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Office Of Nuclear Energy

Annual Review Meeting

Dynamic Simulation Modeling Tool

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ORNL

September 16-18, 2014

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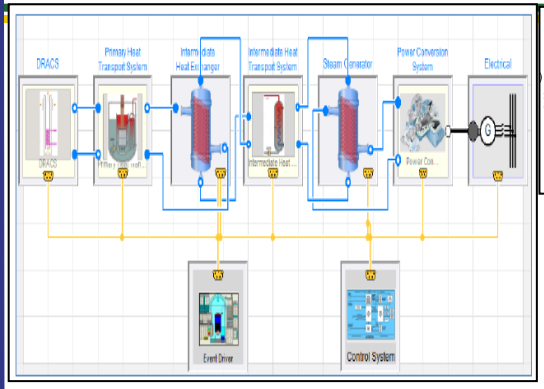
Work Package SR-14OR130108 – Modeling Tools for Dynamic Behavior Simulations of SMRs

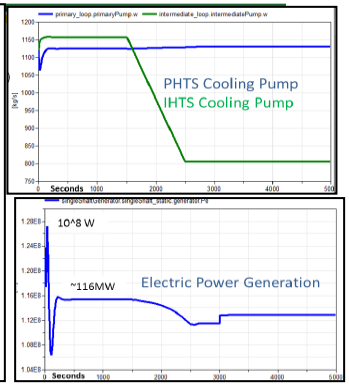
Task Relevancy

- **Simplified Dynamic Modeling for Advanced SMRs**
  - Numerous dynamic models are needed to simulate plant behavior under operational scenarios and in response to transient conditions for advanced SMRs
  - Modelica-based models with user friendly interfaces (Excel/ Web) allow common simulation environment and simplified/ easy access and use for wide range of technical investigators.

ALMR Simulation



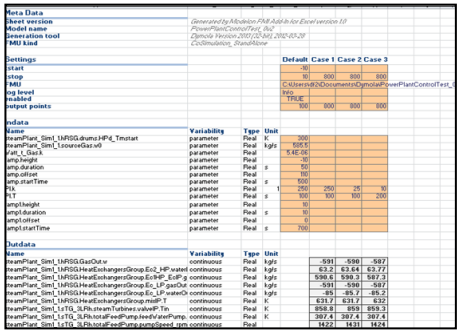
ALMR PRISM Architecture

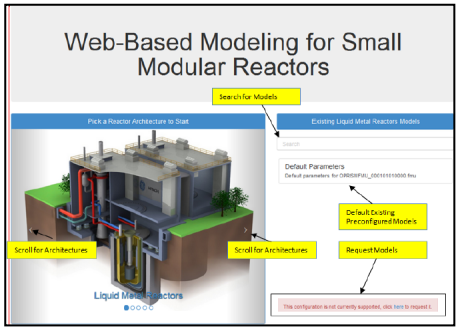


Excel Based Simulation Results

Technical Approach/Accomplishments/Results

- Modelica modeling architecture implemented
- ALMR PRISM (first) plant model completed
- Excel Based Simulation Tool Completed (see below)
- Web-based Simulation Application prototype developed & User Manual drafted (see below)
- Initial collaborators established with University Partners





Expected Deliverable & Schedule

- ✓ FY14 molten salt cooled model deliverable due.
- FY15 web application deliverable due.
- FY15 model repository establishment due.
- FY15 working collaboration with University partners.

2

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Project Overview

- **To create a flexible, portable and powerful dynamic system modeling environment**

- **to facilitate investigation of control system strategies for reactor systems in any number of configurations**

  - Facilitate rapid development of models,
  - Ensure consistency among research products,
  - Minimize duplication of effort

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Technology Impact

- ***The ORNL ModSim Tool is a development, execution environment and repository for reactor subsystem models and end-to-end reactor system models which allows***
  - *Powerful dynamic simulation in the Modelica environment*
  - *The ability to configure components into new power system arrangements*
  - *The ability to collaborate as a community via the internet*
  - *The ability to export models for analysis within the Excel environment opening affordable collaboration to everyone*

