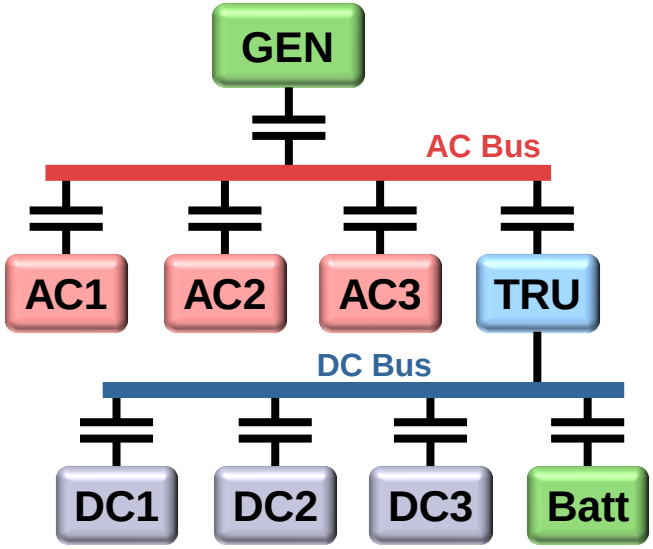
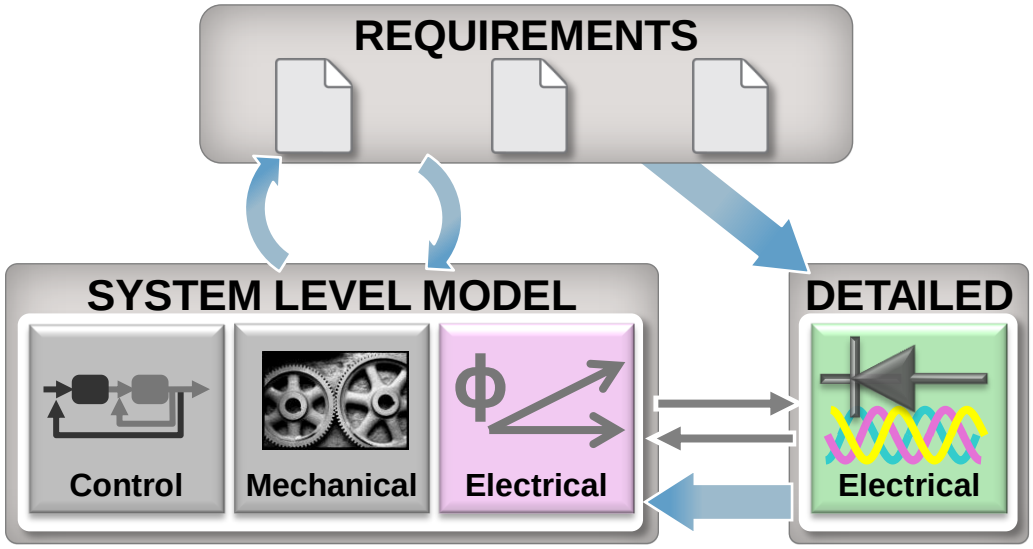




Aircraft Power Network Development with Model-Based Design

Steve Miller

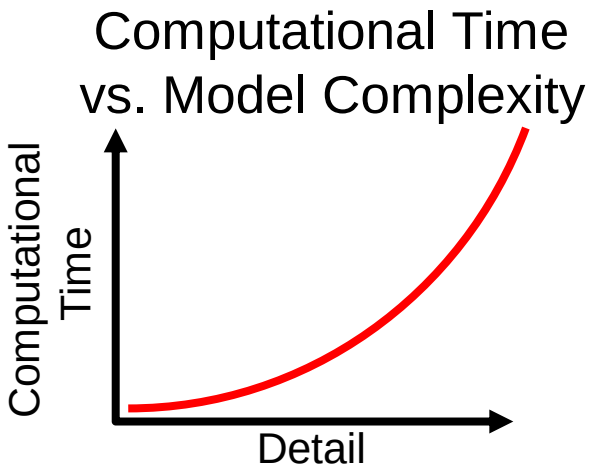
Technical Marketing, Physical Modeling

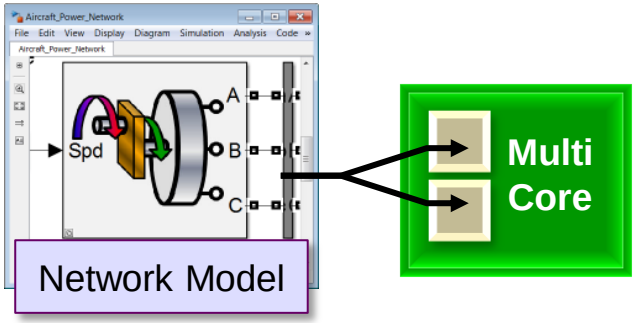
MathWorks

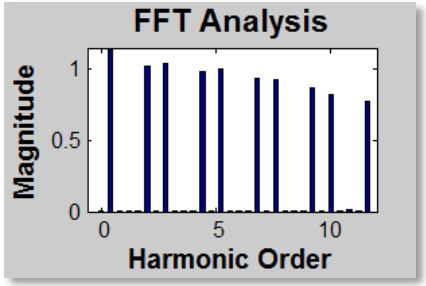
http://www.mathworks.com/physical-modeling/

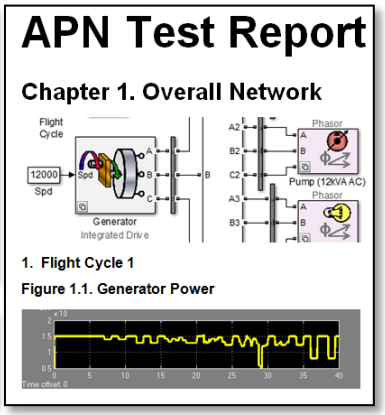
Key Points

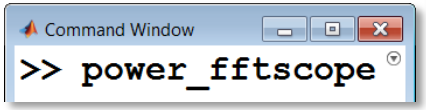
- Configure your model to balance model fidelity and simulation speed
- Accelerate your simulations using optimization algorithms and parallel computing
- Accelerate your development by automating simulation and analysis tasks using MATLAB®











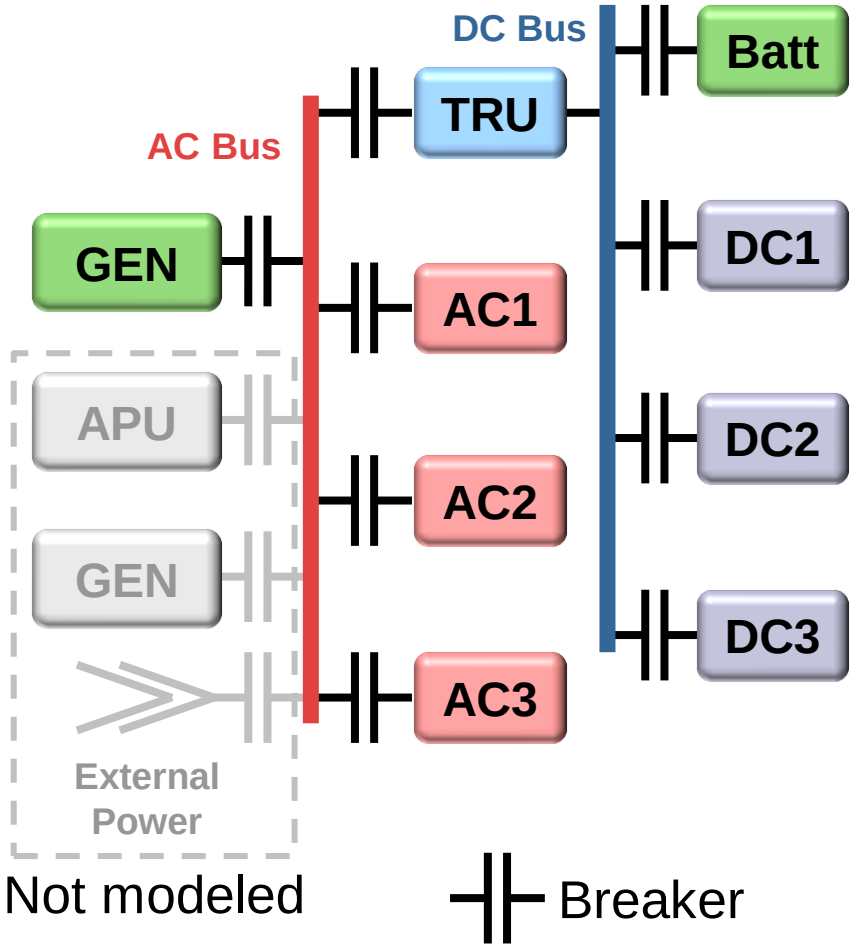
Agenda

- Overview: Aircraft Power Network Model
  - Simulation goals
  - Development process
- Initial Design
  - Linking to requirements
  - Refining requirements
- Detailed Design
  - Generators, loads
  - Harmonic analysis
  - Integrating other domains
- Tuning Abstract Model
- Documenting Results

Aircraft Power Network

System for Analysis

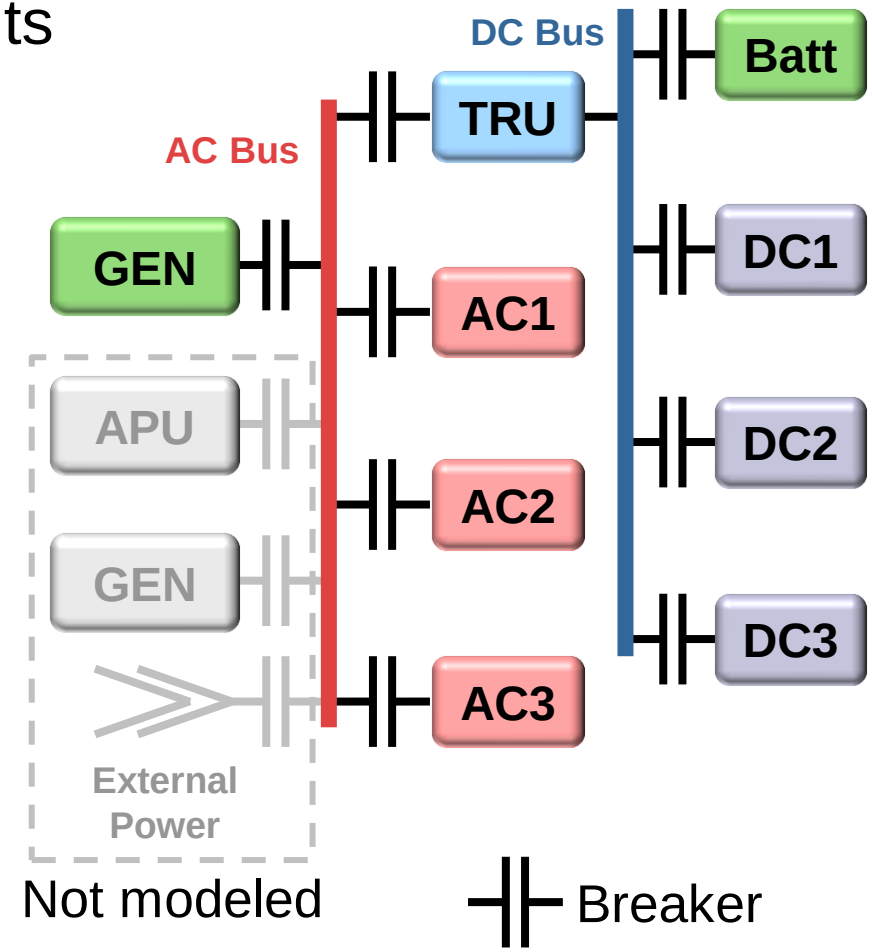
- Half-aircraft model
  - One generator
  - AC bus with loads
  - TRU (Transformer-Rectifier Unit)
  - DC bus with loads and battery
- Breakers open and close during flight cycle



