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Survey on operational experiences of NPPs in a transitioning energy system going from baseload to flexible operation – Germany case study

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Project scope and focus

The **objective** of this project, supported by Energiforsk GINO program is

- to conduct interviews with a number of German operators and other individuals with experiences from nuclear operations during the transition from baseload to flexible operation and to highlight the key insights

The long-term **focus** of this project is

- to address possible impact for NPPs connected in a grid with a new mix of energy generation
- to be able to identify suitable measures in nuclear operations to ensure safety and operability as well as enhancing capability in a more dynamic environment

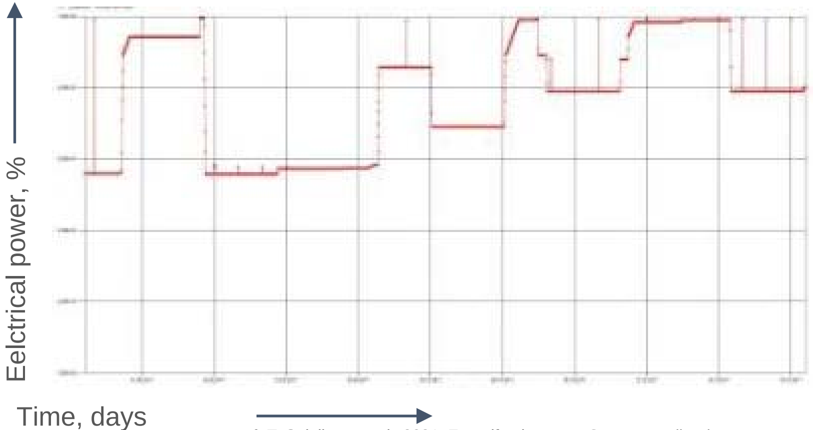
Project Team

Three interviews were carried out during the overall Project time:

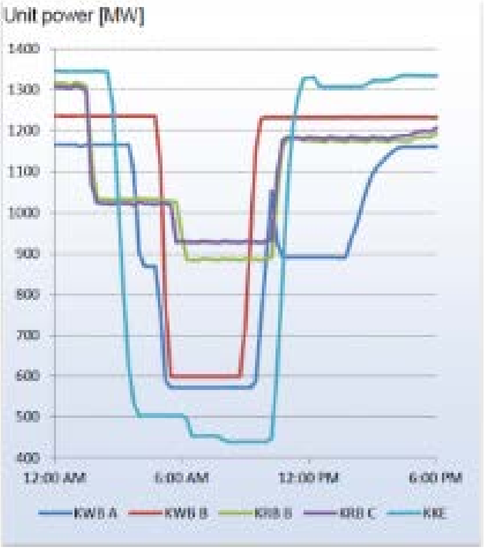
Project Team included participants from

- **German utilities** (RWE, PEL, Vattenfall Germany)
  - BWRs (Gundremmingen and Brunsbüttel NPPs)
  - PWRs (Isar 2, Brokdorf and Grohnde NPPs)
  - High level management (plant manager, vice president, chiefs operation), supported by technical departments e.g. from Fuel
- **GINO steering group** delegates representing
  - Safety authority
  - NPPs (process, electrics, core control)
  - TSO
- **Framatome GmbH**: experts in flexible operation for both PWR/BWR, I&C (e.g. core control), system engineering, fuel (e.g. PCI-guidelines)

Flexible operation by German BWRs
Typical flexibility, 1 month and 1 day



Ref: *T. Salnikova et al., 2021, Energiforsk report,* "Survey on Vibration Impact of Flexible Operation on NPP Based on Operational Experience"

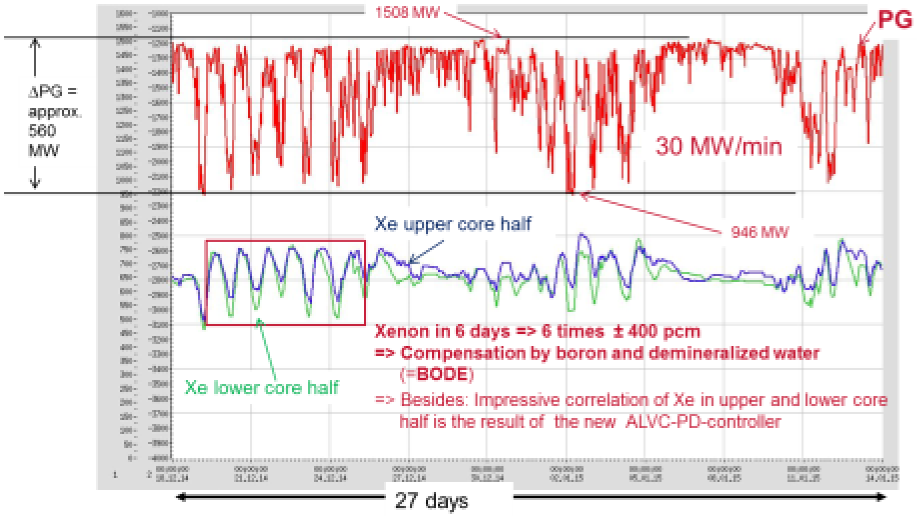


Ref: *Fuchs, M. and Timpf, W., 2011.* Presentation VGB Congress 2011, The Load Change Ability of Nuclear Power Plants – Experience and Outlook, 9/2011

