Modeling and Control of the IRIS IPWR in a High Renewables Grid Using TRANSFORM

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Organization

1. Research Motivation

2. Motivations for Choosing Modelica

3. Model Development and Results

4. Conclusions and Future Work
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Research Motivation

- Evolution of US electricity markets
  - Cheap natural gas ($\approx 3$/MMBTU)
  - High renewables penetration
  - Utility-scale storage (?)

- The new grid and the role of novel reactors

- Hybrid energy applications versus electrical generation
CURENT: Center for Ultra-Wide-Area Resilient Electric Energy Transmission

- Concerned with grid stability and resilience with high renewables penetration (50-80% capacity)

Paradigms for this collaboration

1. Operate in tandem with local wind farms (20-200 MWe) in a distributed generation system
2. Simulation of an SMR plant as part of a wide area grid with high renewables penetration in the context of a unit commitment problem
Contemporary reactor load following

- Load *shaping* at Columbia Generating Station

- Load following mode in Europe
  - Plants participate in primary and secondary frequency control
  - Primarily achieved through use of mechanical shim (black and gray rods)
  - Reactors must be capable of daily load cycling 50-100% rated power in 24 hour periods at 3-5% per minute ramp rate

- Reactor vs. turbine leading: toward coordinated control
Load following with SMRs

Figure 1: Load-following study conducted by NuScale, Energy Northwest, and UAMPS with 50 MWe NuScale module and Horse Butte wind farm
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Why Modelica?

- Acausal physical modeling paradigm
- Modularity of physical components
- Libraries
  1. Standard library with additions from previous modeling efforts at UTK and NCSU
  2. NuKomp Library
  3. TRANSFORM Library
TRANSFORM Library

- Modeling library for thermal hydraulic and energy systems (especially nuclear) simulation developed at INL, ORNL, ANL
- Free and open source
- Augmented MSL Fluid library components

Figure 2: TRANSFORM package
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Figure 3: Architecture of plant and relationships between subsystems.
Westinghouse IRIS

IRIS is an innovative design, but it does not require new technology development, since it relies on the proven light water reactor technology. IRIS is being developed by an international consortium which is led by Westinghouse Electric Co. and includes a number of US and international companies, universities and national laboratories and organizations. The following organizations are members of the IRIS consortium:

- Westinghouse Electric Co. (USA)
- BFNL (UK)
- Bechtel (USA)
- ENSA (Spain)
- Ansaldo Energia (Italy)
- Ansaldo Camozzi (Italy)
- NUCLEP (Brazil)
- Curtiss-Wright (USA)
- TV A (USA)
- Eletronuclear (Brazil)
- CNEN (Brazil)
- National Institute for Nuclear Studies (Mexico)
- Oak Ridge National Laboratory (USA)
- University of Zagreb (Croatia)
- Polytechnic of Milan (Italy)
- University of Pisa (Italy)
- Tokyo Institute of Technology (Japan).

The IRIS design features an integral reactor vessel that contains all the reactor coolant system components, including the pressurizer, steam generators, and reactor coolant pumps. The IRIS integral layout has been previously reported [1,2], and is shown in Figure 1.

Figure 1. IRIS Integral Reactor Coolant System. Main components (a) and coolant flow path (b)

Figure 4: Diagram of IRIS featuring (a) integral components and (b) primary circulation
Nuclear Steam Supply System

Figure 5: The IRIS primary circuit
Balance of Plant

Figure 6: A simplified balance of plant
Figure 7: Block diagram of program with exogenous inputs.
Figure 8: A sample grid demand in a distributed generation system based on scaled wind turbine generation data.
Control Studies: Feed-forward rod insertion

Figure 9: Ramp reactivity insertions of -$0.10 and -$0.25 over 10 s. Reactor response initially evolves quickly followed by slow but significant feedback in 9a. Pressure evolves slowly without similar feedback in 9b.
Control Studies: $T_{avg}$ PID Control

Figure 10: Reactor response and associated reactivity insertion due to action of $T_{avg}$ PID controller.
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Conclusions

- IRIS reactor and a balance of plant developed using TRANSFORM components were simulated in Modelica (Dymola environment)
- Simple controls were tested for plant response
- Preliminary results motivate for choice of actuation, operational principles compared to present ones, figures of merit
Future modeling and control development

- Additional reactor physics considerations
- Development of control logic and hierarchy
  - Advanced controls and operations concepts for balancing multiple plant objectives
  - Potential for FMU export for control development and optimization using MATLAB toolboxes
- Renewables integration
  - External pre-processed input data (distributed generation, net grid demand, frequency)
  - Co-simulation with constrained optimization problem “black box” model
Figure 11: Simulation of unit commitment with combined CAISO and MISO markets.
Modified architecture

Figure 12: A prospective modification to the model architecture that incorporates the notion of the grid.
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