Aircraft Power Network

Simulation Goals

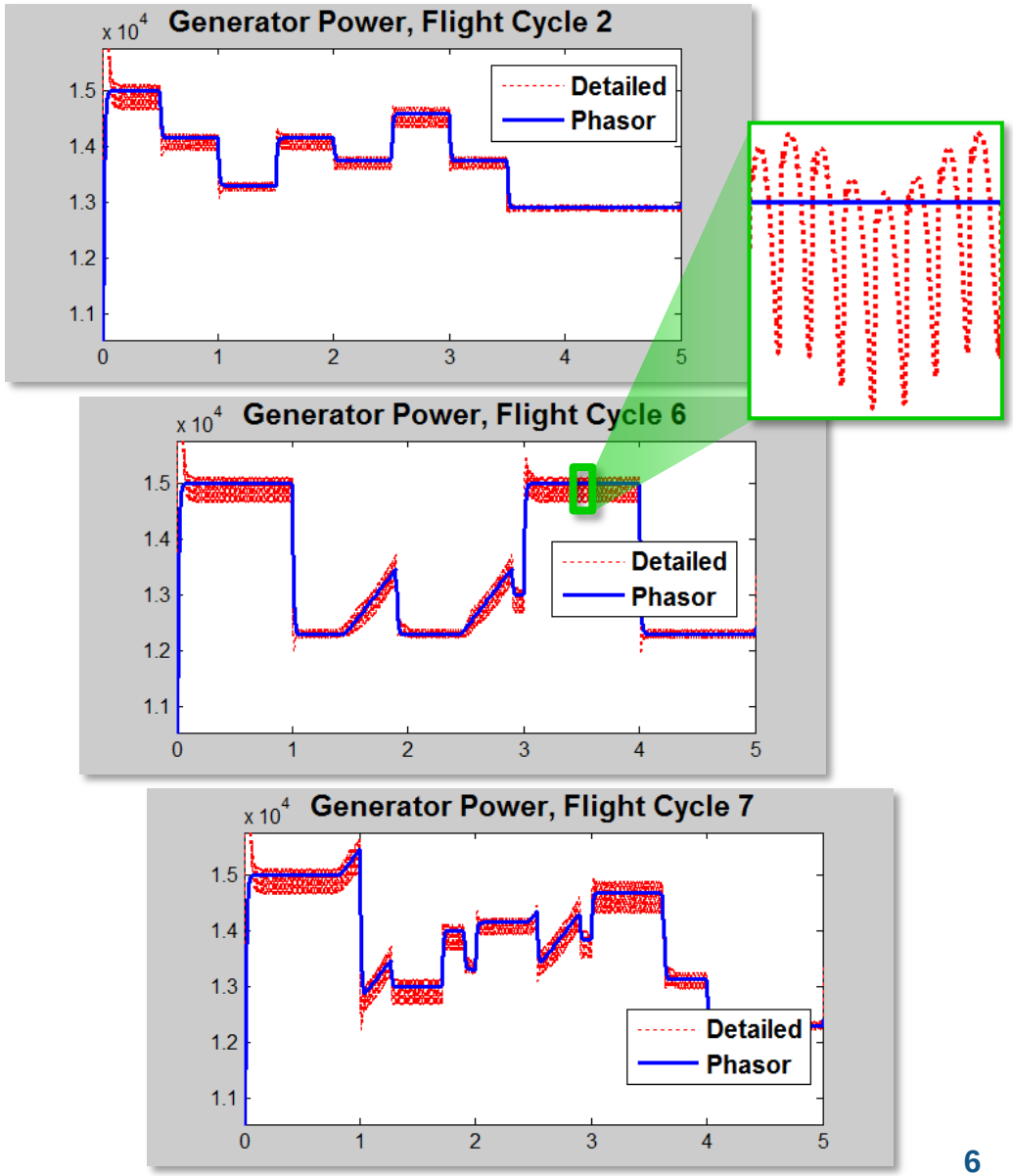
- Determine power requirements
  - Generator, loads, battery
  - Power lines
- Analyze system interactions
  - Electrical, mechanical, hydraulic, thermal, etc.
- Perform harmonic analysis
  - Varying conditions
  - Voltage and current at different nodes in network



Aircraft Power Network

Simulation Results

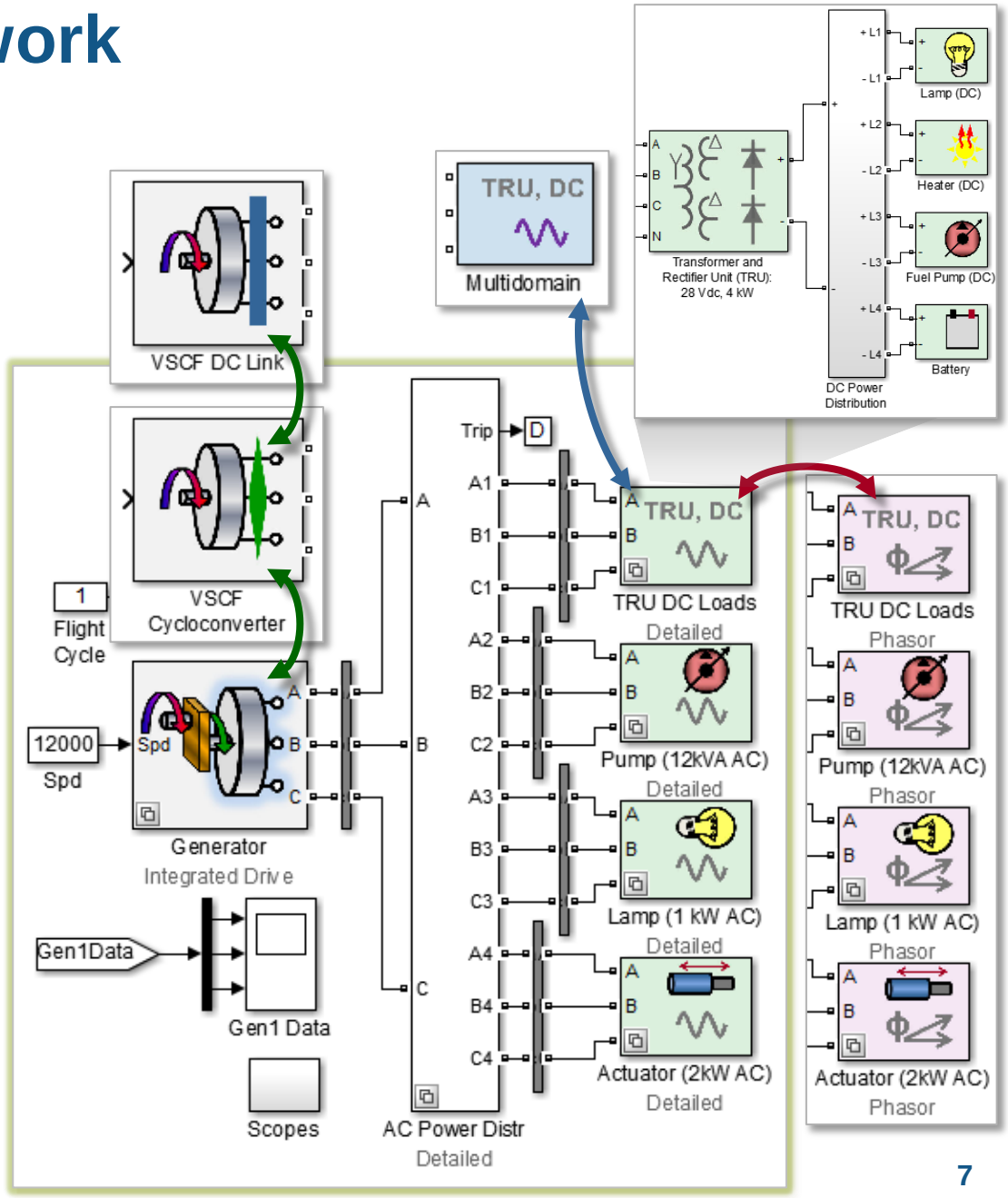
- Results from system-level and detailed models match
- Enables rapid iteration at system level and detailed analysis of electrical system



Aircraft Power Network

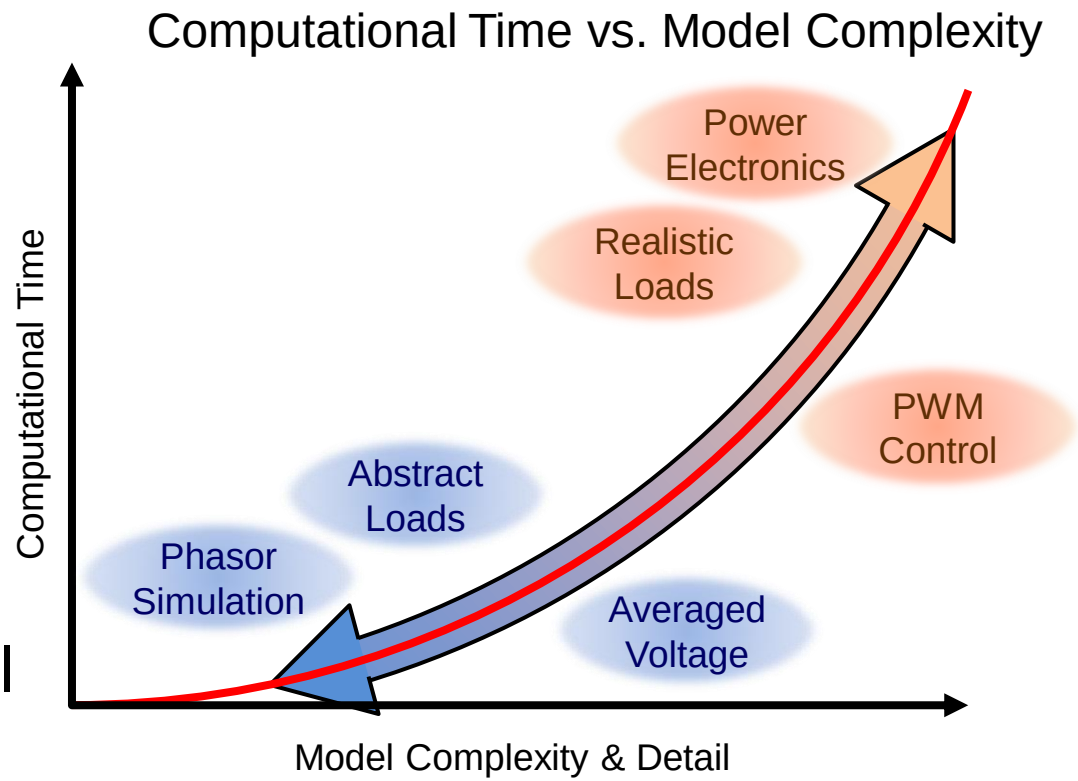
Simulation Model

- Generator
  - Integrated Drive
  - VSCF Cycloconverter
  - VSCF DC Link
- AC Loads
  - Detailed
  - Abstract
- DC Loads
  - Detailed
  - Abstract
  - Multidomain