- ***The tool will allow reactor design concepts to be studied***
  - *Without requiring the modeler to develop a unique set of BOP models*
  - *With multiple reactors coupled to shared infrastructure*
  - *With control system implementations modeled separately so that system models do not require modification for different I&C designs*

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Modeling Tools for Dynamic Behavior Simulations of SMRs FY14 Achievements

FY14 Achievements

- **improved Flexible Model Architecture**
- **Updated all models to fit within Flexible Model Architecture**
- **User's Manual**
- **FHR reactor architecture**
- **Collaborative efforts initiated**
  - Supervisory Control
  - Advanced PRA
  - Universities

FY14 Milestones

- **M3SR-14OR1301086 Level 3 Milestone for Work Package SR-14OR130108, Aug 2014**
  - "*Extend Modeling Tool Architecture to Molten Salt Cooled Reactor*"
- **M2SR-14OR1301085 Level 2 Milestone for Work Package SR-14OR130108, March 2014**
  - "*Update on Small Modular Reactors Dynamic System Modeling Tool*"

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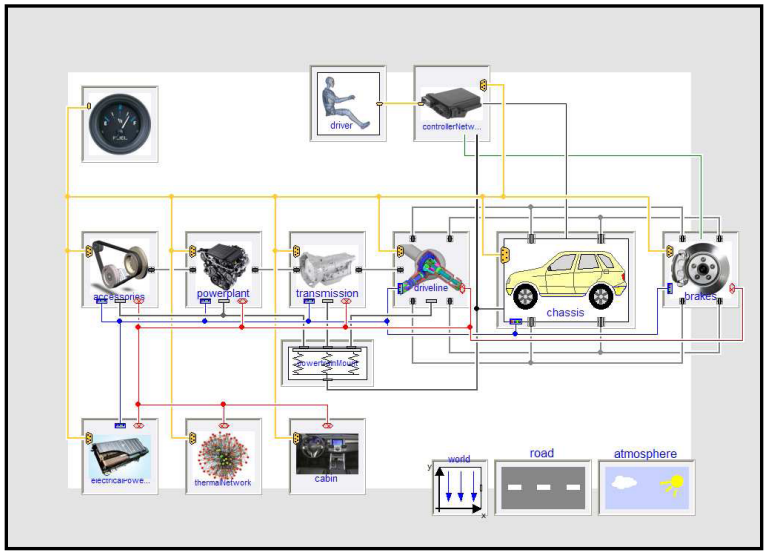
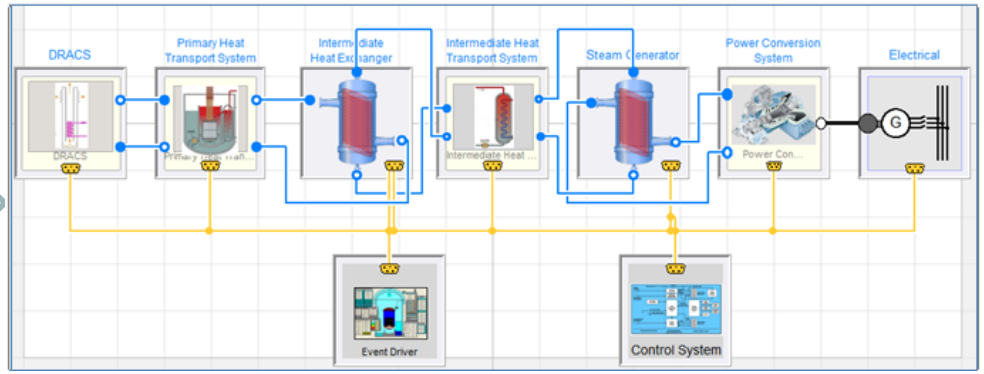
Approach Based on Proven Science



Modelica System model for automotive vehicle



Modelica System Model for Advanced Reactors

the goal is to reduce the time and lower the cost for designing advanced SMRs?

