Global Approach
NPP
Flexible Operations

Matthias KRELL
Managing Director - Framatome Branch Bulgaria
Dr. Tatiana SALNIKOVA
Advisor - Flexible Operation of NPPs

Varna, June 7th 2018

Challenges and needs
Flexible Operation of NPPs, Worldwide

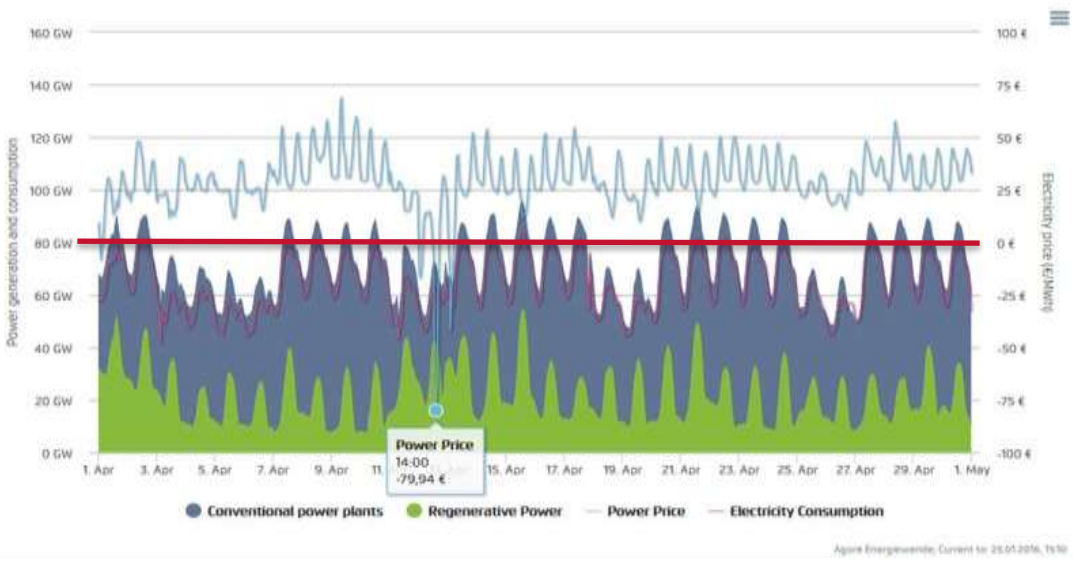
- **Grid Stabilization Services**
  - **high nuclear share in energy portfolio e.g. France**
  - **existing or planned growth of renewables e.g. Germany**
  - **new obligatory grid codes or requirements, production standards and policies e.g. new EU Guideline on Electricity Balancing (2017/2195)**
  - **transfer of maneuverability task from fossil fired plants to NPP e.g. Ukraine**
- **Economical Considerations**
  - **new profitable price models in the countries with deregulated energy markets e.g. Germany, Switzerland, Spain**
    - further harmonization of the EU market rules and products -> EU-wide platforms in 2019
  - **avoiding "negative" or low prices e.g. Germany, USA, Spain**
  - **strong competition against low priced carbon energy e.g. USA**

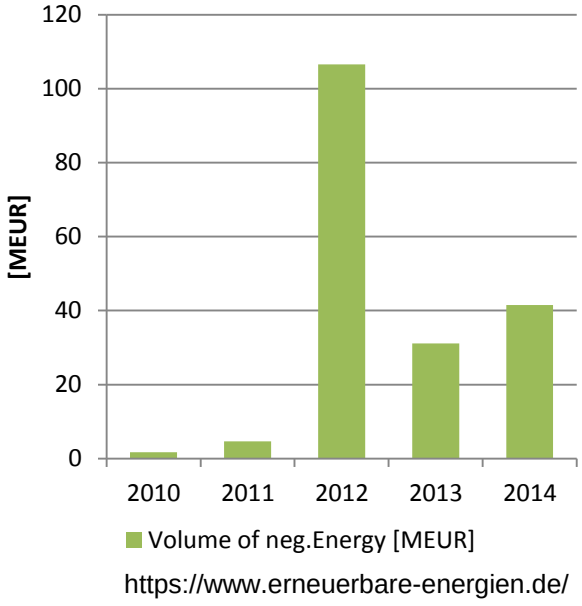
Currently, decision making process for flexible operation is taking place in various countries worldwide [1]. NPPs can not be excluded!