Balancing Fidelity and Simulation Speed

- Key to effective use of simulation
  - Capture only the effects you need
  - Configure the model for your task
- MathWorks products enable you to select the right level of detail for your task

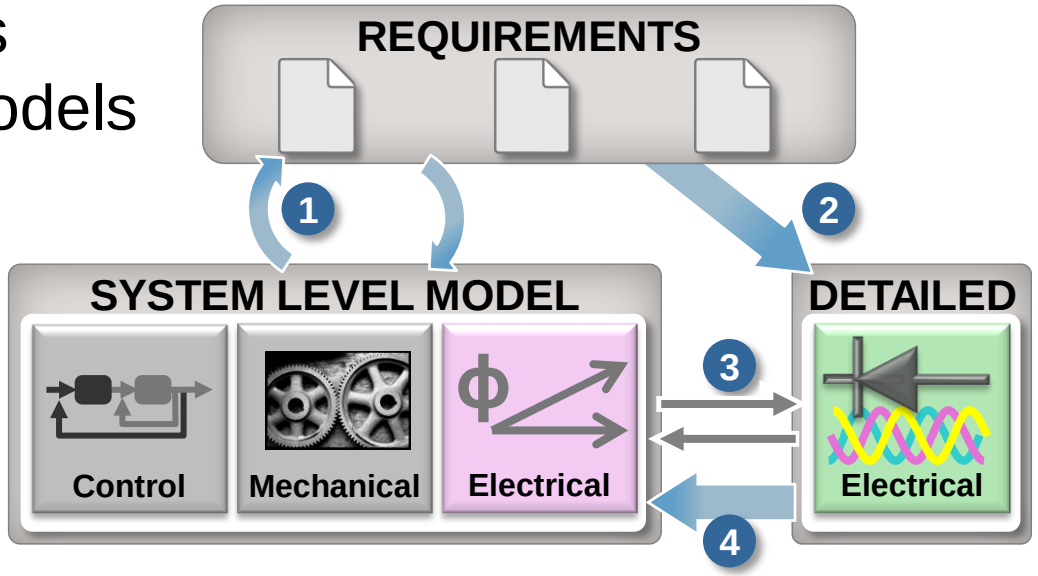


Configure your model to balance simulation speed and model fidelity.

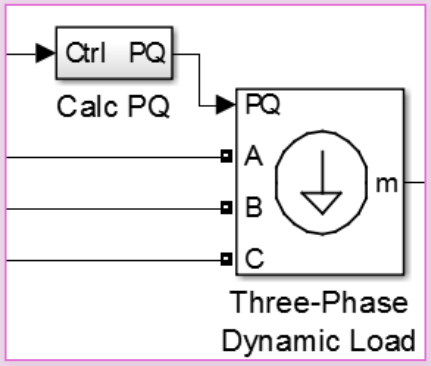
Balancing Fidelity and Simulation Speed

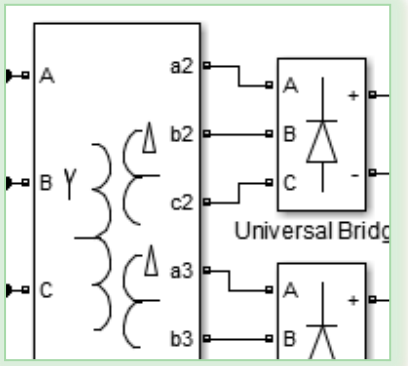
System and Component Level Design

- Design process requires abstract and detailed models
  1. Refine requirements (system level)
  2. Design component
  3. Combine as necessary
  4. Tune abstract model for rapid simulation



- System and detailed models are complementary
  - Match level of detail to simulation task





Airbus Develops A380 Fuel Management System Using Model-Based Design

Challenge

Develop a controller for the
Airbus A380 fuel management system.

Solution

Use MATLAB and Simulink to model and simulate the control logic, communicate the functional specification, and accelerate the development of simulators.

Results

- 100,000 tests run in parallel each weekend
- Months of development time eliminated
- Models reused throughout development
- Additional complexity handled without staff increases

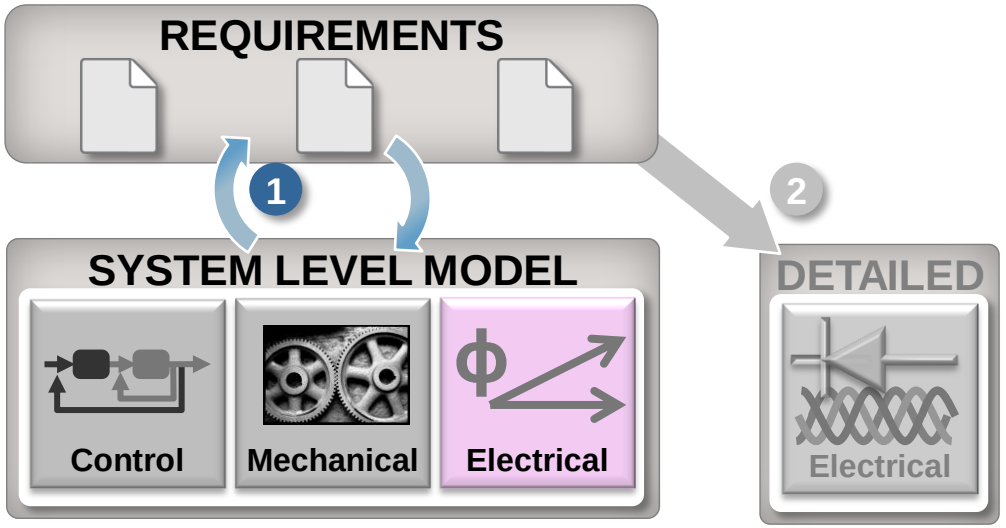
"Model-Based Design gave us advanced visibility into the functional design of the system. We also completed requirements validation earlier than was previously possible and simulated multiple simultaneous component failures, so we know what will happen and have confidence that the control logic will manage it."

Christopher Slack
Airbus

Link to user story

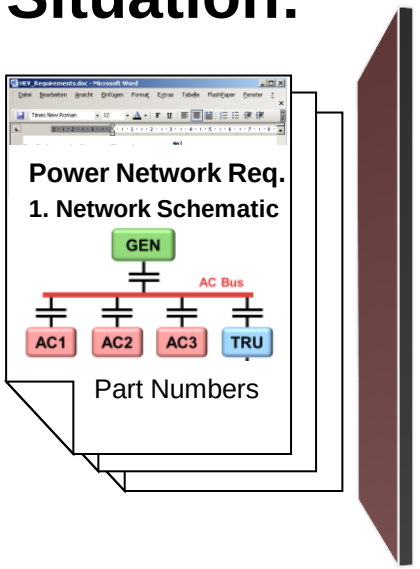
Agenda

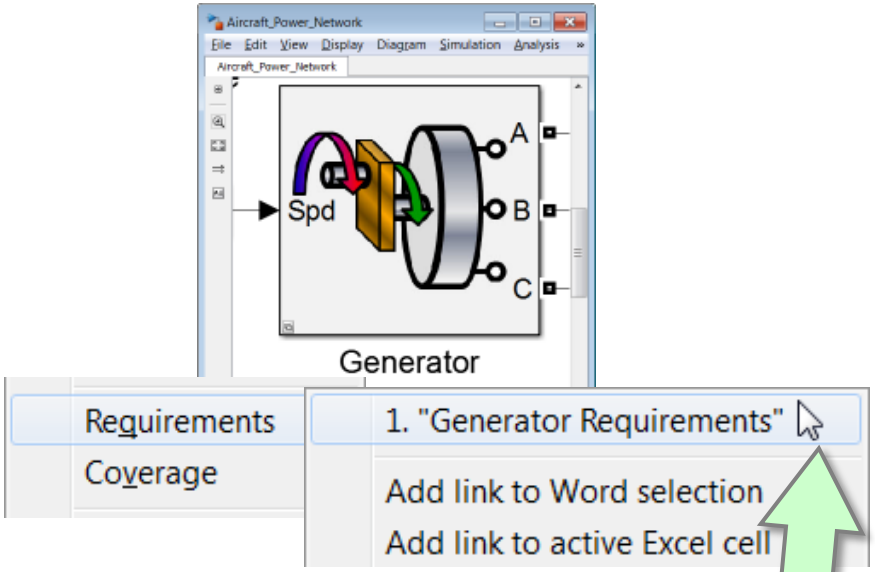
- Overview: Aircraft Power Network Model
  - Simulation goals
  - Development process
- Initial Design
  - Linking to Requirements
  - Refining Requirements
- Detailed Design
  - Generators, Loads
  - Harmonic analysis
  - Integrating other domains
- Tuning Abstract Model
- Documenting Results



Linking Specification and Design

Situation:



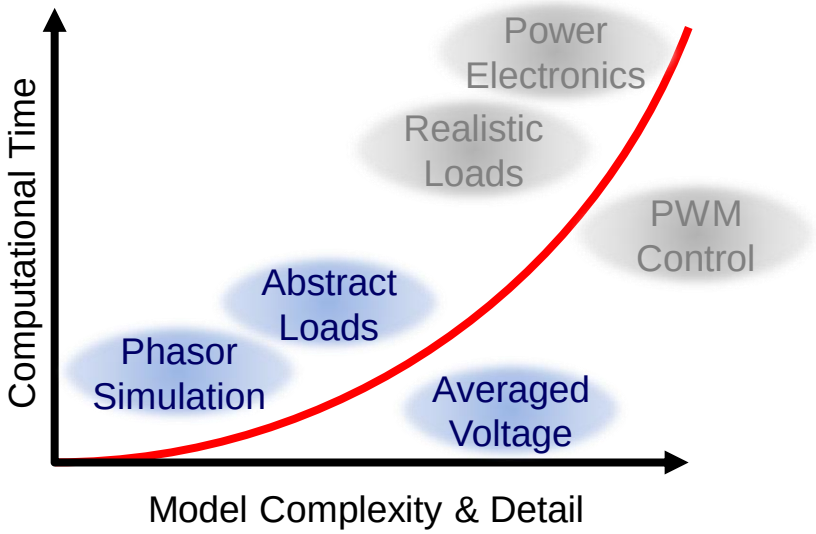


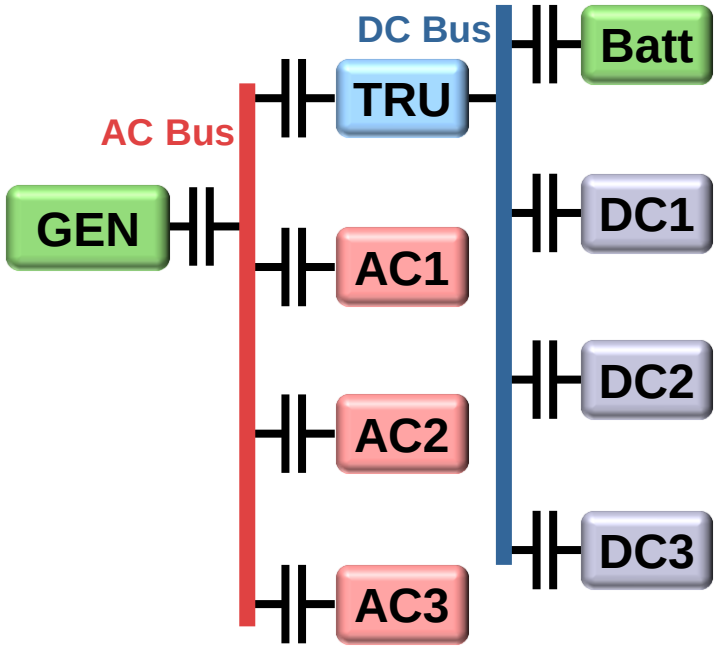
Problem: Difficult to compare design and specification.