Develop tools that allow simulation of early concepts to be developed and shared easily and rapidly

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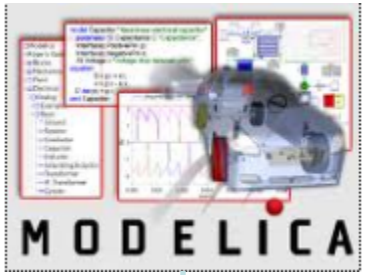
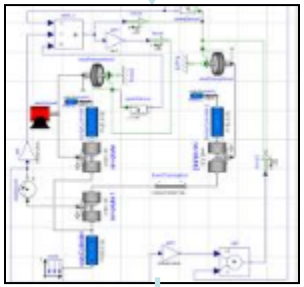
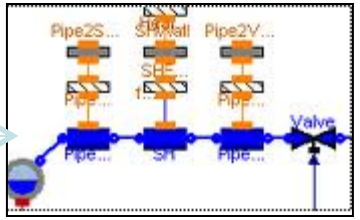
How do we do this?

- We are modeling complex advanced reactors in the MODELICA language
- We are solving MODELICA models with DYMOLA solver
- We are leveraging the MODELICA ThermoPower library for reactor systems







Models are developed from three building blocks

More on the missing pieces in a minute, first what does a Modelica model look like?

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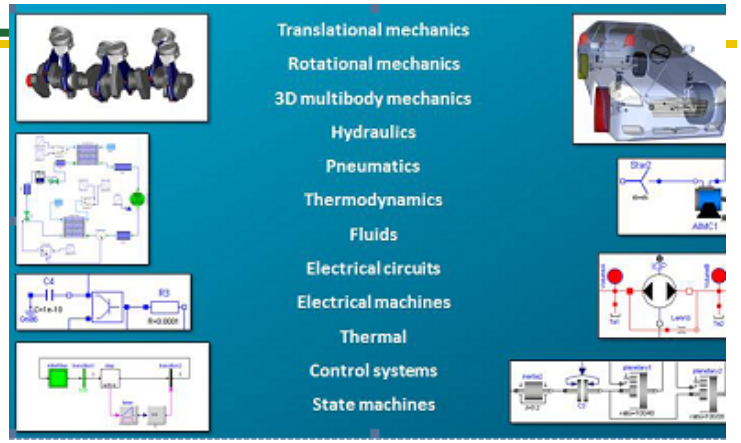
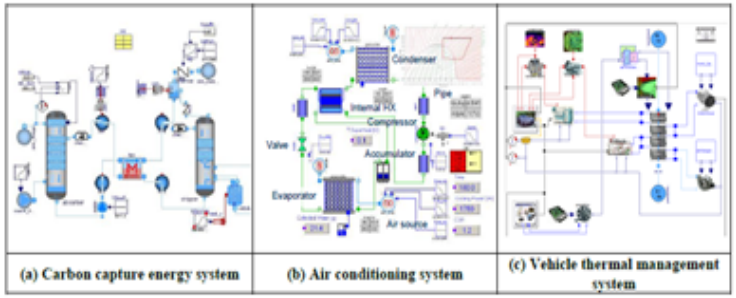
Modelica: Using the Emerging Open-Source Modeling Standard

- Modelica is a nonproprietary, object-oriented, equation-based language used to model complex physical systems.
- Modelica is free, open source, object oriented and has multi-domain libraries that already exist and can readily be modified
- Modelica is a multi-domain modeling language and can handle mechanical, electrical, electronic, fluid, thermal, hydraulic, pneumatic, magnetic, and control systems and their interactions
- Been adopted by other industries for fast turnaround design studies (automotive/aerospace)