[1] IAEA NUCLEAR ENERGY SERIES No. NP-T-3.23 „*NON-BASELOAD OPERATIONS IN NPPs*"

Challenges and needs
Negative Prices - Example Germany

- **Today, the total renewables share in Germany reaches 30%**
- **Goal for 2025 up to 45%**
- **Since 1991, renewables obligation and feed-in tariff - “Undispatchable Energy”**
- **Since 2008, European Energy Exchange allows “Negative Prices”!**





https://www.erneuerbare-energien.de/

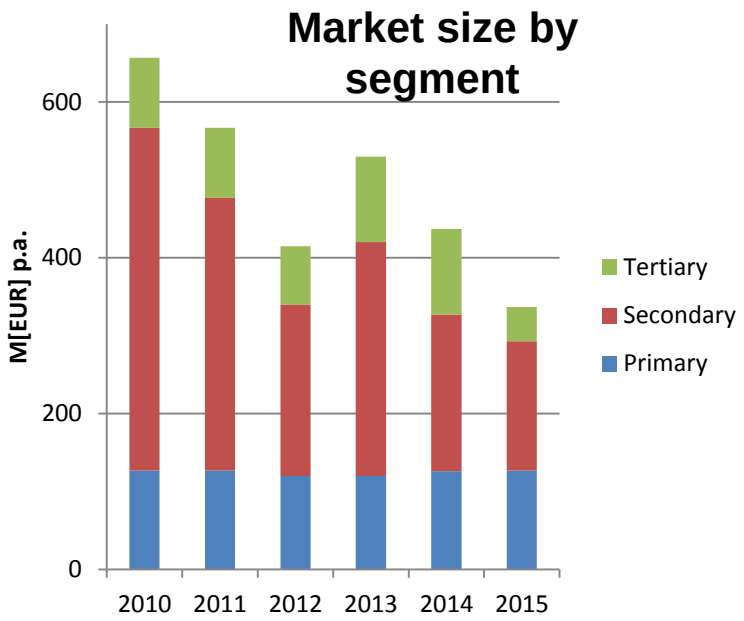
Flexibilization of NPP avoids production for negative and low prices!

framatome

Challenges and needs
Reserve and Balancing Markets - Example Germany

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

	Activa-tion time	Duration	Pro-cured	Refund Pay-as-bid
Primary balancing	30 s	< 15 min	weekly	capacity
Secondary balancing	5 min	< 15 min	weekly	capacity+ energy
Tertiary reserve	15 min	> 15 min, up to few h	daily	capacity+ energy