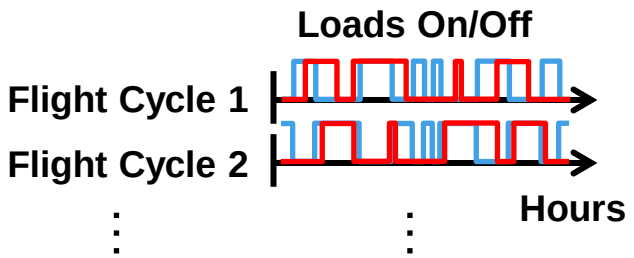
Solution: Use Simulink Verification and Validation to link the design and specification.

Refining Requirements for Power Network

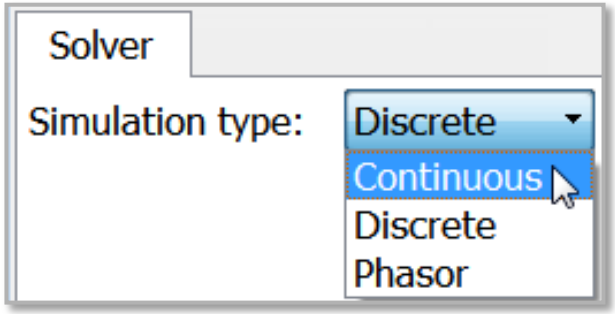
- Operating, peak, and design loads for generators and lines
  - Wide range of network conditions
  - Neglect power electronic switching
- Use abstract models and simulation methods



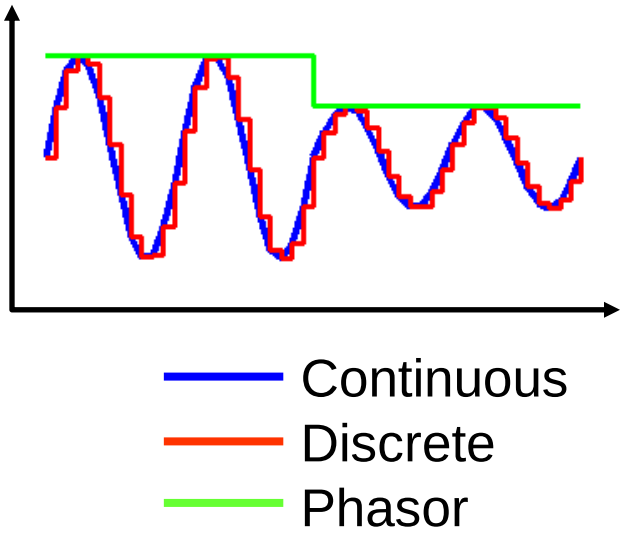




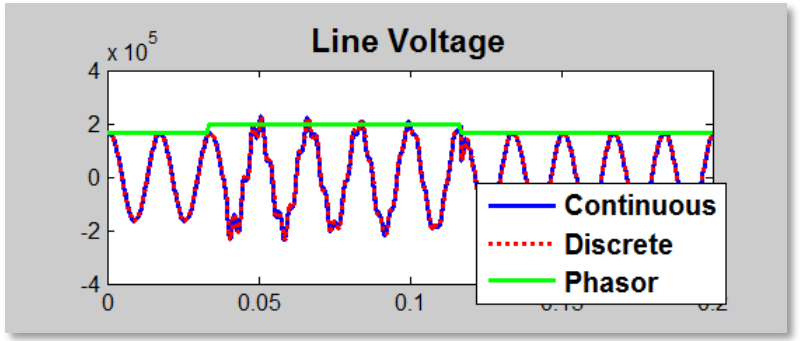
Simulation Modes



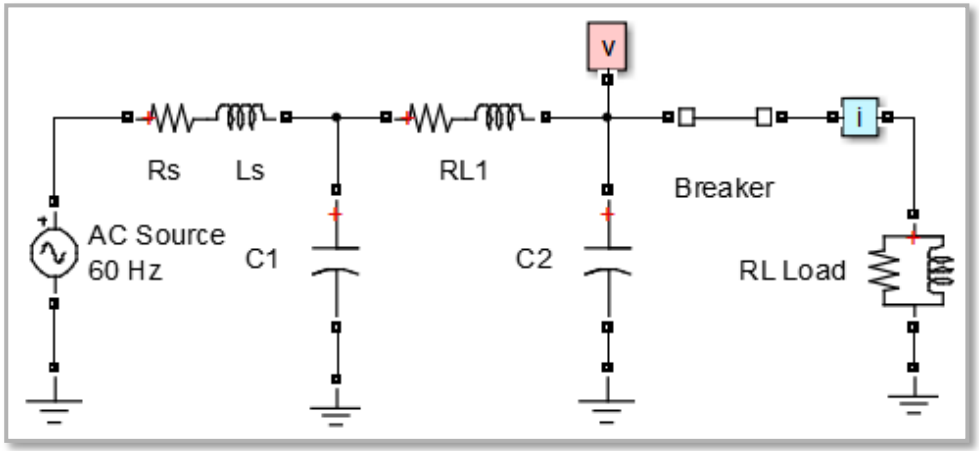
- Continuous: variable-step size
  - Accurate: step size shrinks to capture events
  - Speed depends on # of continuous states and dynamics
- Discrete: fixed-step size
  - Fewer computations per step
  - Very scalable, good for large systems
- Phasor: simplified set of equations
  - Uses algebraic equations to represent voltage and current as phasor
  - Very fast, but solution only at a specific frequency

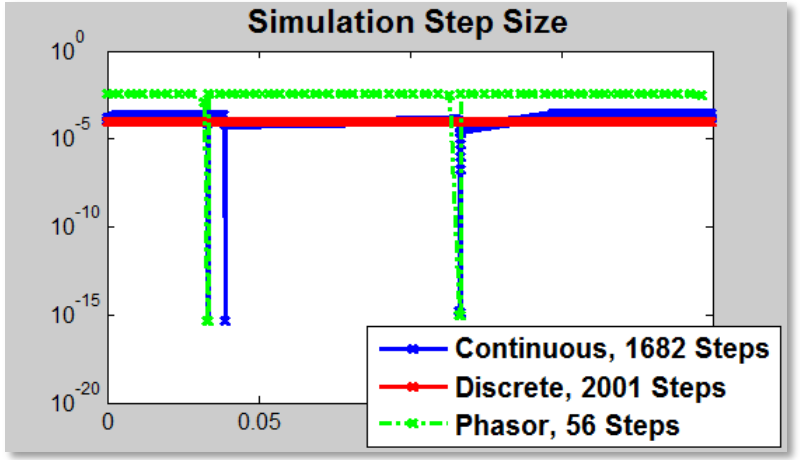


Selecting Simulation Mode



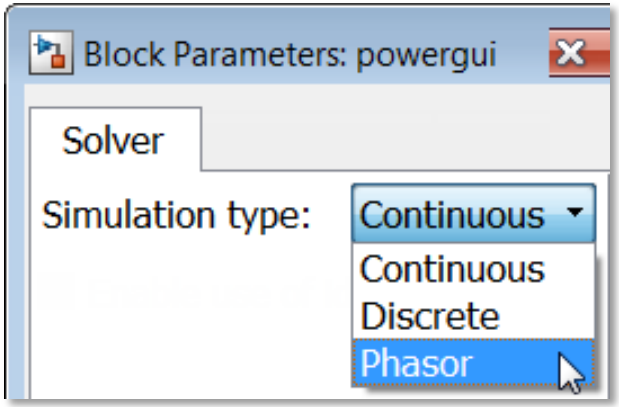
Situation:



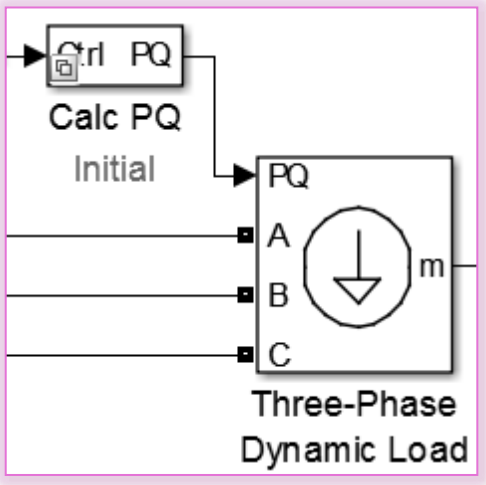


Problem: Analyze transient effects and magnitudes of circuit voltages

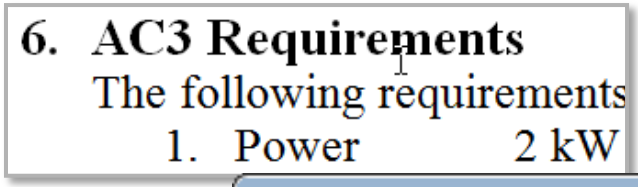
Solution: Select the SimPowerSystems™ simulation mode that is appropriate for the analysis

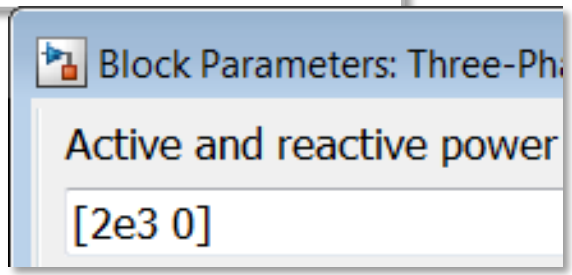


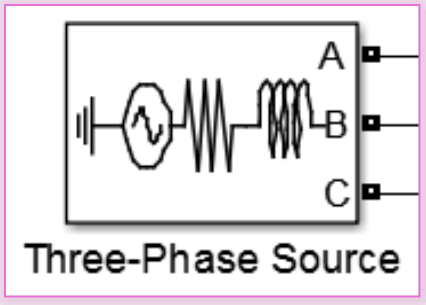
Generic Abstract Model
AC Loads, Sources



- Dynamic Load provides generic abstract model
  - Specify active and reactive powers by signal or voltage sequence
  - Use to define source or load
  - Define initial abstract model based on requirements
- Ideal source enables calculation of generator requirements