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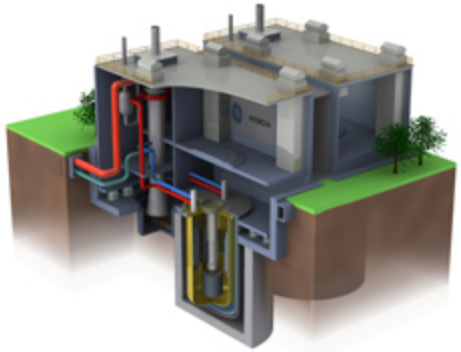
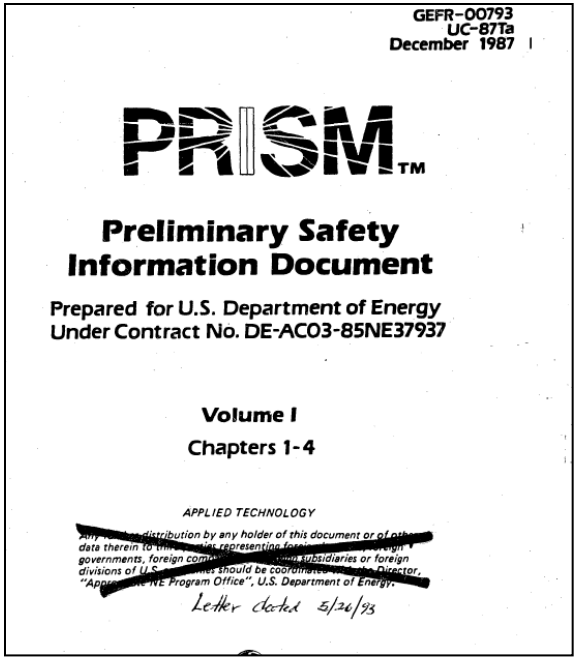
ALMR Concept Modeled



- **PRISM[1] ALMR End-to-End System model created from previous models that include:**
  - *Reactor*
  - *Primary System*
  - *Intermediate System*
  - *Power Conversion*
  - *Grid (Generic model)*



GEFR-00793
UC-87Ta
December 1987

PRISM™

Preliminary Safety Information Document

Prepared for U.S. Department of Energy
Under Contract No. DE-AC03-85NE37937

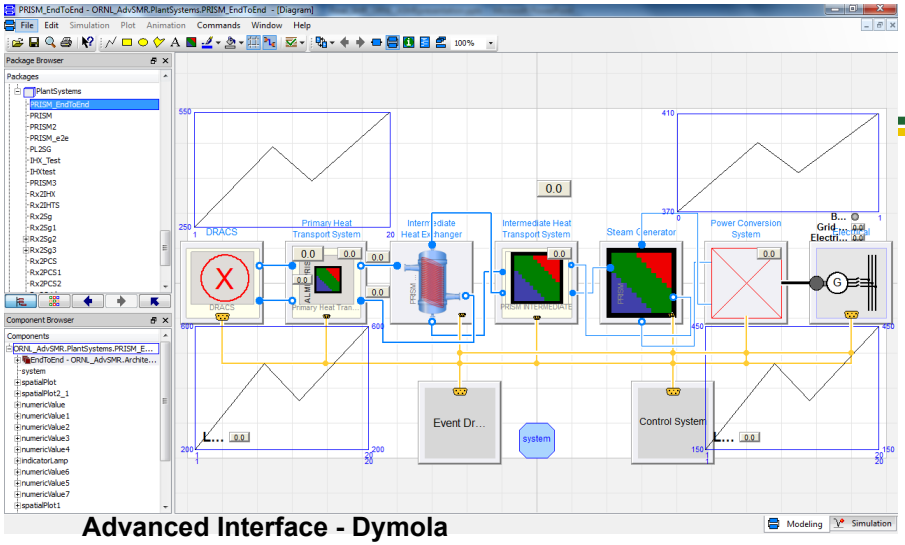
Volume I
Chapters 1-4

APPLIED TECHNOLOGY

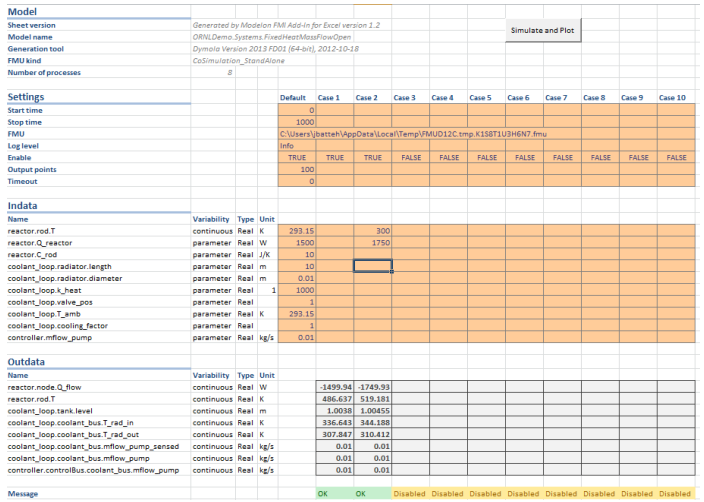
[1]The S-PRISM represents GEH's Generation IV reactor solution to closing the nuclear fuel cycle and is also part of its Advanced Recycling Center (ARC) proposition[1] to U.S. Congress to deal with nuclear waste.[2]It is a sodium-cooled fast breeder reactor, based on the Experimental Breeder Reactor II(EBR-II) design, scaled up by a factor of ten. *[Wikipedia*]