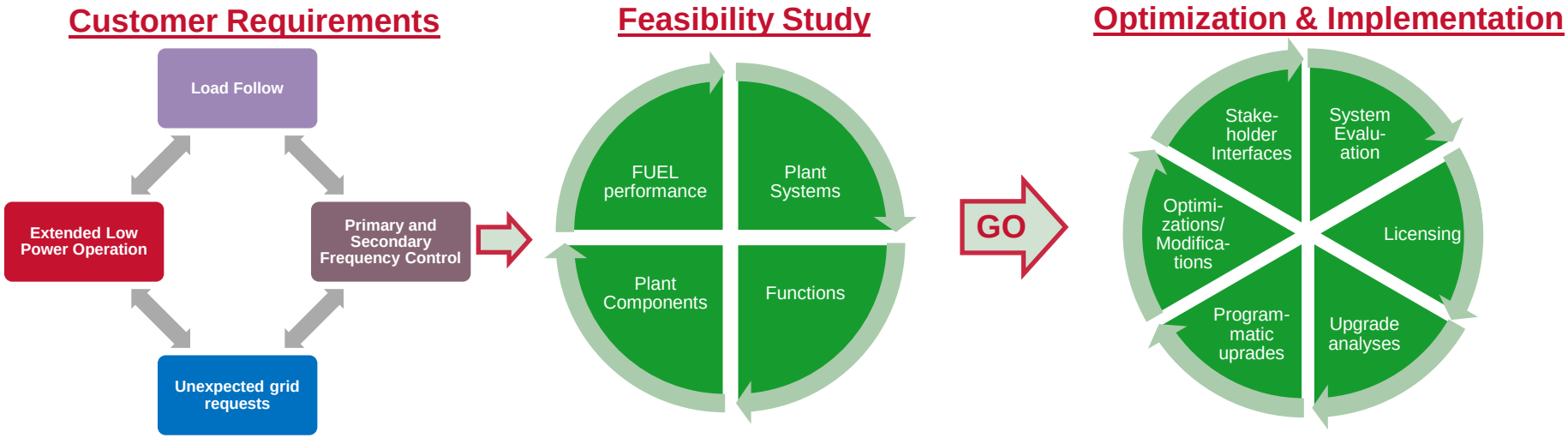


http://neon-energie.de/

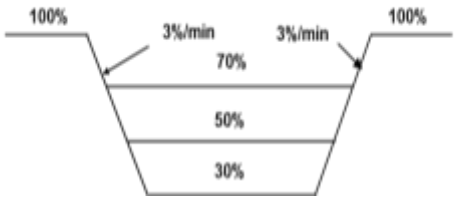
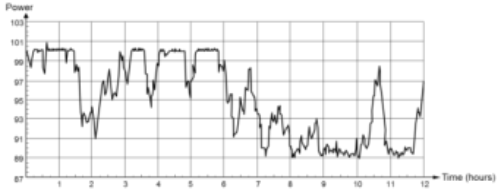
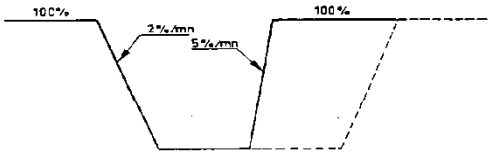
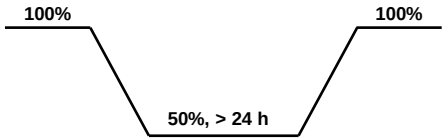
Reserve and balancing markets, together with redispatch and additional interday trading provide increased opportunities - for NPP as well

Global Approach to NPP Flexible Operations

- **NPPs all over the world were originally optimized for <u>Base Load Operation</u> as flexible operation was not required for NPPs**
  - **Main design challenges typically are e.g. fuel integrity, I&C, special need for secondary side surveillance and fatigue monitoring**
- **Overall approach capitalizes on experience feedback**
  - **Reliable, safe and profitable flexible operations of Framatome-designed NPPs in France and Germany over many decades**
  - **Compatible to all customer requirements which can occur regarding all flexible operations modes (implemented, singly or in combination)**



NPP Flexible Operations
Our Solutions

Potential Grid Requirements	Example	Potential NPP Operation Modes
Adaptation to daily demand variation		**Load Follow (LF)** • Low power period: power level, duration • Power range rate (slope): slow, fast • Load Schedule
Adaptation to real-time frequency variation		**Frequency Control (FC)** • Primary (PFC): automatic (amplitude, slope) • Secondary (SFC): remote control (amplitude slope) • possible superimposition of PFC and SFC
Adaptation to Grid disturbances		**Follow unexpected grid requests** • Ramps (amplitude, slope) • Instantaneous return to full power (slope) • House Load Operation
Adaptation to longer term forecasted demand		**Extended Low Power Operation (ELPO)** • Reduce the power level during significant periods (number of occurrences, duration)

All flexible modes can be implemented from semi manual to fully automated mode
AREVA has experience to specify best capability mix based on specific customer needs !

NPP Flexible Operations
Potential Impacts and Optimizations

Control issues
- BoP I&C
- BNI I&C incl. control rod maneuvering program; automated reactivity management Boron/Dilution); axial power distribution control
- Pressurizer level and pressure control channel
- Human Machine Interface

Life-time issues
- Wear e.g. control rod system wear
- Fatigue
- Flow-accelerated corrosion
- Vibrations (secondary side during part load)
- Impact on Design Transients File

Chemistry issues
- Primary side - Boric Acid/ Alkalisation management (pH-value) and treatment
- Secondary side - BOP optimizations (pH - value), SG (cleaning strategy)

FUEL Behavior and transition analysis
- Neutronic and TM Justifications
- Power maneuvering guidelines (PCI)
- Optimization of Fuel management strategies
- Fuel transition global package, if required

Technical specifications
- Plant operating conditions
- Operational technical specifications
- Other current documentation

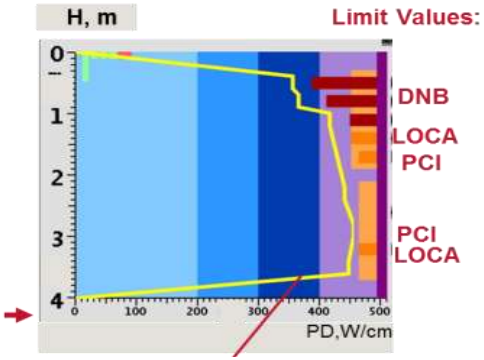
Safety analyses
- 3D power and burn up distributions
- Impact on the Safety Analyses Report (Events; Core and NSSS initial conditions before accidents)