- **Automated remoted secondary** control within a range of 100 MWel (single BWR)
- Minimal power level was set **at about 60 %** to avoid control rod movements (recirculation control), with typical duration of about 3 days
- The **typical ramps** were performed between full power and **70 - 80 %** activated via telephone

Flexible operation by German PWRs
Example: highest overall flexibility, 1 month

- **Remote controlled** flexible operation including different types of ramping services
- All grid services performed in the specified range with a **minimum level at about 60 % REO**
  - FCR up to ± 100 MWel;
  - aFRR up to ± 150 MWel;
  - mFRR typically in the range of ± 300 MWel;
  - Load Follwing, currently with 20 MWel/min



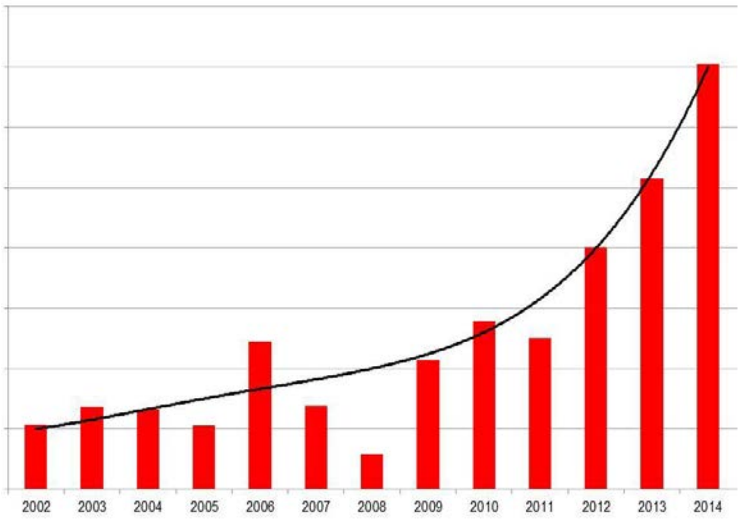
Ref: *Kuhn, A. and Klaus, P., 2016.* VGB Power Tech, 2016. Improving automated load flexibility of nuclear plants with ALFC, 5/2016

Transition from baseload to flexible mode

German case study

Original strategies to "go flexible" or gradual adaptations due to necessity?

- All German NPPs has been **originally designed** for the flexible operation
- Till approx. 2010 used mostly in baseload
- Various optimisations were carried out to reach advanced flexibility not compromising safety and operability
    - E.g. on turbine/core control in interviewed PWRs and BWRs
    - Monitoring and Maintenance concepts were adapted to flexible mode



Grid services provided within 12 years

Transition from baseload to flexible mode

German case study

Key experiences to share? Any lessons learned for preparation phase?

- "Learning by doing": increased operation experience is a main basis for further plant optimizations
- Attention should be payed to following aspects *in advance*
  - **Maintenance strategy**
  - Evaluation of "pure" **part load** operation followed by ramps and frequency control
  - **Vibration** phenomena of the whole plant
  - **Monitoring of the fatigue** usage factor for the most impacted components
  - Proper strategy for **conditioning of the fuel**
  - Change to **digital I&C**, improved power distribution control with **Advanced Load Following Control** and reactivity management (mentioned by PWR)
  - **Control and power electronics** evaluation within the new control requirements / robustness for the increased switching frequency (mentioned by PWR)
  - **Control parameter settings** to get the formal qualification from the grid operator e.g. for FCR (mentioned by BWR)
  - …

What is your view on the safe operations of NPP in the short and long term during and after the transition?

Experiences of reactor operations including core management

- Required **cycle adjustment** of the reactivity inventory of the core to the expected loss of produced energy
- The **fuel elements** of different suppliers have shown their capability
- The **control rods** have a limitation regarding hoop-strain due to swelling of absorber-> Checking in advance required, since the control rods are exposed to higher flux during power transients (PWRs).
- The **control rod drives** require fine motion control and robustness for a high number of movements (PWRs)
- Consideration of **xenon imbalance** / minimize movement of control rods to reduce load on fuel rods (BWRs)

Experience from maintenance of plant

- **Erosion corrosion** monitoring is an important aspect.
- For the most impacted components **inspection and maintenance intervals** have been reduced e.g. control valves (PWRs)
- **Control rod drives** / coil measurements of the control rods (PWRs)
- No unexpected negative effects, **advantage for some compo**nents as they are kept in move (mentioned by BWR)

What do you consider are the key capability for effective FlexOp?

