Forum Nuclear technology, ”Operational experience with flexible operation, ISAR 2”, Berlin, 02.02.2020 (Müller C., 2020)

Control improvements carried out by Framatome allowed NPPs to increase the range of power levels for the grid services and to perform them in a reliable and safe manner

Impact/Conclusions



Reserves products for frequency control in Finland



- New nuclear power plants, and to some extent, the existing plants are technically able to provide various grid services incl. frequency and voltage control, if an adequate market design is established.
- The activation time for Fast Frequency Reserve product (**FFR**), though, is likely to be too fast for NPPs.
- Frequency Containment Reserve for Normal operation (**FCR-N**) is expected to be partly replaced by automatic Frequency Restoration Reserve (**aFRR**). With increased competition in the **aFRR** markets, they could become attractive for NPPs.
- **FCR-D** (Disturbance) reserve should be analyzed.
- Automatic and also manual Frequency Restoration Reserve (**FRR**) may be the best candidates for the ancillary services products provided by NPPs.

Positive particular business cases for each plant based on detailed plant specific analyses is the key to NPP flexibility!

Contacts and data sources

German utilites

- PEL (Preussen Elektra GmbH), especitally ISAR NPP
- EnbW (Energie Baden-Wuerttemberg AG)
- RWE AG

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