Training issues
- Operator training
- Simulator

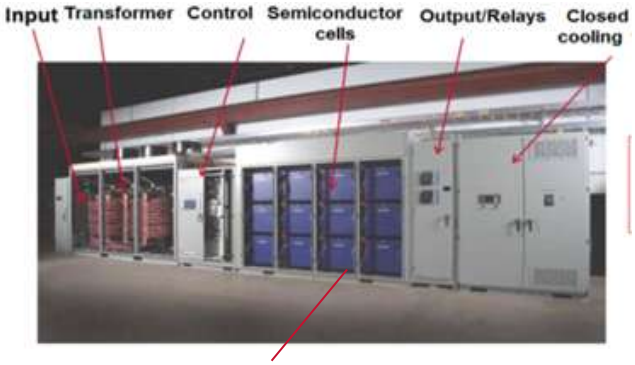
framatome

NPP Flexible Operations
Our Portfolio for tailored Solutions

Control optimizations

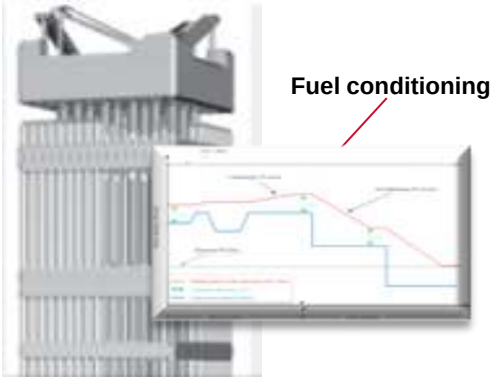


Load Follow Control

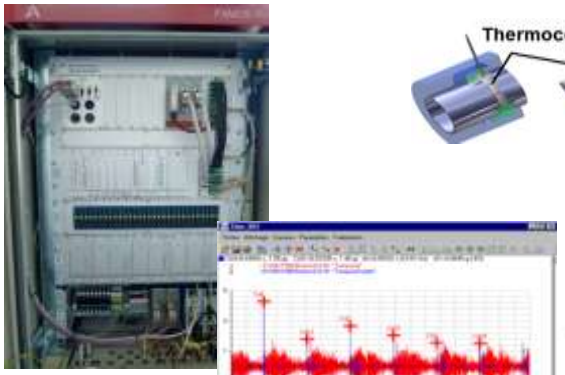


Variable Frequency Drives

Fuel

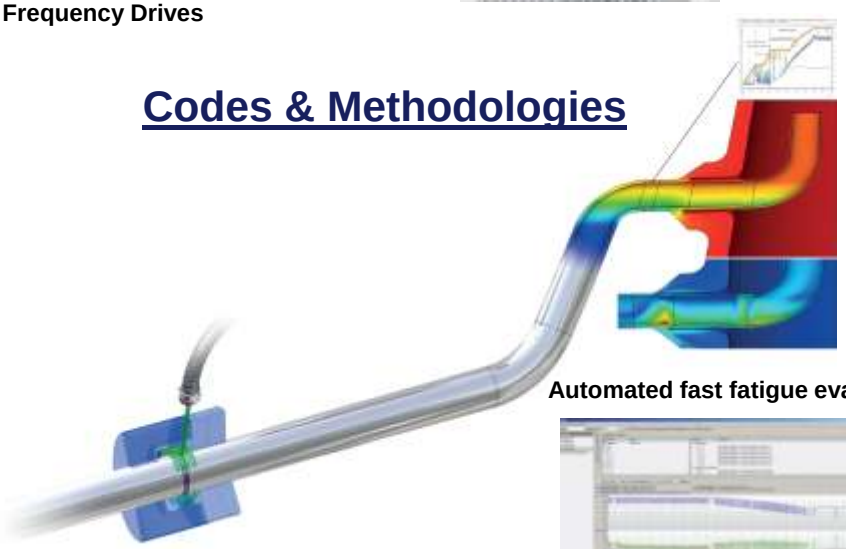


Monitoring & Diagnostic & Maintenance



FAMOSi

Codes & Methodologies

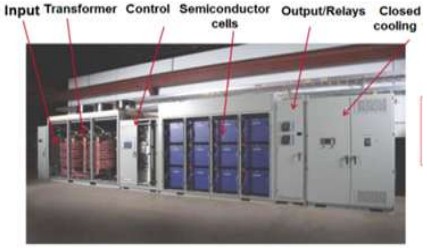


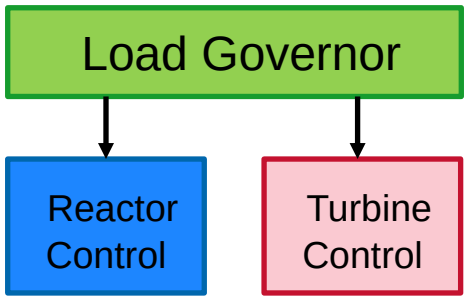
Automated fast fatigue evaluation

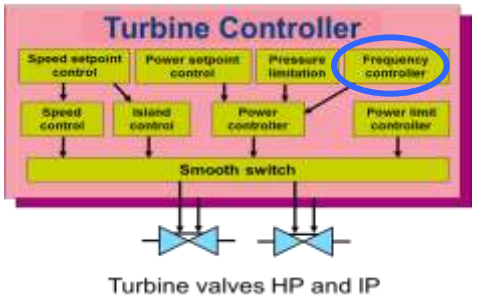
framatome

Transfer of the Concepts
Example: Control Optimization

- Introducing of Load Governor
- Modernization of Turbine Control
