Operating Experience and Opportunities with Flexible Nuclear Plant Operations

ESIG 2020 Spring Technical Workshop

Sherry Bernhoft
Senior Program Manager

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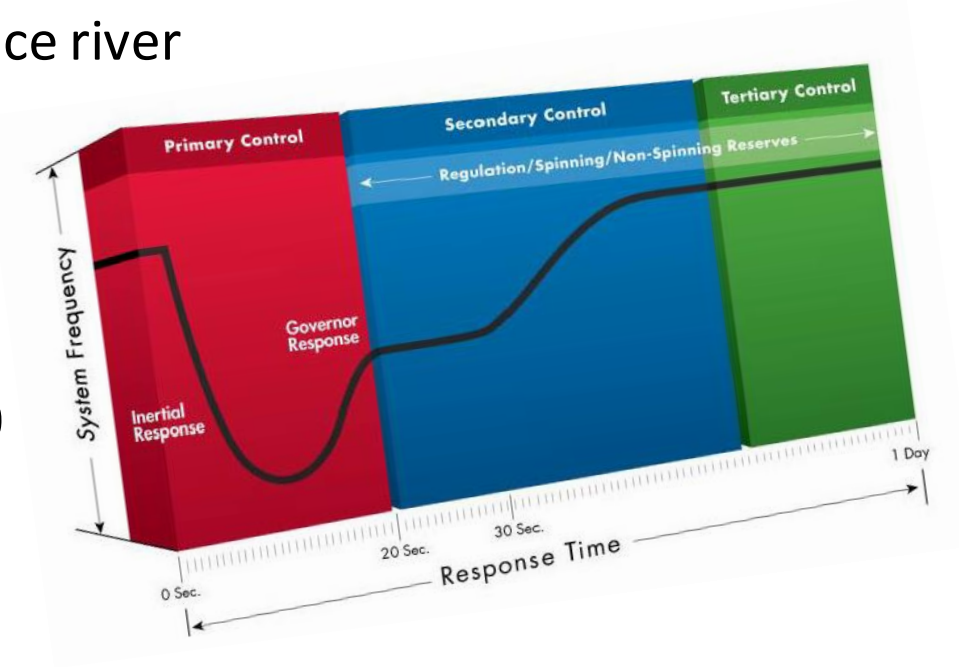
Nuclear Power Plant Flexible Operations is Not New

- Past Operating Experience (OE) in the United States
  - Until mid-1980's nuclear plants were used for frequency control
  - Nuclear Regulatory Commission changed their rules for reactor power control
  - Columbia NPP has decades of flexible operations to balance river flowage

- France
  - 58 reactors with over 30 years of flexible OE
  - Output can vary between 20% and 100% power within 30 minutes, twice a day for load following
  - Provide primary and secondary frequency control
  - Use grey control rods to vary reactor power



Nuclear power plants were designed for flexible operations

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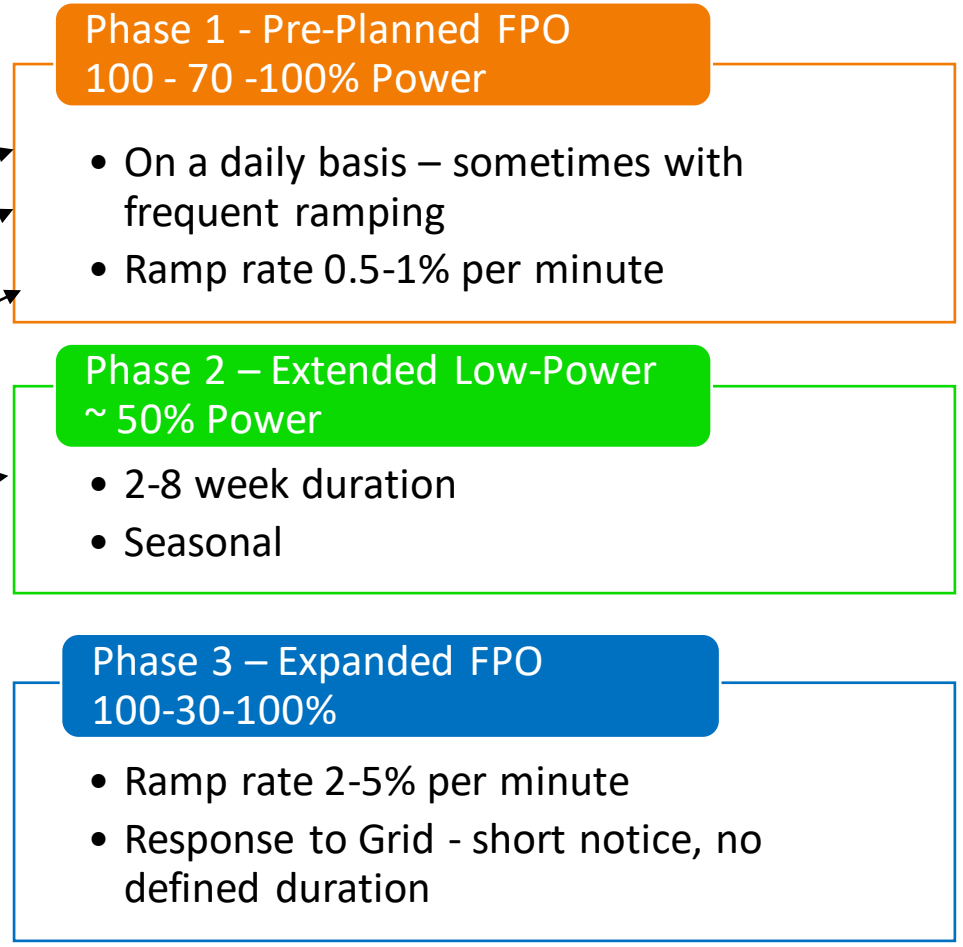
Recognizing the Need to be Flexible in Today's Market