Now that we know what the models look like, what was our test case?

User-Tailored Interfaces

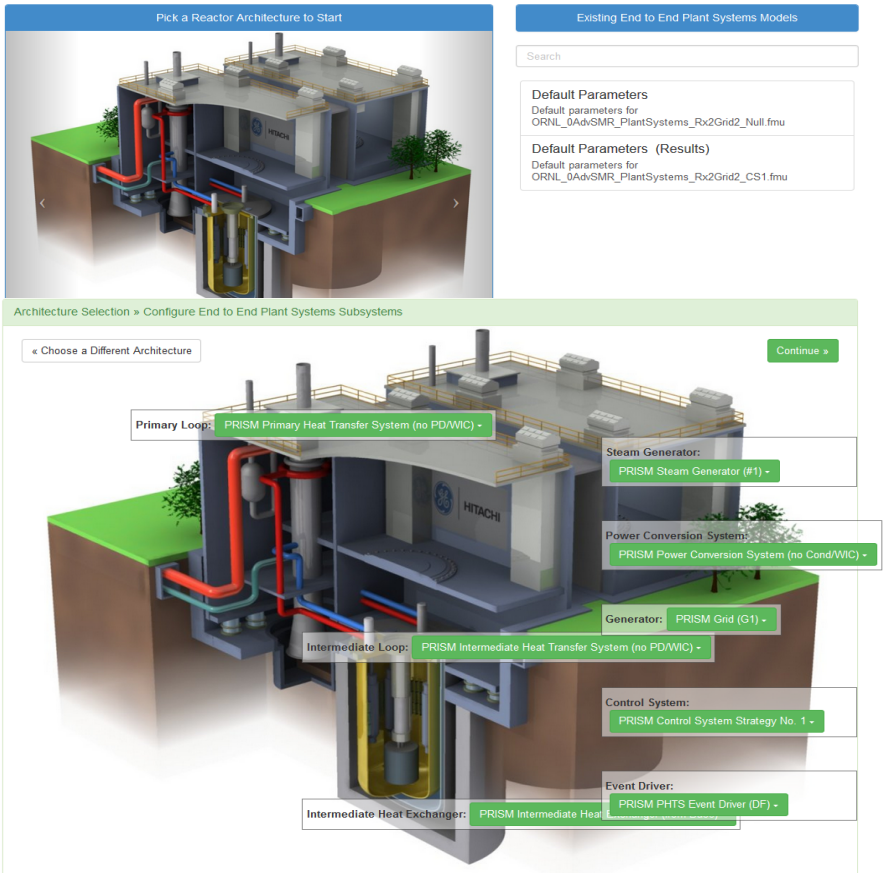


Advanced Interface - Dymola



Intermediate Interface - FMIE

Web-Based Modeling for Small Modular Reactors



Beginning Interface – Web Application
http://smr.apps.xogeny.com/#/

Interfaces exist for all user levels.

Goal is to lower threshold for simulation and modeling use.