  - primary frequency control
  - secondary frequency control
- Modernization of Reactor Control
  - fully automated modes (FAM, ALFC, T-mode)
  - possible optimization of part load diagram
- Variable recirculation speed
  - typically for BWR but also for PWR

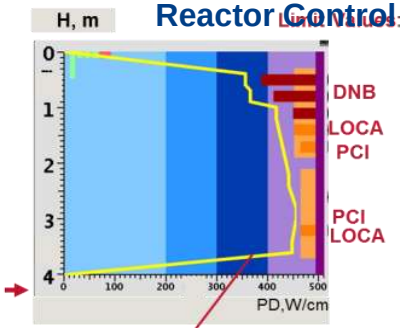






Turbine valves HP and IP

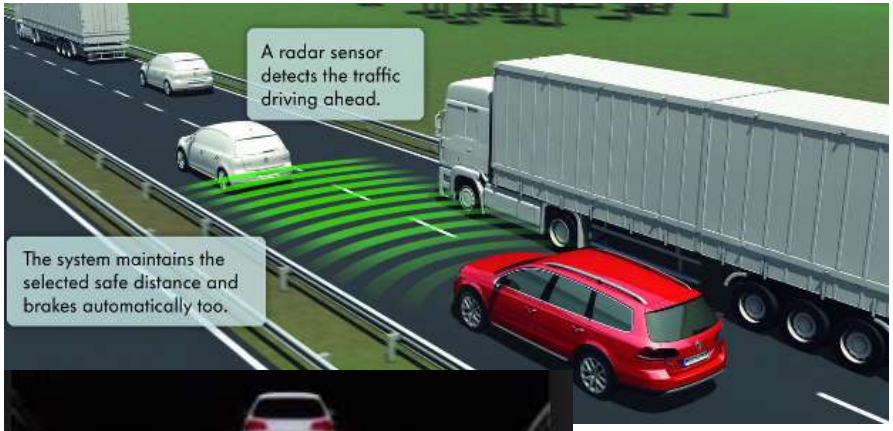
Reactor Control

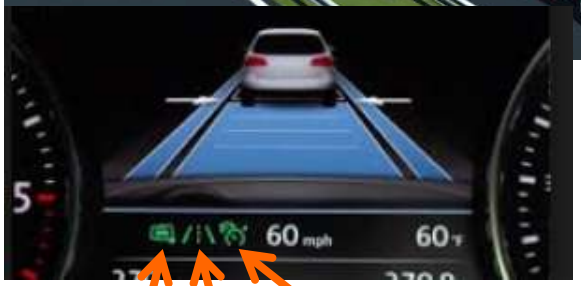


Advanced Load Follow Control (ALFC) with Visualized Reactivity

Advanced Load Following Control (ALFC) with PREDICTOR feature

More and more car driving is supported by assists
→ in future fully automatic by the autopilot





Side Assist

Lane Assist

Adaptive Cruise Control (ACC)