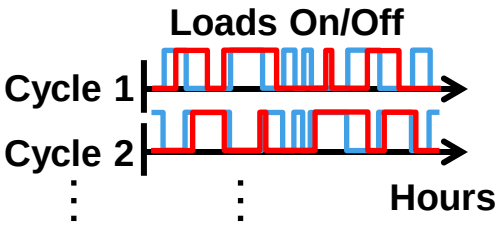


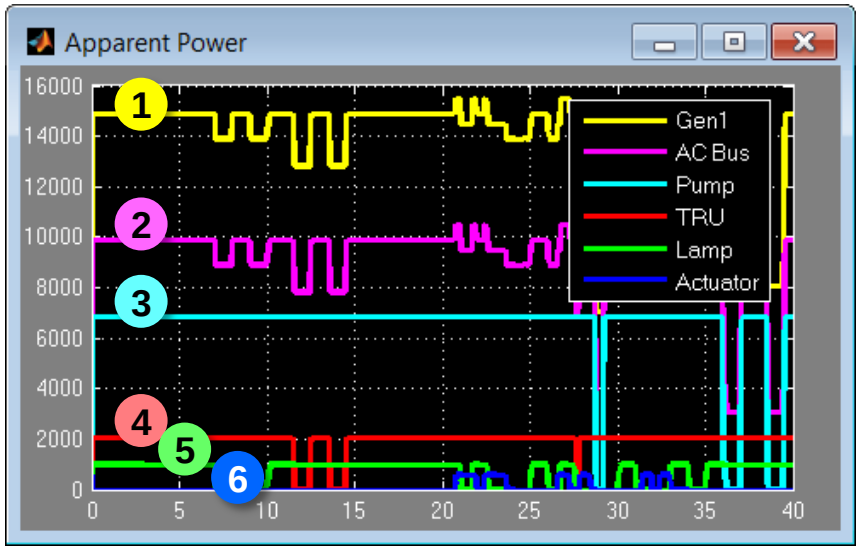


Refining Power Requirements for Generator, Lines

Situation:

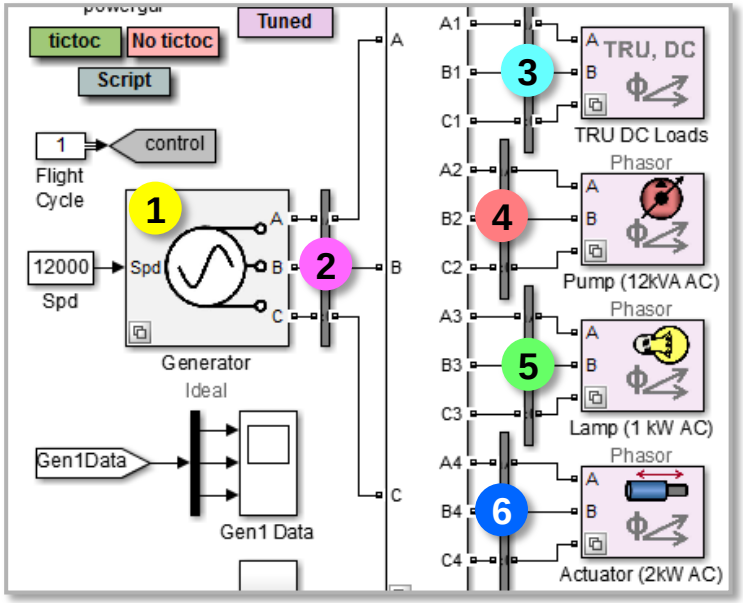
Unit	Rated	PF	Eff.	Duty
TRU	2kW	0.95	0.8	Continuous
Pump	6.8kW	0.95	0.8	Standby
Gen1	50kW	0.9	0.9	Continuous
Lamp	2kW	1	0.9	Intermittent





Problem: Refine initial requirements by testing a wide range of conditions

Solution: Use abstract loads, sources, and phasor simulation to refine power requirements



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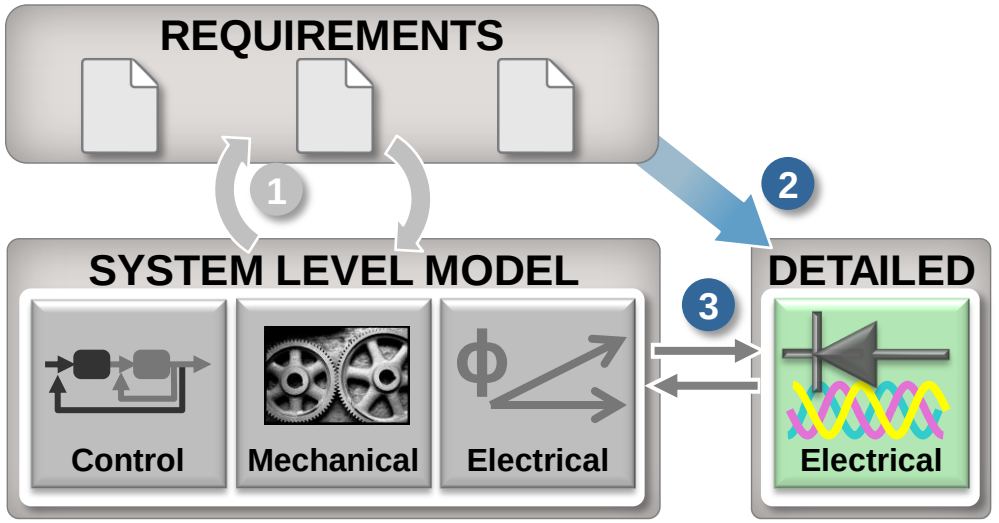
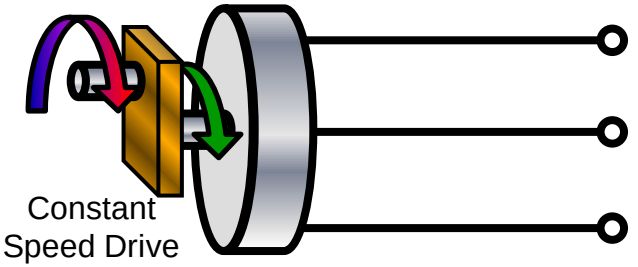


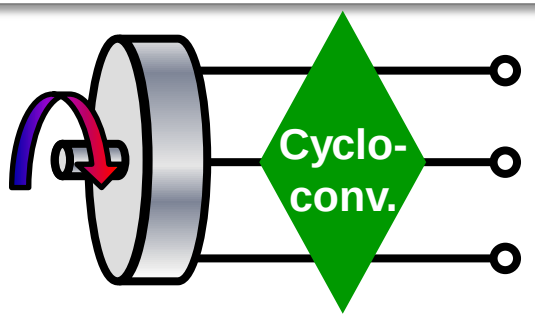
Aircraft Power Generation
Options

- Several options currently in use (commercial, military)
- Common components:
  - Generator
  - Power electronics to convert power

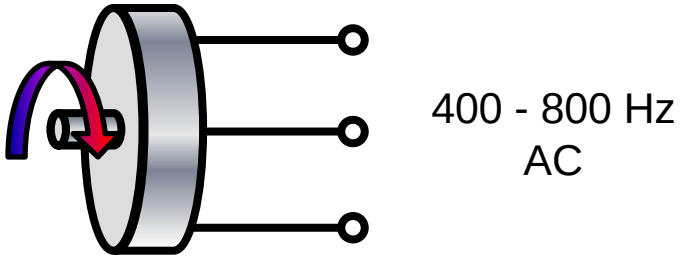
Integrated Drive Generator



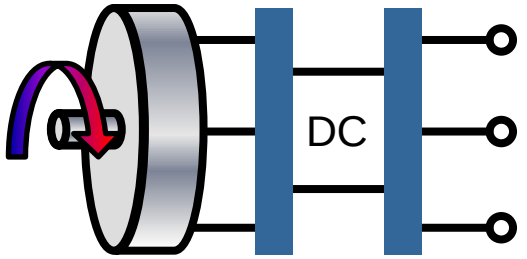
VSCF[1] Gen., Cycloconverter



Variable Frequency Generator



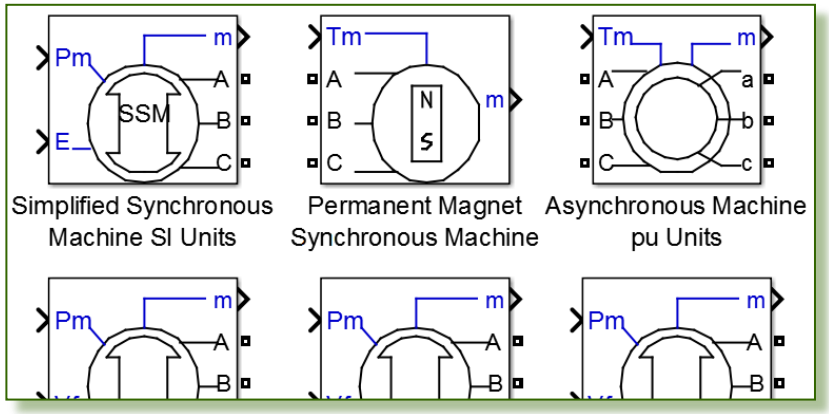
VSCF Gen., DC Link

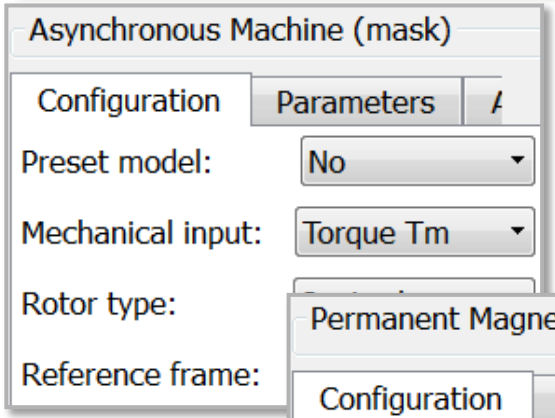


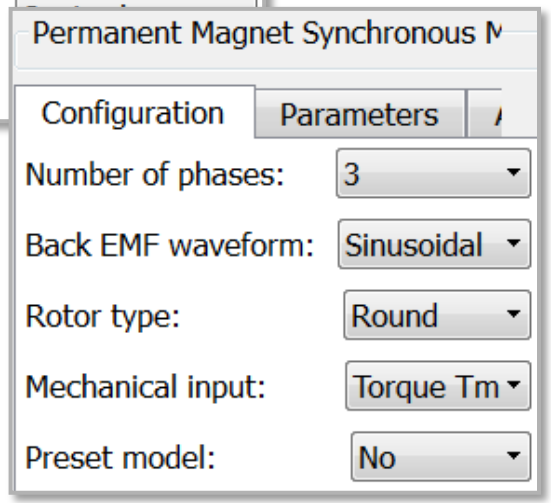
[1]Variable Speed Constant Frequency

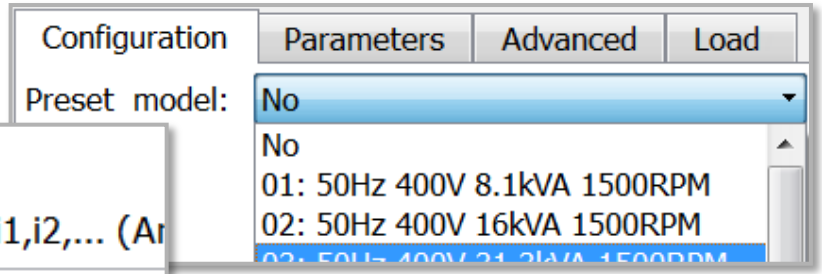
Power Generation
Machines Library

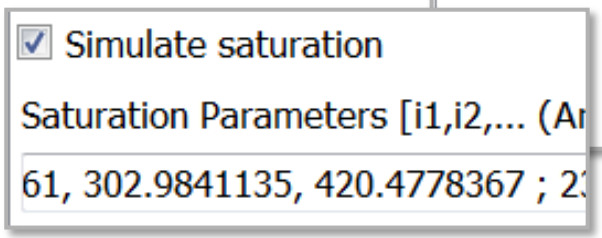
- Many types provided
  - Synchronous, Asynch., PMSM…
  - Excitation models (AC1A, etc.)
- Many parameterization options
  - Types, phases, inputs …
  - Preset models
  - Enable/Disable effects





