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

Richard Bisson and Jamie Coble

University of Tennessee, Knoxville

American Modelica Conference 2018

Organization

1. Research Motivation
2. Motivations for Choosing Modelica
3. Model Development and Results
4. Conclusions and Future Work

Organization

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

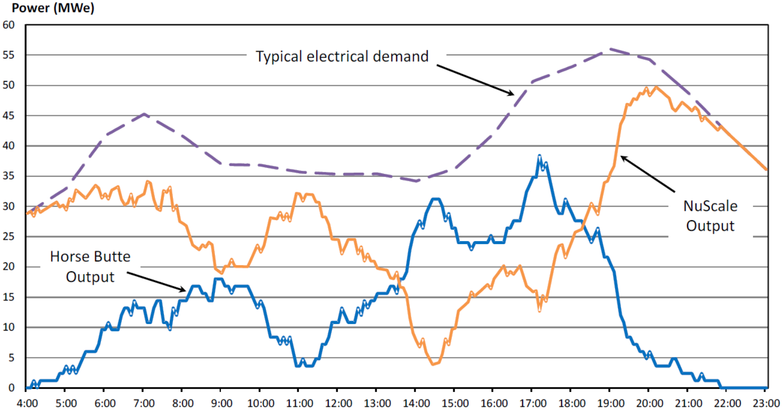


Figure 1: Load-following study conducted by NuScale, Energy Northwest, and UAMPS with 50 MWe NuScale module and Horse Butte wind farm
`http://www.nuscalepower.com/images/our_technology/nuscale-integration-with-renewables_icapp15.pdf`

Organization

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

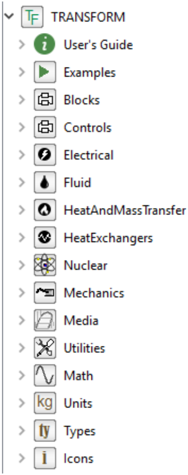


Figure 2: TRANSFORM package

Organization

Model Architecture

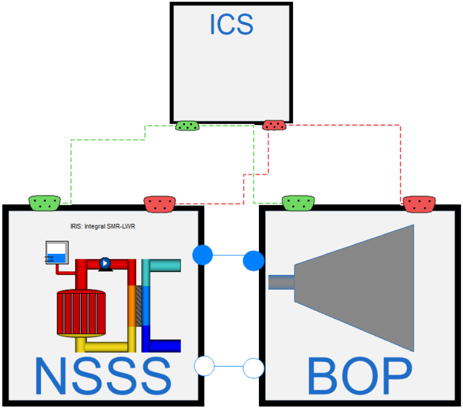


Figure 3: Architecture of plant and relationships between subsystems.

Westinghouse IRIS

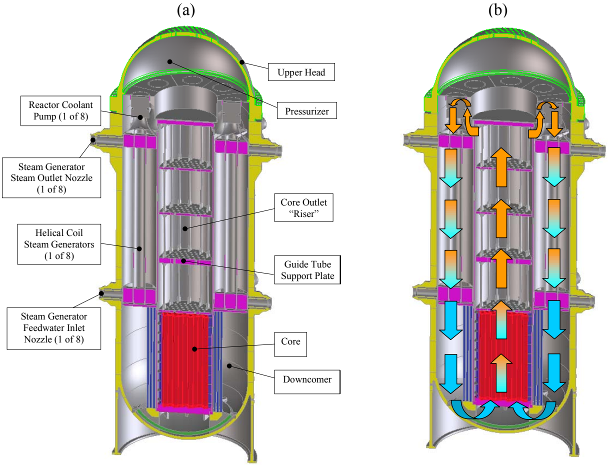


Figure 4: Diagram of IRIS featuring (a) integral components and (b) primary circulation