ALFC - PREDICTOR technology is just the autopilot for the PWR

ALFC = Advanced Load Following Control

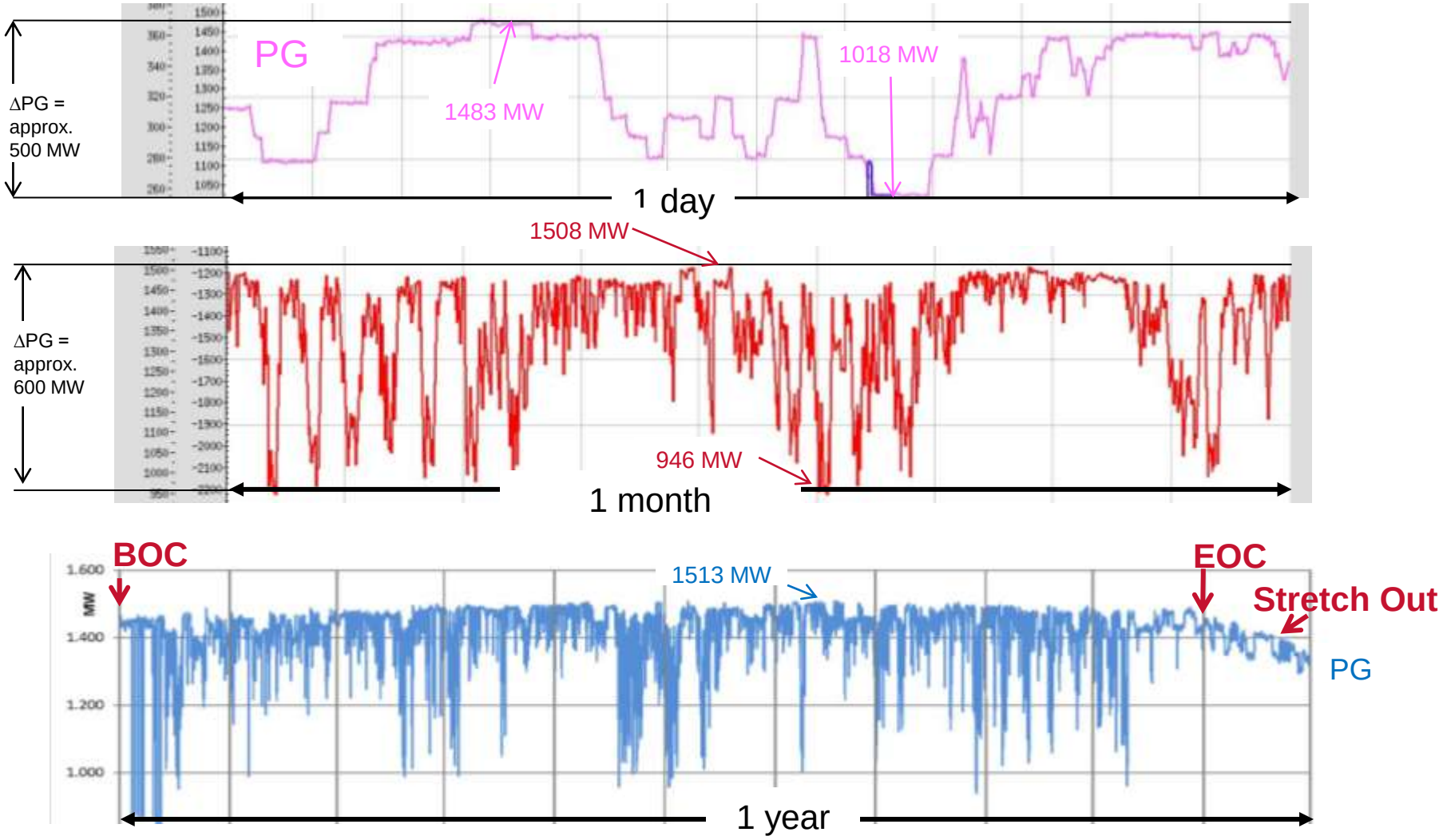
WANO/INPO favored reactivity management

framatome

Advanced Load Following Control (ALFC)