- EPRI research program started in 2013
  - Support transitioning from base load, to flexible operations
  - Assess long-term impacts on the nuclear fuel and plant
  - Develop proactive management strategies
  - Employing a phased approach

- Recent Operating Experience
  - Xcel – Day Ahead Market
  - Exelon – Advance Nuclear Dispatch
  - Columbia – Load Shaping Agreement
  - Bruce Power – Surplus Base Generation
    - CANDU reactor design allows steam bypass mode
  - Europe
    - Belgium and Spain
  - United States
    - Several utilities are actively evaluating options



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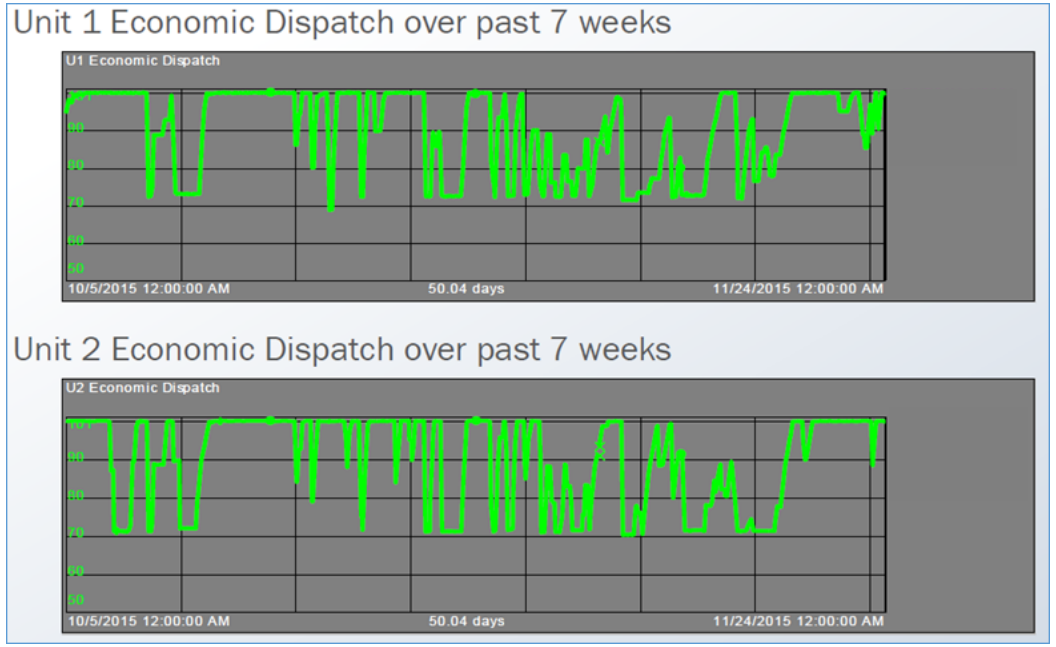
Key Lessons Learned

- The plant operator is responsible for maintaining a safe operating window
- Training is critical
- Chemistry can be challenging – more frequent monitoring may be warranted
- Water usage may increase for PWRs
- Inspection frequencies need to be adjusted for critical components
- Flow accelerated wear rates change
- Maintenance practices need to be robust
- Most plant impacts are latent and additional monitoring for unexpected changes is needed



Data provided by Exelon for a PWR

Flexible Operations is being successfully implemented with manageable impacts

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An Operating Protocol Is Needed

- Only a licensed plant operator can change reactor power levels
- The rate, depth, duration, frequency and time in reactor core life are tied to core physics
  - Need to be well defined up front
  - Ensure the plant stays within a safe operating envelope at all times
- Plant Management can decide to opt out of flexible operations based on other plant activities
  - Require the full attention of the control room operators, or
  - Require stable core power to complete