From a plant design point of view

- Capability of the **reactivity control**:
  - Deal with imbalance of xenon content after power changes
  - Boron acid management and recovery as well as Deionat production (PWRs)
  - Frequent power control by the speed controlled recirculation pumps in the range between 60 and 100 % without disturbing local core power distribution by movement of control rods (BWRs)
- Adaptation of the **design and/or monitoring and/or maintenance concept**:
  - E.g. robustness of the design of the piping (prevent thermal stratification), nozzles (thermal siphons) and heat exchangers -> Identification of the critical components for thermal fatigue to be monitored
- Other important features:
  - **Balance of water chemistry** (specific parameters); introduction of the spray control valves (continuously), PWR

From an operations point of view

- Plant shift has to be **well-trained at simulator** at special requirements and faults even if automatic mode is installed.
- **Exclusion** of the plant **from provision** of grid services has to be possible and practices without any difficulties if any doubt of any kind arise.

What are your experiences on inter-organizational issues?

- Importance of the **proper communication** between load dispatcher and NPP, **clear** way and **often tested** to avoid misunderstandings.
- In principle, the following **ways of communication** and control are possible:
  - Shift operator activates primary control on request for the planned range → power controller adapts power automatically
  - Shift operator activates possibility for plant control in a certain power range and with the pre-defined ramp rate (secondary control) → load dispatcher can set plant power level within the allowed range, remotely
  - Information of shift operator by phone / mail → operator sets manually power level and ramp rate
- **Significant role of automatic way** of communication.
  - Important: activation of the primary/secondary control is still in the hand of the operator!
- **Up to date information** about capabilities and limitations of the plant with respect to flexible operation **by load dispatcher** to plan the plant flexibility in the proper way.
- Challenge: often **required transients in both directions** in the same time

What kind of plant specific necessary studies and analyses of this transition have been done?

- **Generic study** analyzing overall impact on the whole plant incl. the core, evaluation of the current flexibility and required optimizations
- Collecting the operational experience and **analyzing** of the corresponding **measured data**
  - e.g. impact on corrosion products or temperature transients
- Various **detailed evaluations** for different flexible operation modes incl. ELPO
  - e.g. erosion corrosion analyses with COMSY-tool for different part load levels to optimize the maintenance (PWRs)
- Main performed **optimizations**
  - Adaptation of the **pressurizer controls**, Introductions of the **digital I&C** and optimization of the **power distribution controller**, introduction of the **reactivity management** incl. visualization in three PWRs and **predictor technology** in ISAR 2 NPP, developed with a strongest support and advise of the NPP stuff (PWRs)
  - Based on the experience it is recommended to develop a **procedure** which contains major boundary conditions and limitations, e.g. power ranges, ramp rates, area in power flow map, incl. corresponding simulator test program (BWRs)
  - **Fatigue analyses** for the critical components, adaptation of the monitoring and maintenance concept

What kind of plant specific tests have been performed, prior to or following, this transition?

- Flexible capability of German NPPs tested during the **commissioning phase** e.g. ramp rate of 10 % REO/min and also part load operation

- **Commissioning tests** for the **new digital reactor control** incl. introduction of the **advance load following control** and **predictor** were performed. Started by test program **at plant simulator** to be able to compare the simulated plant performance with the real one and to train the shift team (PWRs)

- All NPPs providing ancillary services have performed **prequalification tests** e.g. for PFC, aFRR, mFRR. Beforehand **on-site hardware-in-the-loop-tests** of the existing plant equipment, especially turbine controller often has been performed, using a real time digital plant and grid simulator.

Overall Feedback

- **"Build-in" flexible capability** is the key factor for German NPPs
- Till approx. 2010 they were used mostly in baseload
  - Since that time overall Grid services provided by the German NPPs increased significantly.
- **Plant-by-plant evaluation** and **lessons learned** from other NPPs allowed German NPPs to develop operation envelope with minimal overall impact on the plant
- **Main optimisation** were required in the following fields
  - Introduction of the digital **I&C** was vary favourable for further performed optimisations like ALFC & predictor technology
  - **Power maneuvering guidelines** (PCI) / Fuel management strategies
  - **Monitoring and Maintenance concepts** were adapted to the level of flexibility and allow safe and reliable flexible operation
- Communication between load dispatcher and plant is very important
  - **Remote control is favorable**, giving Load dispatcher up to date information for reasonable decision.
  - **Training on simulator** is a "must" even after fully automated control has been introduced
  - Always **possible exclusion of the plant** from provision of grid services

Contacts / Future ideas

- We would like to thank German utilities and personally *Dr. Fuchs*, *Mr. Hackel*, *Mr. Müller* and *Mr. Rades* for the provided overall project support from
  - **PEL (Preussen Elektra GmbH)**
  - **RWE AG**
  - **Vattenfall GmbH**

- Future project ideas
  - Similar interviews with some **German TSOs** (TenneT, Amprion, 50Hertz, ..) to get more insights in Grid/NPP interphases that has not been addressed in detail yet
  - Similar interviews **with EDF and RTE**, having feedback from 58 NPPs over 30 years
  - **Feasibly study to adapt main outcomes** from this project to any pilot plant in Nordic grid (PWR and /or BWR)

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