Operational experience with flexible operation

PG = Generator Power



framatome

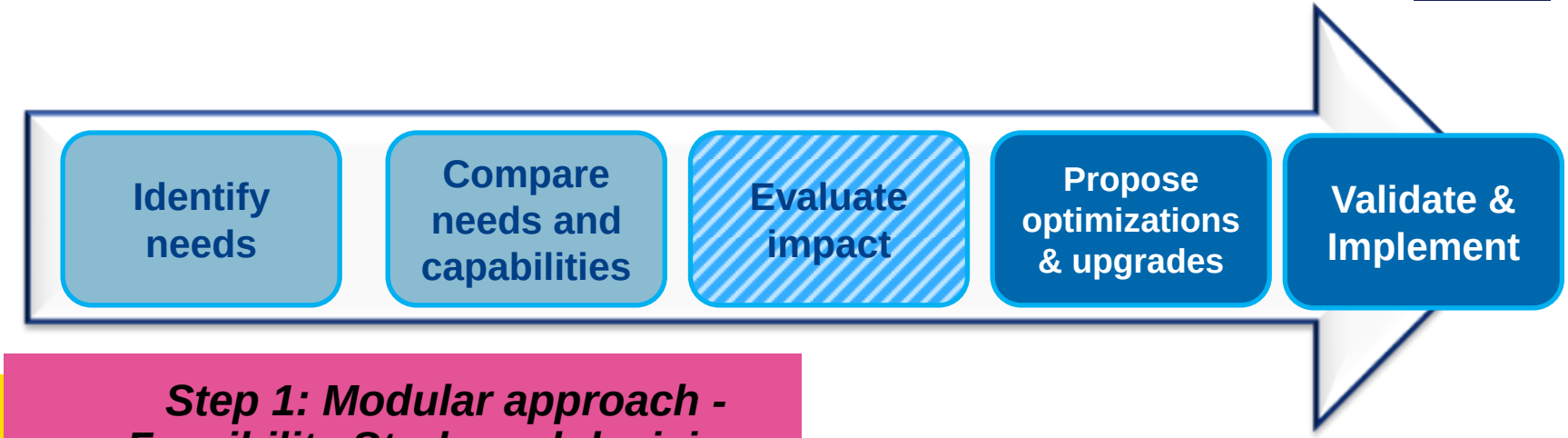
Summary

- **Since the 1970's, Framatome designed flexible NPP of different technologies**
- **These plants (~25% of the existing NPP worldwide) operate in a safe, profitable and reliable manner accumulating hundreds of years of operation experience (mostly France and Germany)**
- **Currently, fully automated grid-related operation control is available for all reactor types**
  - **cumulated experience over 20 years in Germany**
  - **enable new profitable price models in the countries with deregulated energy markets**
- **Together with the appropriate optimization concept for the whole plant the flexibility of NPP can be significantly improved and profitability increased**

Other NPPs can benefit from the overall Framatome experience incl. design, modernization and optimization.

framatome

Outlook



Step 1: Modular approach - Feasibility Study and decision-making for going flexible

GO

Step 2: Agreement on Upgrades and Optimizations and their Implementation

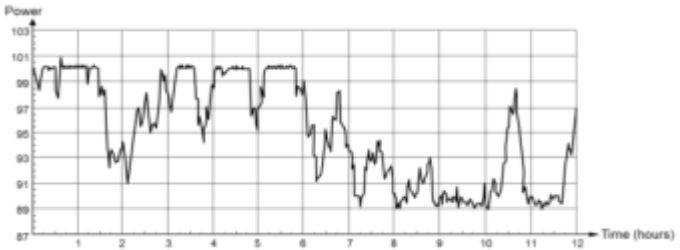
References:

OEM: in Germany and in Switzerland, in France, China, South Africa;

NON OEM: Korean NPP, Westinghouse NPP in USA

Feasibility studies and, if needed, related plant upgrades and optimizations can be performed to evaluate and enable any NPP to become more flexible!

framatome



Thanks for your attention!

Matthias KRELL
Managing Director - Framatome Branch Bulgaria
Dr. Tatiana SALNIKOVA
Advisor - Flexible Operation of NPPs