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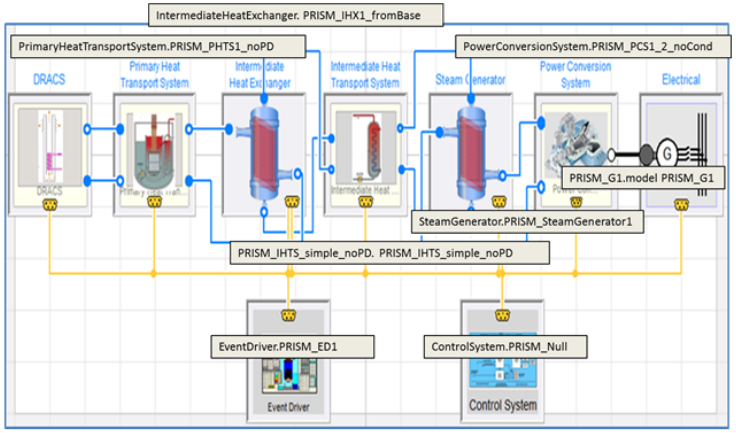
Flexible and Powerful Simulation

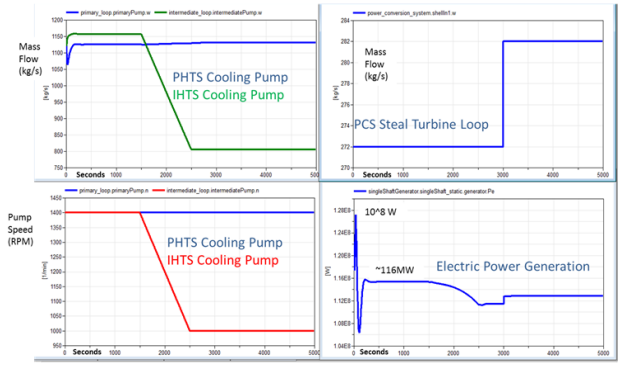
Baseline "Null" Configuration without control
ORNL_AdvSMR.PlantSystems.Rx2Grid2



Baseline "Null" Configuration without control

Two Events:

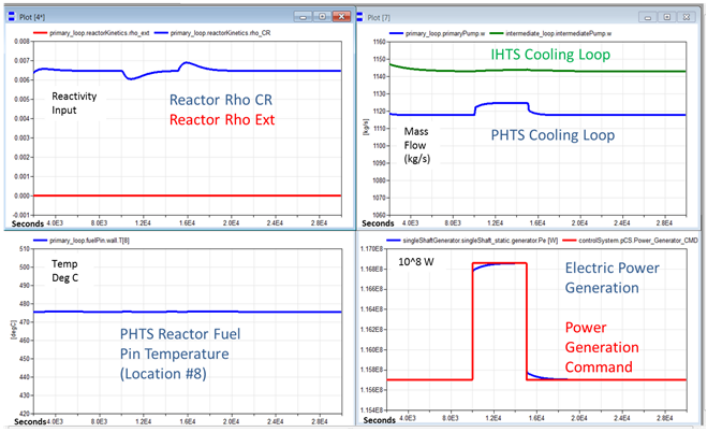
1. IHTS Intermediate Pump Speed Change @ 1500 seconds.
2. PCS Mass flow increase @ 3000 seconds.



- **Two control strategies associated with a single transient**
- **Transient is simulated step change in reactivity**
- **#1 is controlling outlet temperature**
- **#2 is controlling differential temperature**

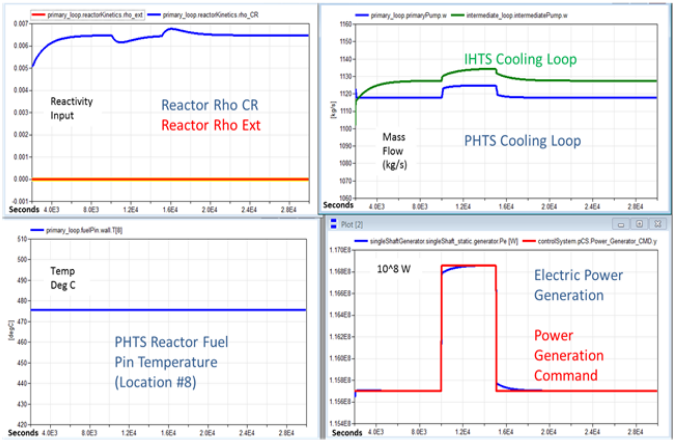
Baseline "Null" Configuration with Control Strategy #1

Trapezoid Power Generation Command Profile – 1.2MW Ramp, Hold, Negative Ramp over 5000 seconds



Baseline "Null" Configuration with Control Strategy #2

Trapezoid Power Generation Command Profile – 1.2MW Ramp, Hold, Negative Ramp over 5000 seconds



The initial transients step change in reactivity with subsequent control system evaluation.