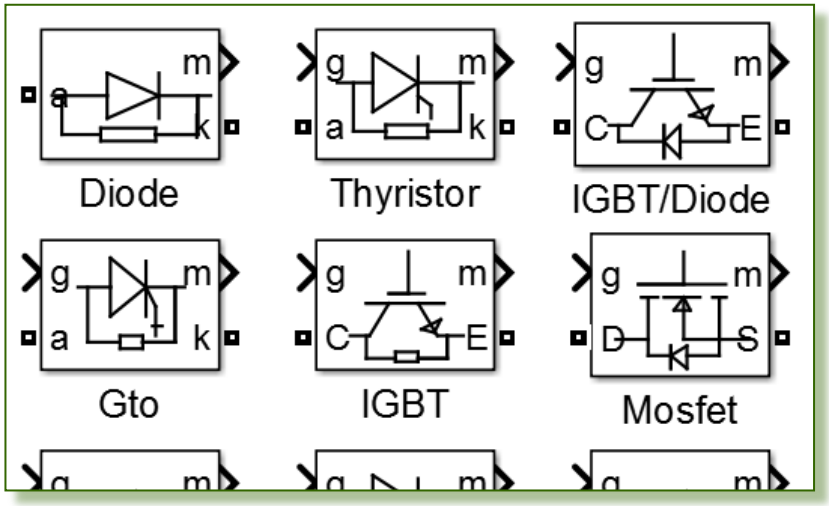


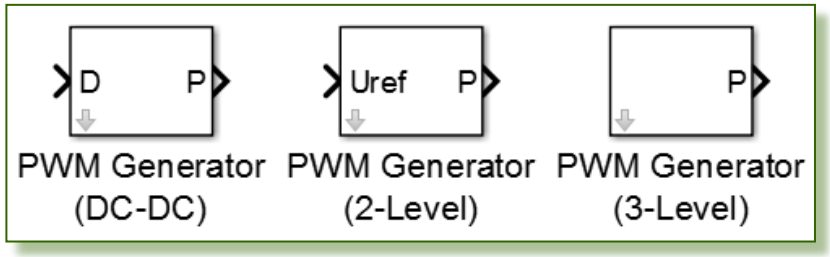


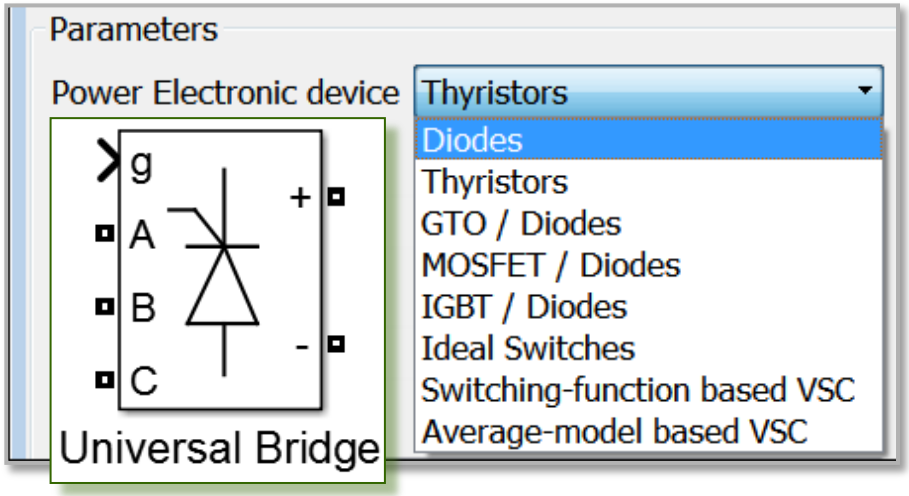


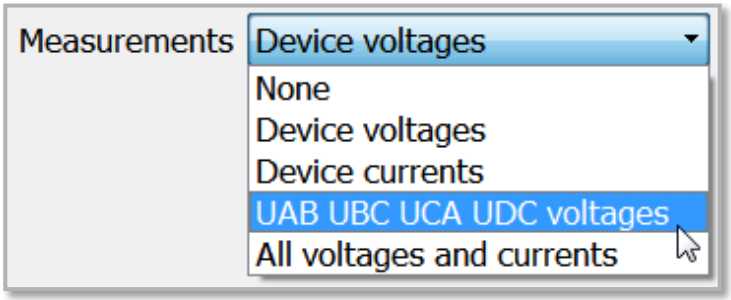
Power Electronics

- Many devices provided
  - Diode, thyristor, IGBT, MOSFET
  - PWM and signal generators
- Configurable bridges
  - Select device type
  - Switching function and Average-model options for increased speed
  - Log internal measurements



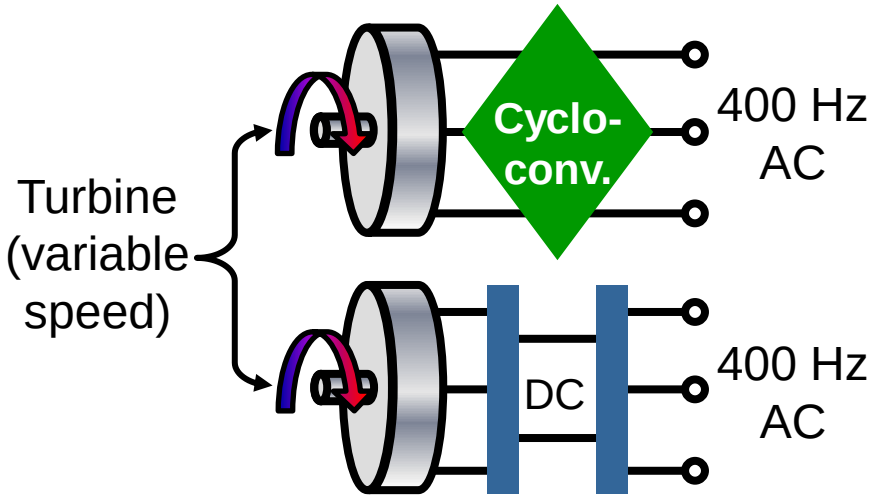


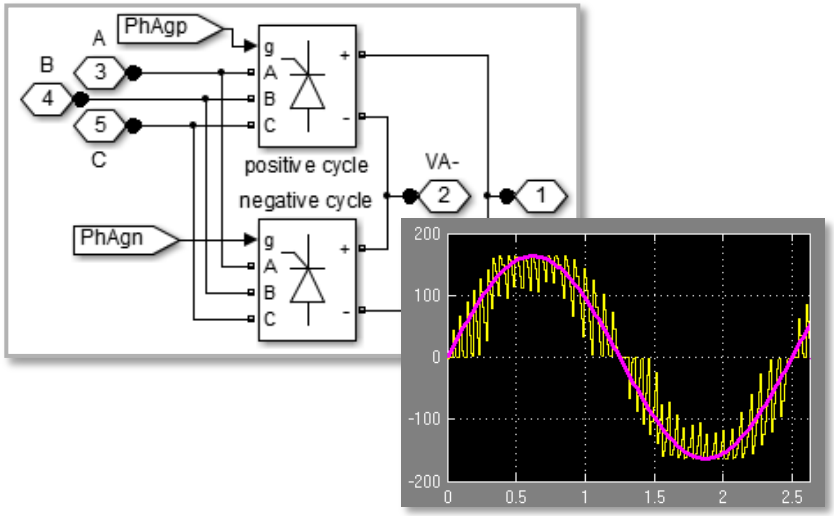


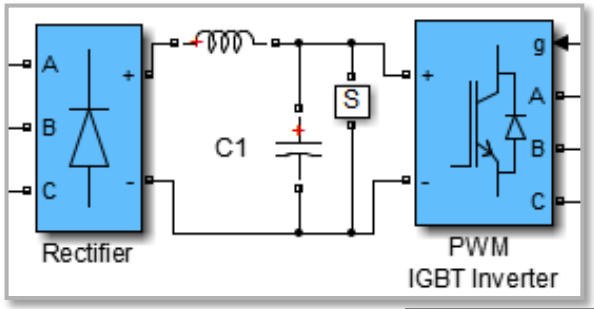


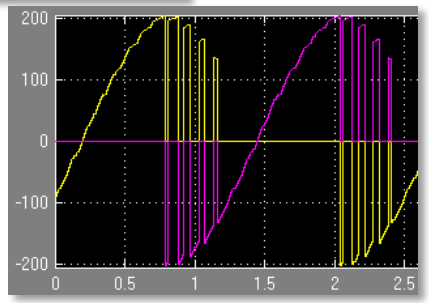
Modeling Power Generation

Situation:







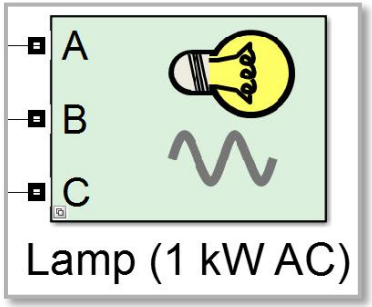


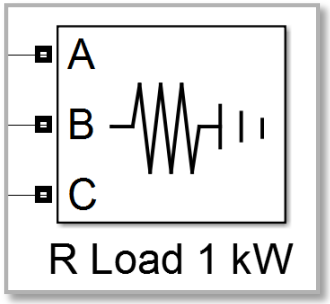
Problem: Evaluate options for generating AC power for network

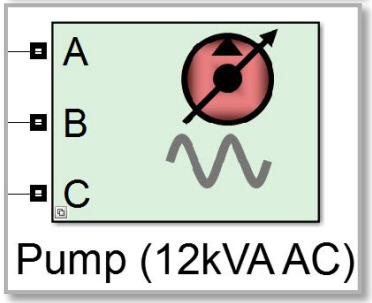
Solution: Use SimPowerSystems to model, simulate, and evaluate options

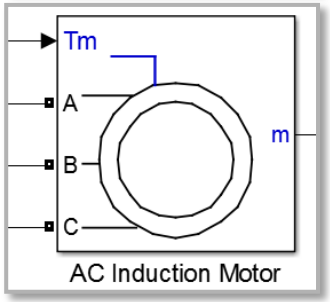
AC Loads

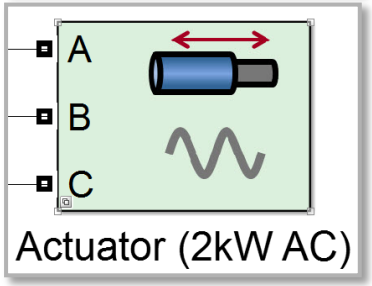
- Options for AC loads include:
  - RLC loads and branches
  - Transformers
  - Machines
  - Drives
    (machine + converter + control)
- Many configuration options
  - Configurations and fidelity

