Flexible in Operation

Increase safety and profitability
Framatome’s world-wide solution

CORP MKG – T. GAIN
Sweden, January 2018
Future of nuclear energy is flexible ... reasons why
In the 80’s ..... and now

- Automatic
- Energy efficient
- Reliable
- Stable
- Faster - quicker
- Safer

... and profitable
Our understanding of your electricity market

- Climate-neutral long-term strategy for energy
- Share of weather-dependent vs. conventional energies
- Grid demand variations
- Balancing energy market (bidding for positive and negative)
- Harmonization of the EU market through the new European platforms

Problem is not to produce enough electricity, but if (a) electricity will be available when needed, and (b) production of energy is variable so as to use the source as an energy balancing resource

- Low price of electricity
- Investments significant business risk
- Uncertainty about electricity market trends
- Difficulties building new power plants

Problem is not to erect new power stations, but to design and operate facilities in the most financially flexible way able to accommodate for future energy market evolutions and needs
**Why encourage flexibility in nuclear power generation**

<table>
<thead>
<tr>
<th>Grid</th>
<th>Nuclear</th>
<th>Solar/wind</th>
<th>Hydro</th>
<th>Fossil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base load</td>
<td>+</td>
<td>-</td>
<td>↑↓</td>
<td>+</td>
</tr>
<tr>
<td>Stability – Peak demand</td>
<td>(+ (*))</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Load follow</td>
<td>(+ (*))</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

*All designs are flexible with low carbon*:

- Considering grid stability
- Considering climate changes
  - Drastic reduction of fossil energies
  - Modification of river flows
- Considering alternative solutions for changes in energy policies

⇒ Nuclear is therefore a viable option, if performances are similar to fossil plants
Why make nuclear power production flexible

Flexible nuclear power can be more profitable than new natural gas/hydro plants to meet grid variations when...

- Intending to extend the lifetime of your nuclear power plants to 60 years
- The usage factor of the fleet is difficult to estimate (due to market uncertainty), putting your ROI at risk

Thus, there is a need to “industrialize” the flexibility of your nuclear power fleet to adapt to the market variations, optimize outages and maximize the ROI of your plants

⇒ **FLEX-OPS** can ensure the ROI of your investments in your nuclear power fleet

- Difficult to obtain permit for new hydro plant
- CO₂ emissions for new gas plants (R&D to reduce emissions but with strong impact on costs)
- Cost of nuclear power is less dependent on unpredictable fuel prices than natural gas power
- Price of natural gas is not predictable at mid / long term

On the other hand, the costs of nuclear power is more predictable and more stable

**Nuclear is ready now to provide power balancing services and frequency control**
Future of nuclear energy is **flexible**

... however what about technical and financial risks
### Flexible operation: performances target and achievements

<table>
<thead>
<tr>
<th>Power plant type</th>
<th>Time to start</th>
<th>Maximal load variation within 30 s</th>
<th>Load range</th>
<th>Maximum load ramp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas turbine</td>
<td>10-20 mn</td>
<td>20-30 %</td>
<td>0 – 100 %</td>
<td>20 % / mn</td>
</tr>
<tr>
<td>Combined cycle gas</td>
<td>30-60 mn</td>
<td>10-20 %</td>
<td>0 – 100 %</td>
<td>5-10 % / mn</td>
</tr>
<tr>
<td>Coal plant</td>
<td>1-10 hours</td>
<td>5-10 %</td>
<td>0 – 100 %</td>
<td>1-5 % / mn</td>
</tr>
<tr>
<td>PWR designed for base load</td>
<td>2 h to 2 days</td>
<td>--/--</td>
<td>--/--</td>
<td>0,2% / mn</td>
</tr>
<tr>
<td>PWR GENII designed for Tertiary Reserve</td>
<td>2 h to 2 days</td>
<td>1 %</td>
<td>50-100 %</td>
<td>2 % / mn</td>
</tr>
<tr>
<td>PWR GENIII – III+ designed for Tertiary Reserve</td>
<td>2 h to 2 days</td>
<td>3-5 %</td>
<td>50-100 %</td>
<td>3 % / mn</td>
</tr>
<tr>
<td>All PWR with Framatome’s solution</td>
<td>2 h to 2 days</td>
<td>5 %</td>
<td>30-100 %</td>
<td>5 % / mn (qualified up to 14%)</td>
</tr>
</tbody>
</table>

Fully Automatic Load Follow Control applicable to all reactors reaches European GENIII+ target for load follow operation, better than coal and comparable to combined cycle gas plants.
Framatome has a solution for each of potential customer’s concern, developed in a profitable way

⇒ Critical success factors include defining only what is essential in terms of flexibility

⇒ Offer a full range of customized solutions with a single point of accountability to maximize profit and improve safety
## Flexible operation: Value Drivers & Value Proposition