Nuclear flexible operations requires close coordination

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Optimizing Nuclear Flexible Operations

- Pilot study to quantify the cost of NPP flexible operations
- Expand The Range of Flexibility, i.e. 100-30-100%
  - White Paper published in 2019 on possible ‘pinch points’
  - Research started in 2020 to address options
- Frequency Control and Other Grid Services
  - Study on NPP frequency control considerations is in progress
  - Working with DOE on an Economic Drivers for Nuclear Flexible Operations study
- Nuclear Beyond Electricity
  - Thermal storage
  - Water de-salinization
  - Hydrogen generation

White Paper December 2020: Technical, regulatory and financial aspects of using NPPs for primary frequency control

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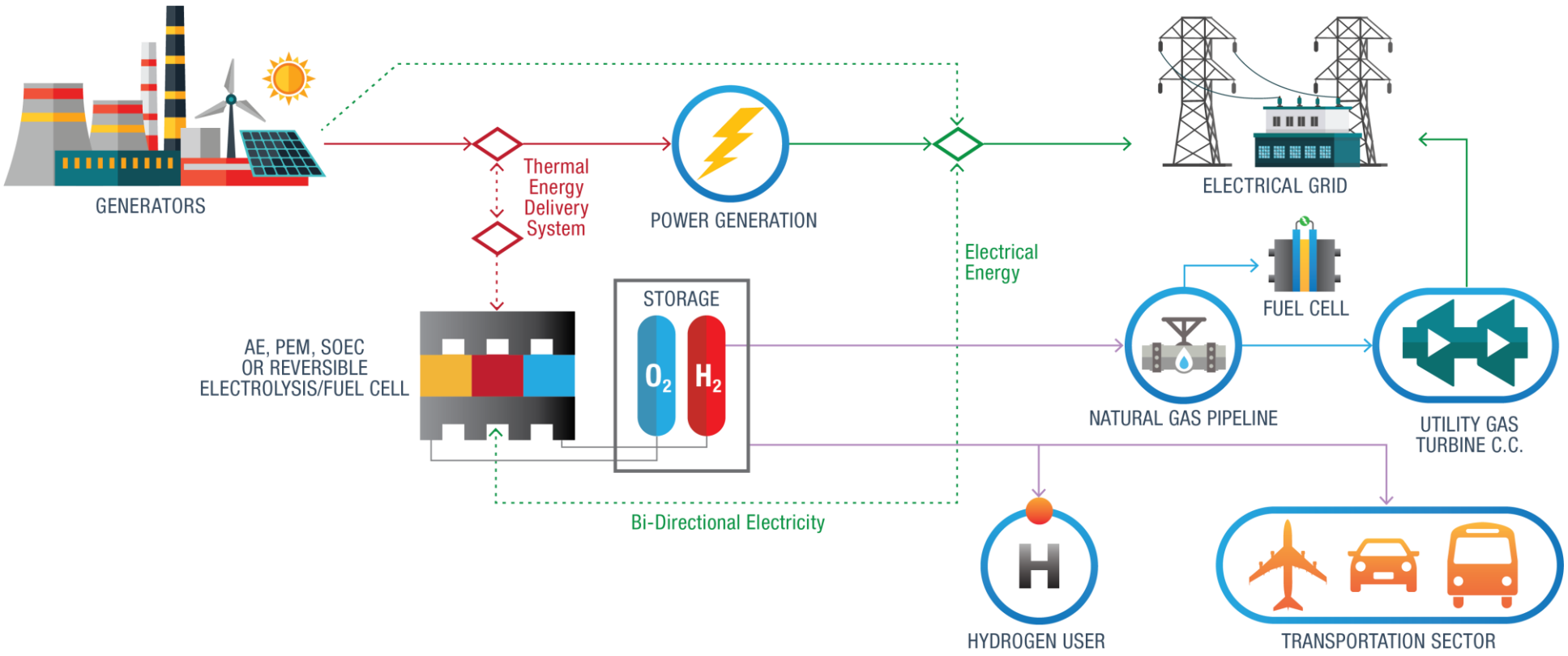
Example: Hydrogen Production via Steam Electrolysis



1) Provides second source of revenue
2) Provides energy storage, for electricity production or hydrogen user
3) Provides opportunity for grid services; reserves and grid regulation

US Department of Energy is funding demonstration projects for H2 production at existing NPPs

Source: Idaho National Laboratory

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Small Modular and Advanced Reactors Provide Increased Flexibility

*HTSE = high temperature steam electrolysis
**S-I = sulfur – iodine thermochemical process

Source: Nuclear Reimagined, Third Way, Oct. 2017

Together…Shaping the Future of Electricity

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