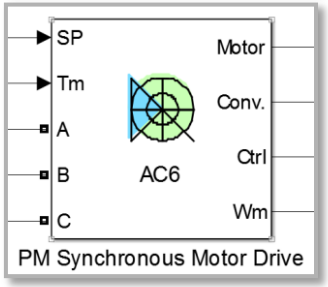


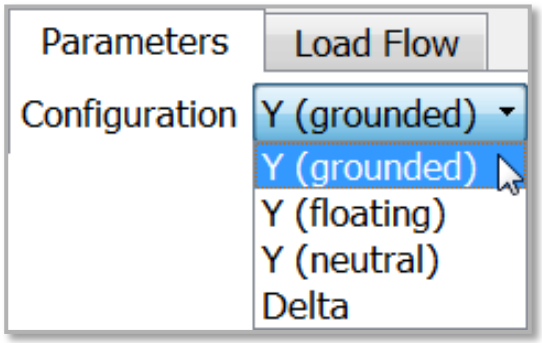


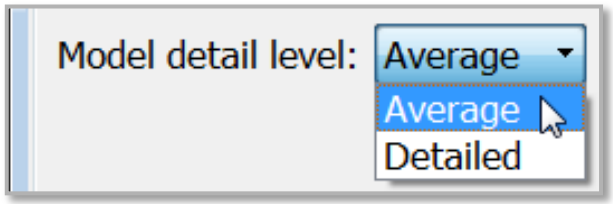




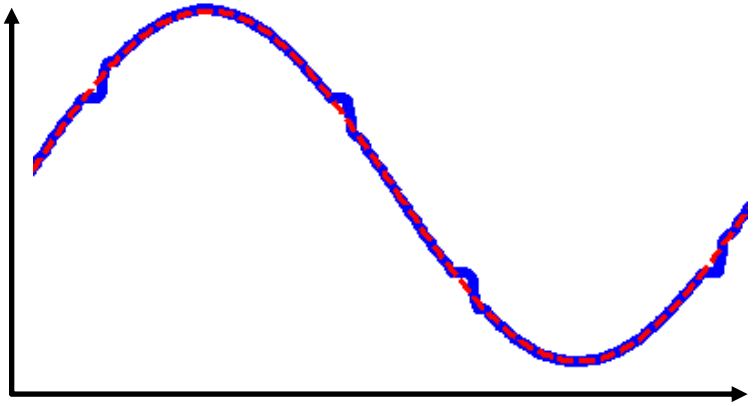




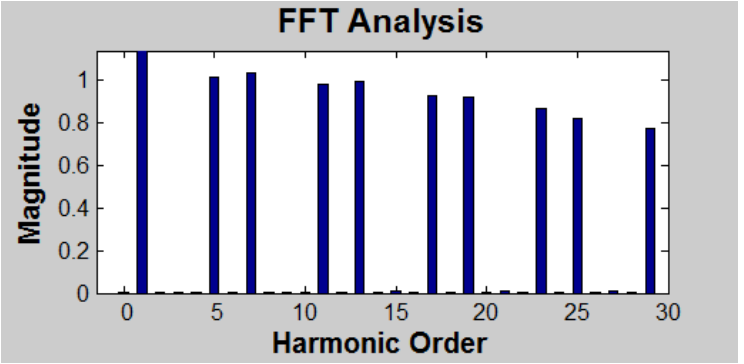




Analyzing Power Quality
Total Harmonic Distortion (THD)

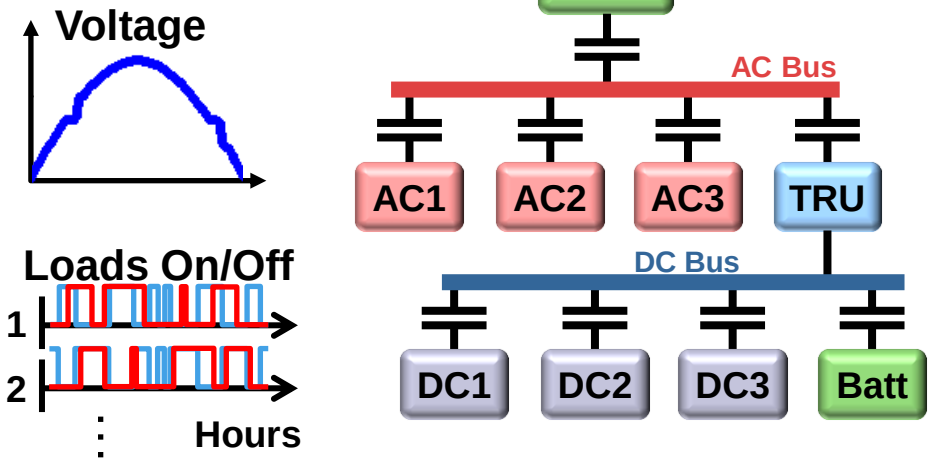


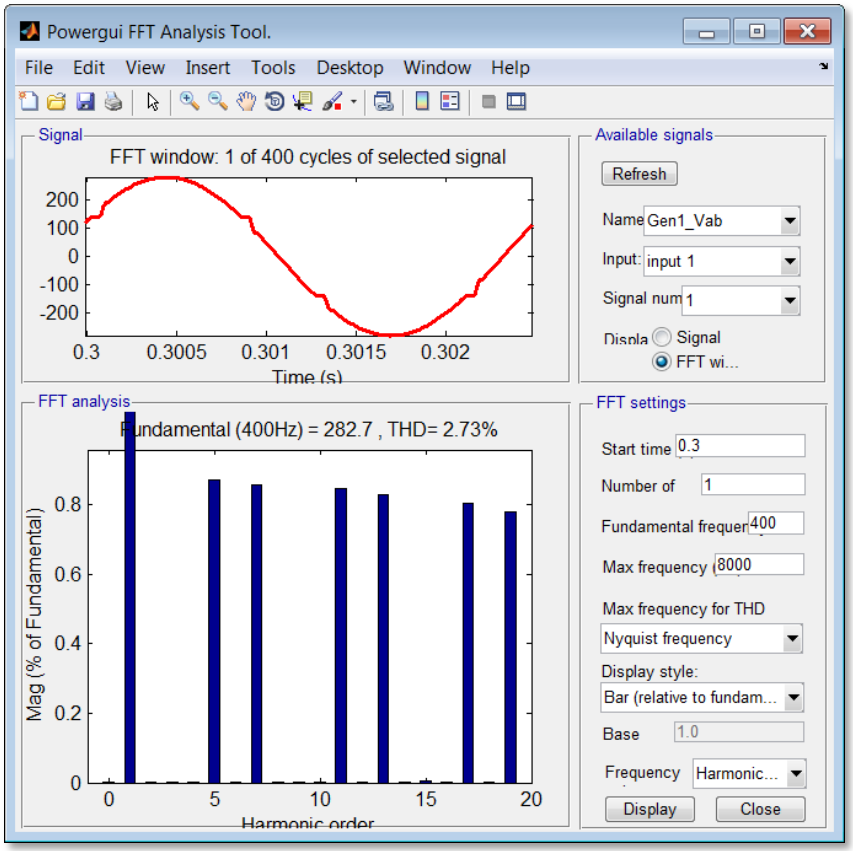
- Loading can cause distortion of supply voltage waveform
- Effects of poor power quality
  - Heating in generator
  - High neutral currents
  - Unnecessary switching in power electronics
- THD provides a measure of AC power quality
  - Important to measure under varying network conditions
  - Easy to calculate with MathWorks products



Analyzing Power Quality

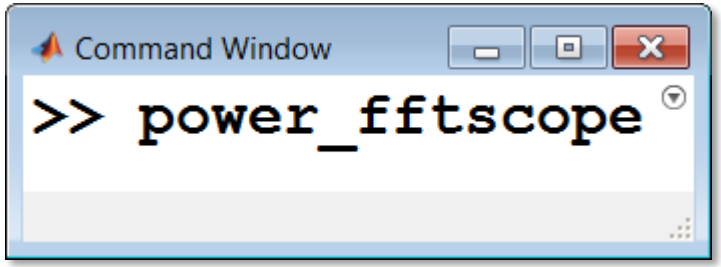
Situation:





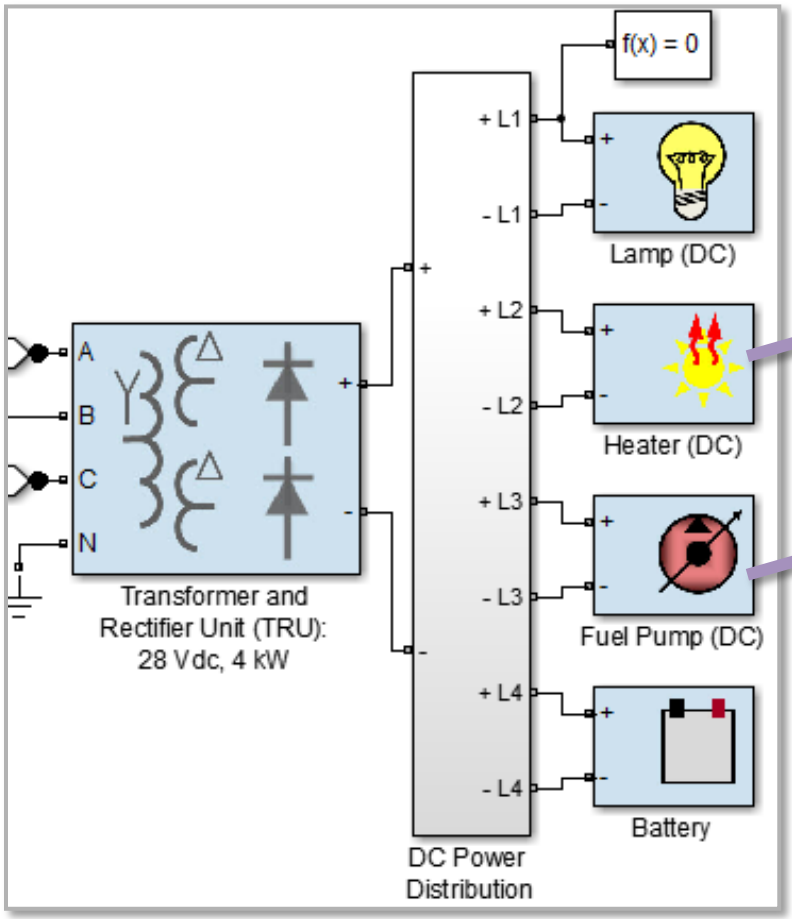
Problem: Evaluate power quality within network under various conditions

Solution: Use SimPowerSystems and MATLAB to automate calculation of total harmonic distortion (THD)