No detailed analysis has been performed goal was to demonstrate the tool.

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Modifying and Executing Models Outside of Dymola

- FMI Excel Tool Allows sophisticated compiled models to be modified and executed through an Excel Interface, without a Dymola License

Meta Data							
Sheet version	Generated by Modelon FMI Add-In for Excel version 1.0						
Model name	PowerPlantControlTest_0v2						
Generation tool	Dymola Version 2013 (32-bit), 2012-03-28						
FMU kind	CoSimulation_StandAlone						
Settings				Default	Case 1	Case 2	Case 3
tstart				-10			
tstop				10	800	800	800
FMU				C:\Users\df2\Documents\Dymola\PowerPlantControlTest_0v2.fmu			
log level				Info			
enabled				TRUE			
output points				100	800	800	800
Indata							
Name	Variability	Type	Unit				
steamPlant_Sim1_1.hRSG.drums.HPd_Tmstart	parameter	Real	K	300			
steamPlant_Sim1_1.sourceGas.w0	parameter	Real	kg/s	585.5			
Watt_t_Gas.k	parameter	Real		5.4E-06			
ramp.height	parameter	Real		-10			
ramp.duration	parameter	Real	s	50			
ramp.offset	parameter	Real		110			
ramp.startTime	parameter	Real	s	500			
PI.k	parameter	Real	1	250	250	25	10
PI.T	parameter	Real	s	100	100	100	200
ramp1.height	parameter	Real		10			
ramp1.duration	parameter	Real	s	10			
ramp1.offset	parameter	Real		0			
ramp1.startTime	parameter	Real	s	700			
Outdata							
Name	Variability	Type	Unit				
steamPlant_Sim1_1.hRSG.GasOut.w	continuous	Real	kg/s		-591	-590	-587
steamPlant_Sim1_1.hRSG.HeatExchangersGroup.Ec2_HP.waterI	continuous	Real	kg/s		63.2	63.64	63.77
steamPlant_Sim1_1.hRSG.HeatExchangersGroup.Ec1HP_EclP.g	continuous	Real	kg/s		590.6	590.3	587.3
steamPlant_Sim1_1.hRSG.HeatExchangersGroup.Ec_LP.gasOut	continuous	Real	kg/s		-591	-590	-587
steamPlant_Sim1_1.hRSG.HeatExchangersGroup.Ec_LP.waterO	continuous	Real	kg/s		-85	-85.7	-85.2
steamPlant_Sim1_1.hRSG.HeatExchangersGroup.mixIP.T	continuous	Real	K		631.7	631.7	632
steamPlant_Sim1_1.sTG_3LRh.steamTurbines.valveIP.Tin	continuous	Real	K		858.8	859	859.3
steamPlant_Sim1_1.sTG_3LRh.totalFeedPump.feedWaterPump.	continuous	Real	K		307.4	307.4	307.4
steamPlant_Sim1_1.sTG_3LRh.totalFeedPump.pumpSpeed_rpm	continuous	Real			1422	1431	1424

Functional Mockup Interface Add-in for Microsoft Excel® enables steady-state and dynamic simulation of physical models integrated in a spread sheet environment.

- **Batch-simulations**
- **parameter sweeps**

Model Configuration/Case Settings

Adjustable Model Inputs

Resulting Model Outputs

Recall we discussed missing pieces. The first piece was the ability to simulate outside of the proprietary solver. To do this we cheat and use another propietary tool – but one that is much cheaper and easier.