Nuclear Steam Supply System

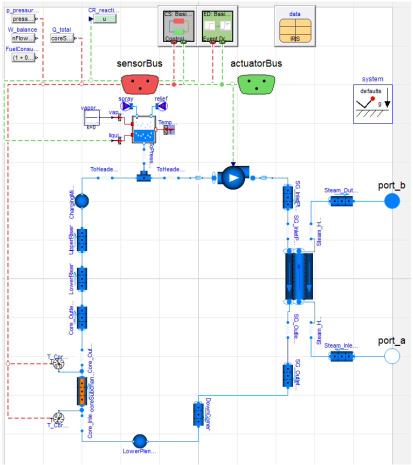


Figure 5: The IRIS primary circuit

Balance of Plant

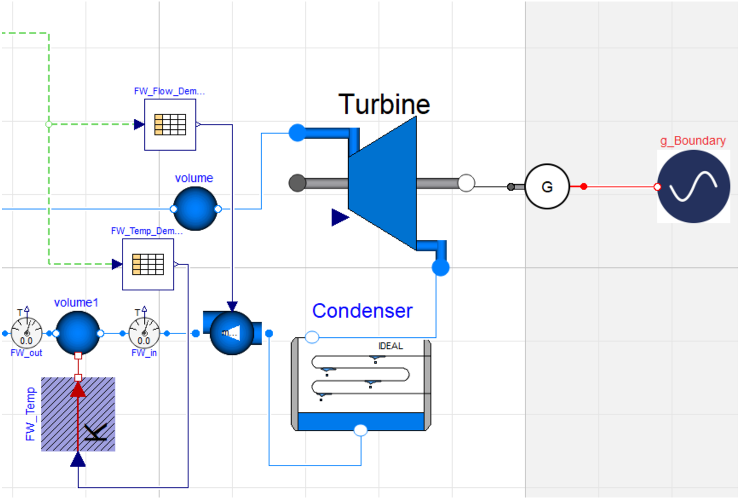


Figure 6: A simplified balance of plant

Control Signals

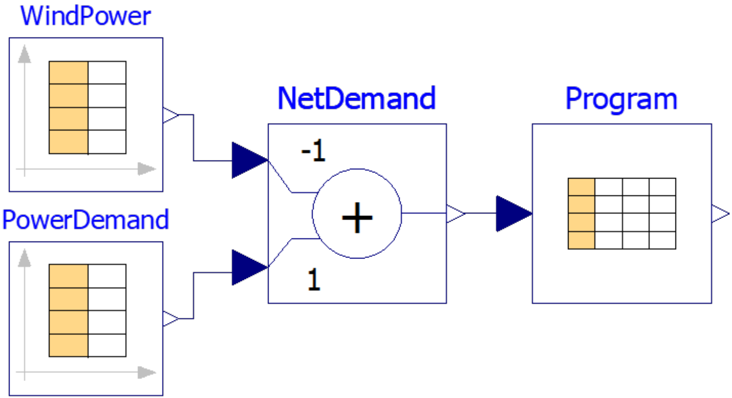


Figure 7: Block diagram of program with exogenous inputs.

A Model of Renewable Integration

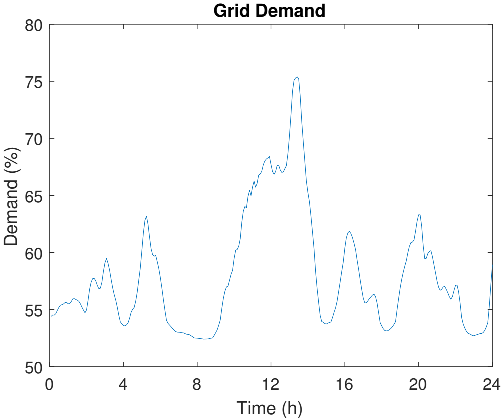
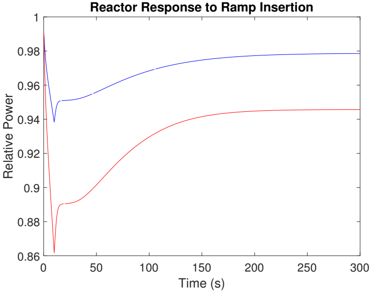
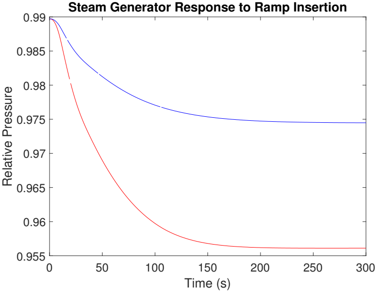


Figure 8: A sample grid demand in a distributed generation system based on scaled wind turbine generation data.

Control Studies: Feed-forward rod insertion



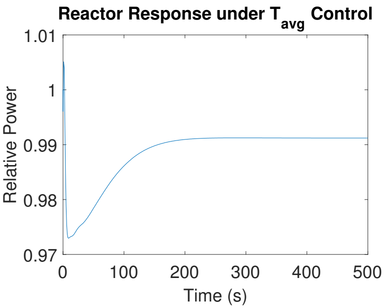
(a) Thermal Power



(b) SG Outlet Pressure

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



(a) Thermal Power (b) Control Rod Reactivity

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

Organization

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

Unit Commitment

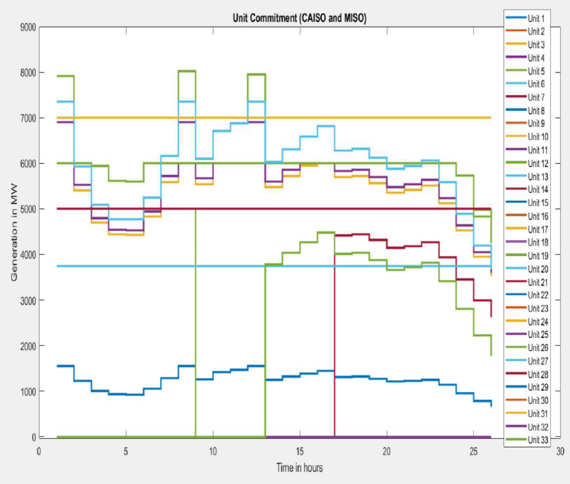


Figure 11: Simulation of unit commitment with combined CAISO and MISO markets.

Modified architecture

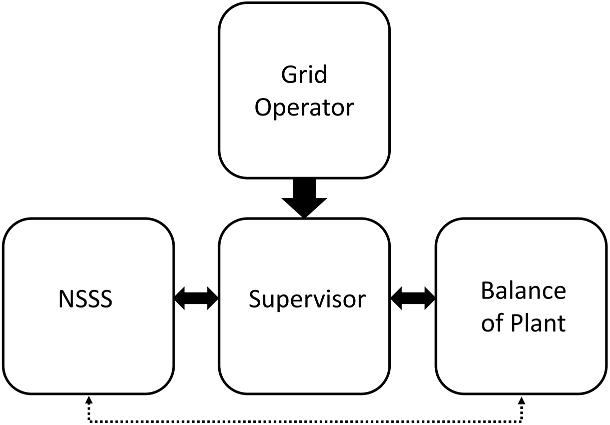


Figure 12: A prospective modification to the model architecture that incorporates the notion of the grid.

Acknowledgements

This work was supported primarily by the ERC Program of the National Science Foundation and DOE under NSF Award Number EEC-1041877 and the CURENT Industry Partnership Program.

Other US government and industrial sponsors of CURENT research are also gratefully acknowledged.