<table>
<thead>
<tr>
<th>Electricity market</th>
<th>Availability / Operation / Maintenance</th>
<th>Asset management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better flexible performance than coal/oil and comparable to combined gas plants</td>
<td>Transients impacts mitigation: Xe monitoring</td>
<td>Plant life time and aging monitoring</td>
</tr>
<tr>
<td>Minimize production for low/negative prices: low power operation</td>
<td>Less LCOs and SCRAMs</td>
<td>Identify real design capabilities in detail</td>
</tr>
<tr>
<td>Fulfill the obligatory grid requirements:</td>
<td>Pellet Clad Interact monitoring minimizes the risk of fuel failures</td>
<td>Optimize fuel resources, economics and refueling outage schedule</td>
</tr>
<tr>
<td>Increase output net power</td>
<td>Less boron (recycling), less wastes</td>
<td>Easier and safer operation: mitigates human failures</td>
</tr>
<tr>
<td>Increase revenue by paid dispatch and by higher paid ancillary services</td>
<td>Optimize maintenance means during outages (small fleet)</td>
<td>Increase the net value of the plant and limit industrial risks</td>
</tr>
</tbody>
</table>

### Value propositions:
- Fulfill grid operator requirements
- Maximize plants’ performances and profitability
- Easier to operate with higher performances
- Fuel economies
Future of nuclear energy is flexible

… Framatome has the solution tailored to meet your needs
Flexible in Operation – Thibaut Jain – Sweden / January 2019

Since the 1970’s, Framatome has supplied nearly 100 NPPs with flexible operation capabilities. Framatome has also upgraded various existing designs to improve upon their flexibility. Of these NPPs, most operate in flexible mode in a safe, profitable and reliable manner.

In France, 58 EDF plants have used flexible operation since 1984 and have accumulated hundreds of years of favorable operating experience.

In Germany, more than a decade from 4 plants operating at fully automated mode.

Countries with flexible nuclear reactors all experienced grid-specific profitable economical models. Such mode is available for all types of reactors and enables economies in OPEX, long term asset, no carbon increase, stable price, increased reliability, and new profitable price models in some countries expectations.

Fuel power maneuvering guidelines have been developed based on extensive testing and analyses that ensure safe and reliable performance during all flexible operation modes.

If the flexibility is required, Framatome has a customer-tailored solution.
Summary

YOUR CHALLENGE

Most nuclear plants are designed or currently optimized for base load operations
Evolution of the grid and market share, climate changes
New drivers for customers:
- Flexibility in the grid
- Long-term asset and profitability
Solution limited by the design, operation modes and organization impacts: solution adapted to the customer

OUR SOLUTION

Our solution is unique, we offer the complete scope and are able to adapt to customers’ needs:
- Applicable to all types of reactors
- Customizable following operator’s needs from full automated embedded solution to limited-to-design solution
- Covering all the plant’s scope “from the Reactor Core to the Grid”, including all safety systems and logics”
- Adapted to aging monitoring, lifetime extension, fuel economy, safety improvement …

YOUR BENEFITS

Better flexible performance than coal/oil and comparable to combined gas plants
Minimize carbon taxes (replacement of old fossil fire plants, ability to produce ancillary services)
Minimize production during periods of low/negative prices
Increase the net value of the plant and limit industrial risks
Optimize fuel resources, economics and refueling outage schedule
Optimize maintenance means during outages (small fleet)
PCI monitoring leads to less or prevents fuel leaks
Summary

FRAMATOME together with EDF has the complete know-how and experience with respect to flexible operation mode

- design new NPPs including advanced fully automatic I&C
- optimize and upgrade existing NPPs
- fuel development and transition

Our overall technical expertise covers “from Reactor Core to the Grid”

Our Mission is to make NPP a valuable asset for balancing of today’s Grid in each required flexible mode:

- Load Follow
- Primary and Secondary frequency Control
- Unexpected Grid Requests
- ELPO
Future of nuclear energy is Flexible … questions

with Dr Tatiana Salnikova – Framatome GmbH
Flexible in Operation – Thibaut Jain – Sweden / January 2019

Turn-key flexible operation solution for entire plant

- Procedures/ Training/Simulators/Licensing support
- Equipment limits analyses/tests Equipment Reliability/Risk
- Coolant management/ treatment e.g. Fully automated Boric acid recovery system
- Continuous fast online Incore instrumentation/ precise calibration
- Automated Reactivity management e.g. Xenon online predictions
- Refueling cycle optimization / Outage management
- Automated surveillance of conditioning limits (LOCA, DNB, PCI..)
- Hybrid delivery and alternative solutions
- All types of flexible operation modes e.g. fully automated secondary frequency control
- Ageing management, lifetime extension e.g. Monitoring /Diagnostic/ Analyses
- Flexibility optimization within licensed limits
- Automated surveillance of conditioning limits (LOCA, DNB, PCI..)