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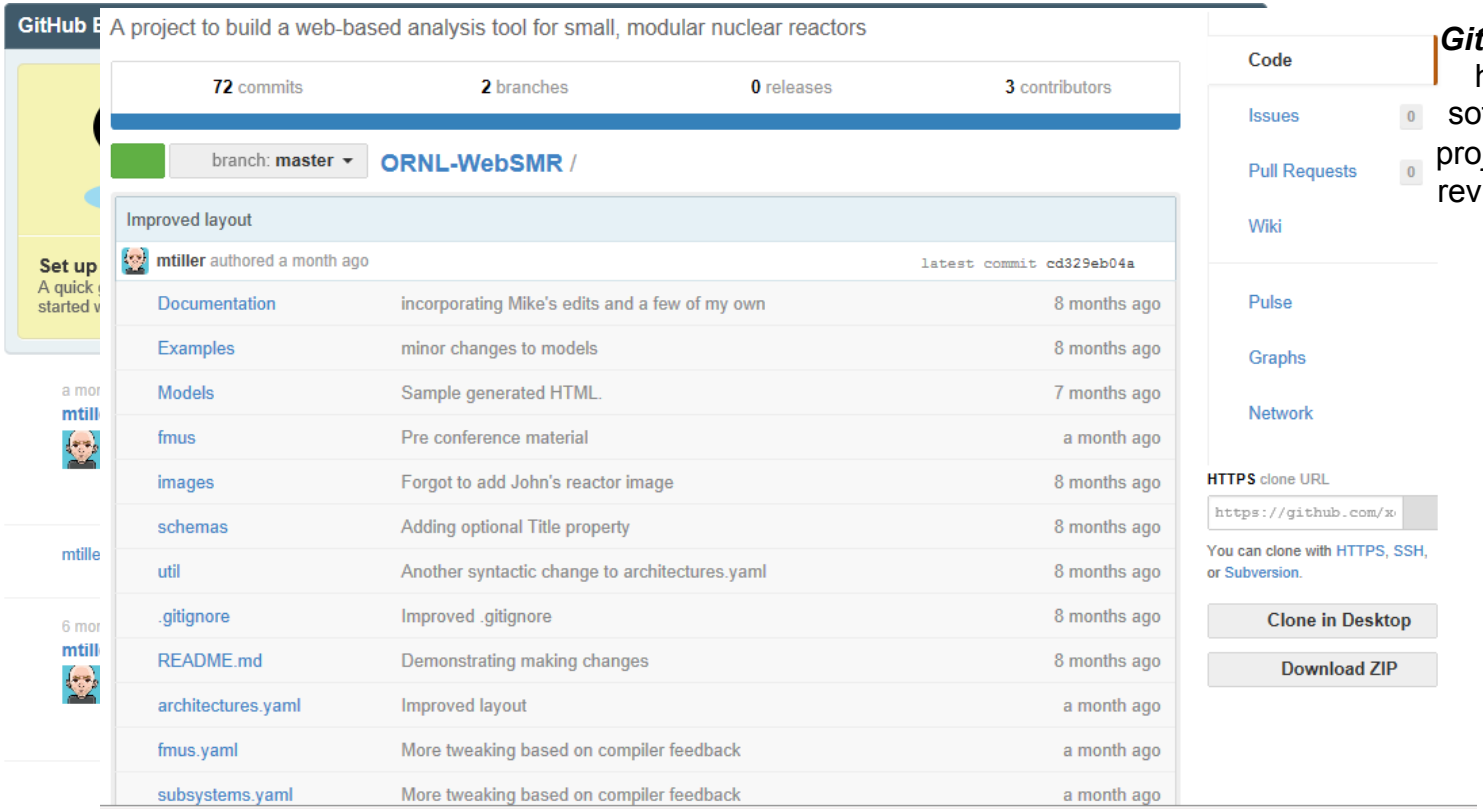
Sharing and Collaboration

Web-based model development collaboration through Github with open and secure repositories for proprietary and non-proprietary work

github SOCIAL CODING



GitHub is a web-based hosting service for software development projects that use the Git revision control system.

The final missing piece is creating a modeling environment that allows collaborative sharing and modification with version trontrol

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Conclusion

- ***The ORNL ModSim Tool creates a set of common tools to investigate advanced reactor concepts and applications***
- ***The tool saves time and money by giving researchers libraries of functioning models to begin with, modify and share***
- ***ModSim facilitates collaboration by***
  - *Using an open-source and emerging simulation environment*
  - *Having access via the internet*
  - *Having the ability to create models that operate within the Excel environment*

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