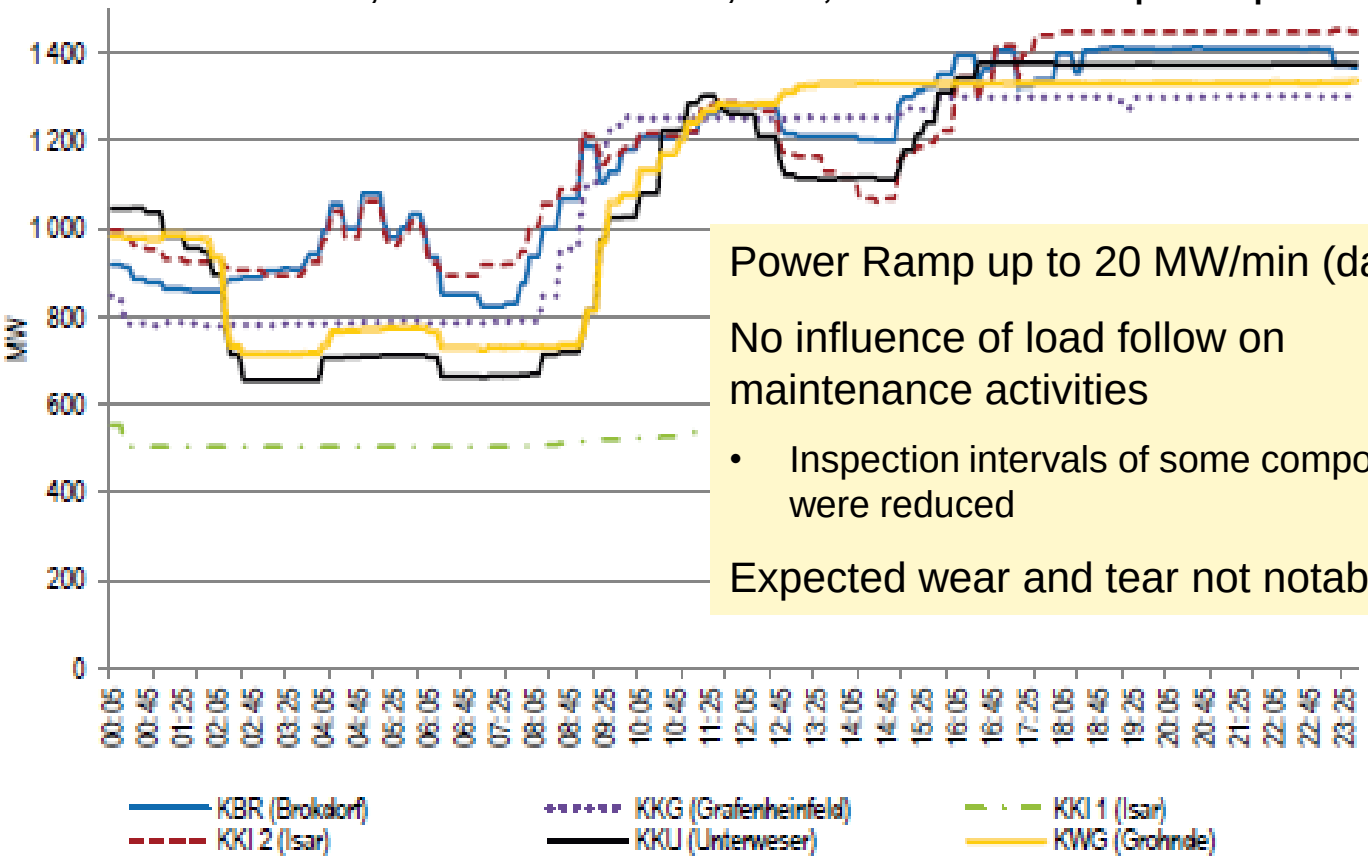
Varna, June 7th 2018

Back up

German Case - Exempels

Operating experience
Example (E.ON, NPP Fleet, 1 day)

M. Fuchs E.ON, Atoms for Future 2013, Paris,"Load follow from operator point of view"



Power Ramp up to 20 MW/min (daily)

No influence of load follow on maintenance activities

- Inspection intervals of some components were reduced

Expected wear and tear not notable yet

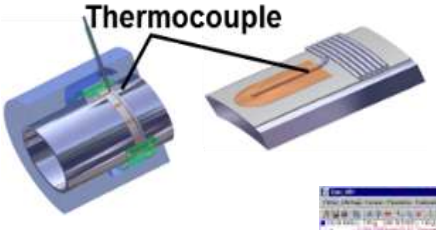
Courtesy of E.ON Kernkraft

NPPs belong to the most flexible plants in the German grid and can cope with the grid requirements and provide additional services in a favorable manner

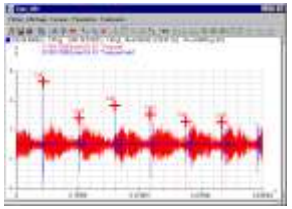
framatome

Transfer of Life time management options Monitoring – Diagnostic – Maintenance

- **Possible Improvement of Control Rod Drive Mechanism**
- **Improvement of the Core Power Distribution Monitoring**
- **Installation of Fatigue Monitoring Systems (primary and secondary side) and applying Fatigue Analyses Concept (AFC)**
  - **FAMOSi applied in e.g. VVERs (Mochovce 1 & 2)**
  - **AFC applied for Westinghouse NPP (Beznau)**



- **Execution of Flow-Accelerated Corrosion Analyses with AREVA COMSY Tool**



- **Installation of Vibration Monitoring Systems (MSR, Condenser, etc.) based on AREVA Vibration Monitoring Toolbox**

» **A proactive acting is essential for a safe and economical long term operation of the NPP taking into account flexible operation mode**

Transfer of other Concepts
Chemistry and Fuel related topics

- **Chemistry issues for primary and secondary side**
  - **pH control through Boric Acid / Alkalization management and Balance of Plant optimizations to reduce corrosion product transport**
  - **Zinc Chemistry for dose rate minimization**
  - **Steam Generators: Application of Filming Amines for minimization of deposit load and SG cleanness strategy (SG Fouling Index Toolbox)**
- **Fuel Behavior and Transition Analysis**
  - **For Framatome Fuel, power manoeuvring guidelines preventing Pellet Cladding Interaction (PCI) were established**
  - **Over many years, successful application in France and Germany**
  - **Currently, FUEL justification analyses in another countries (e.g. China, Belgium, South Africa, UK, USA)**