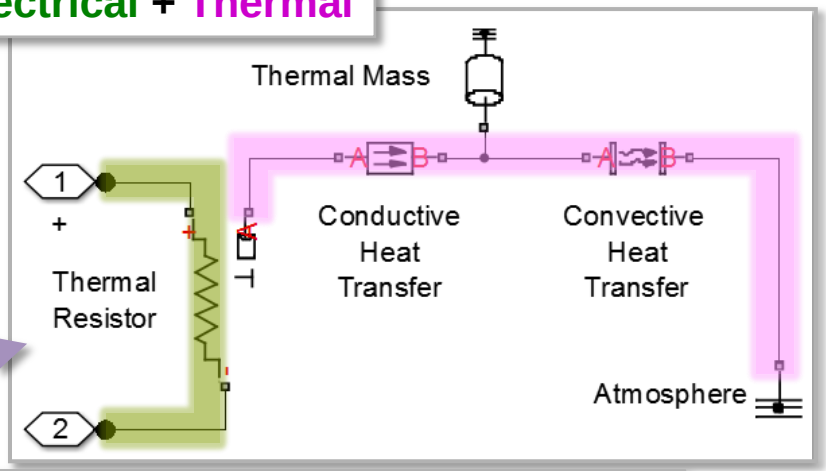
DC Loads

- Pure electrical and multidomain options

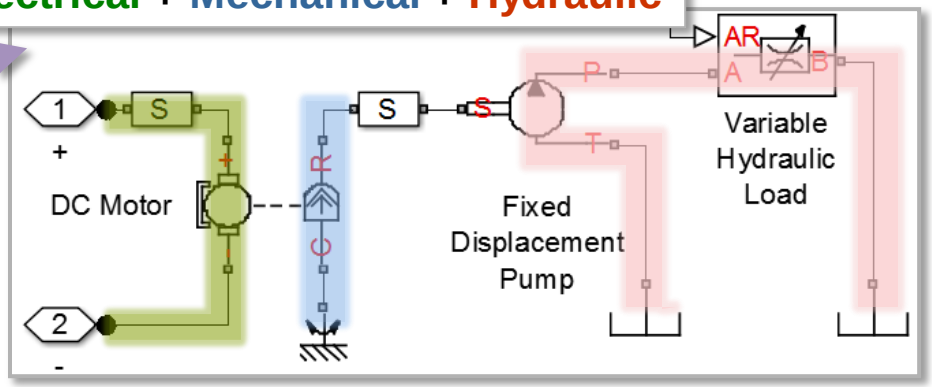


Multidomain

Electrical + Thermal

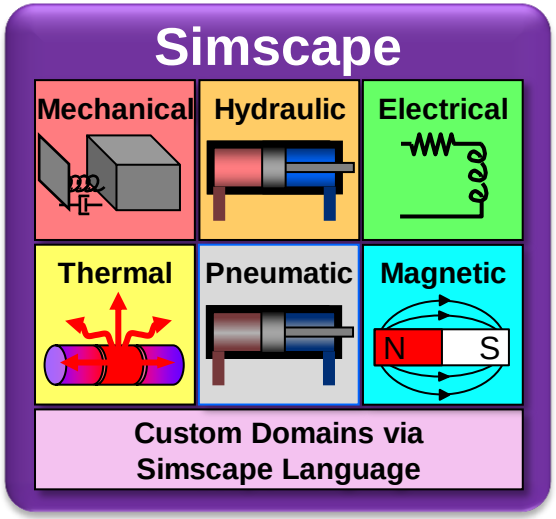


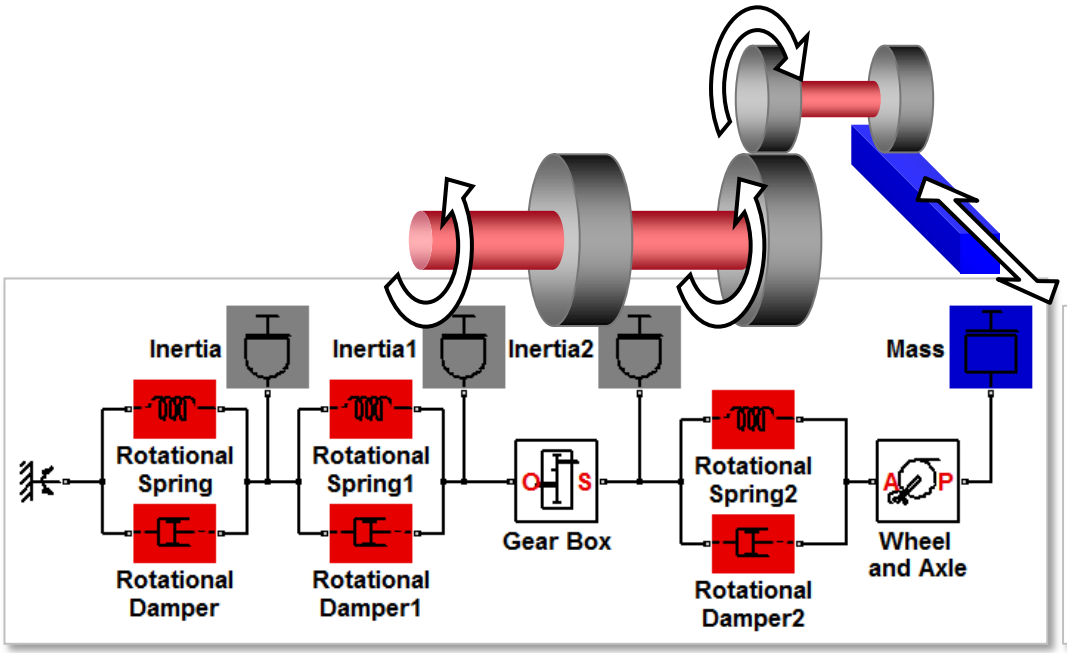
Electrical + Mechanical + Hydraulic

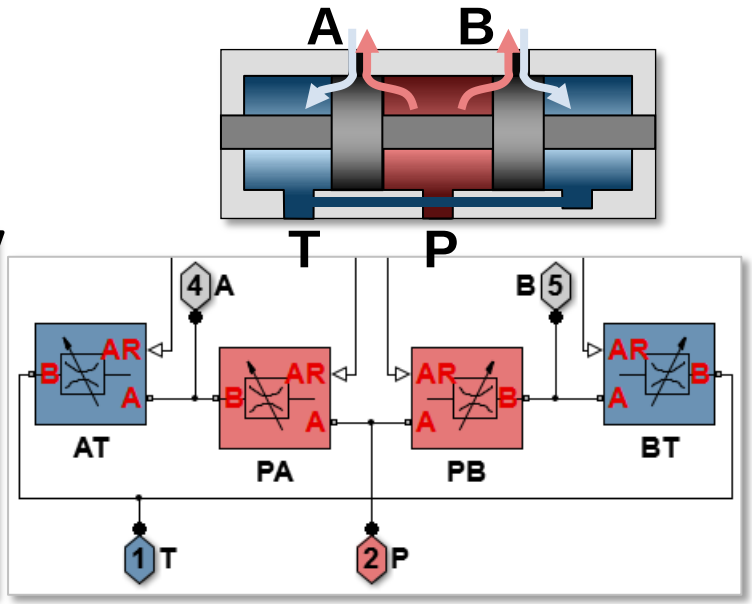


Modeling Physical Systems

- Foundation library of physical elements
  - Mechanical, hydraulic, electrical…
- Create custom components using Simscape™ Language

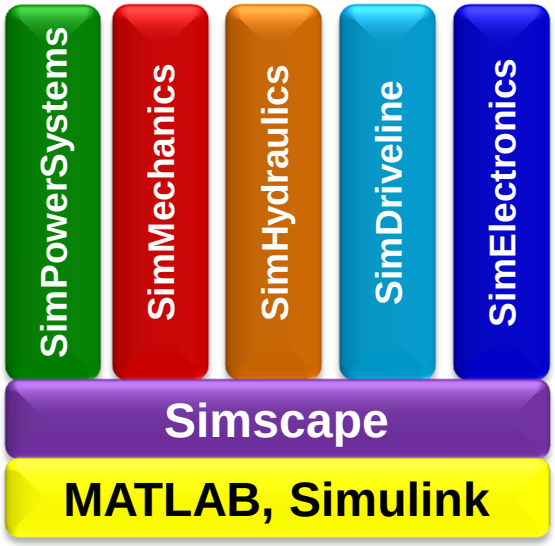


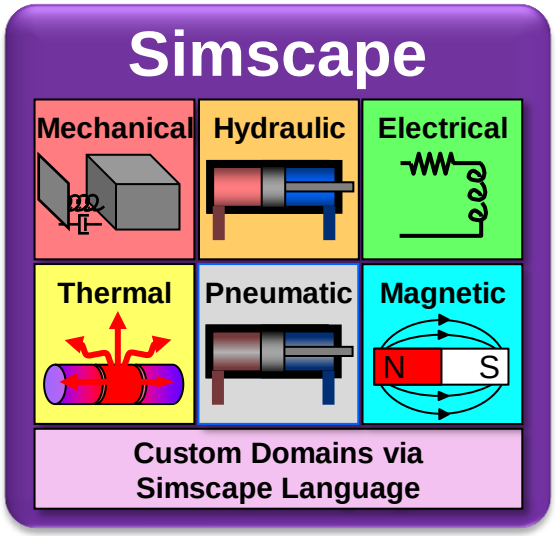




Simscape Add-on Libraries

- SimDriveline™
  - Gears, leadscrew, clutches, tires, engines
- SimElectronics®
  - Actuators, sensors, and semiconductors
- SimHydraulics ®
  - Pumps, actuators, pipelines, valves, tanks
- SimMechanics™
  - Multibody systems: joints, bodies, frames
- SimPowerSystems™
  - Three-phase electrical networks

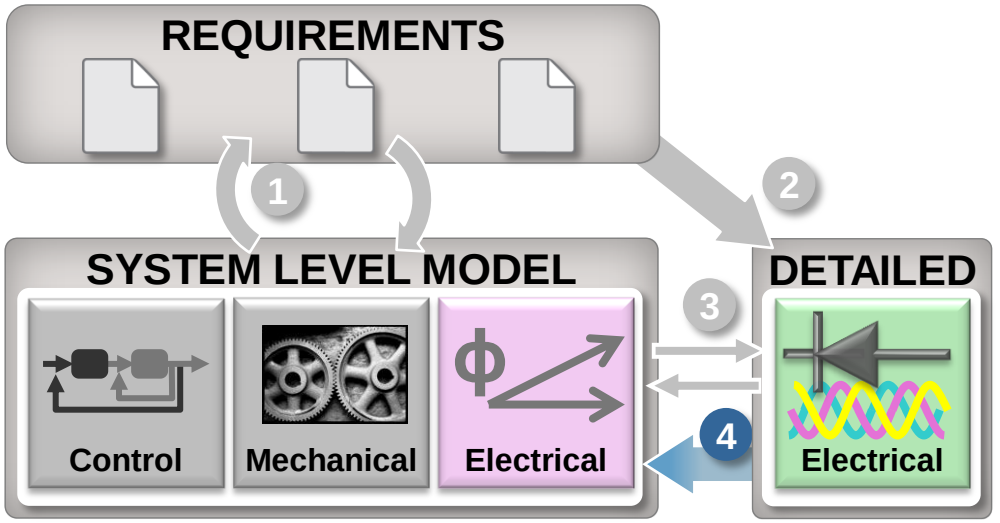




Multidomain physical systems

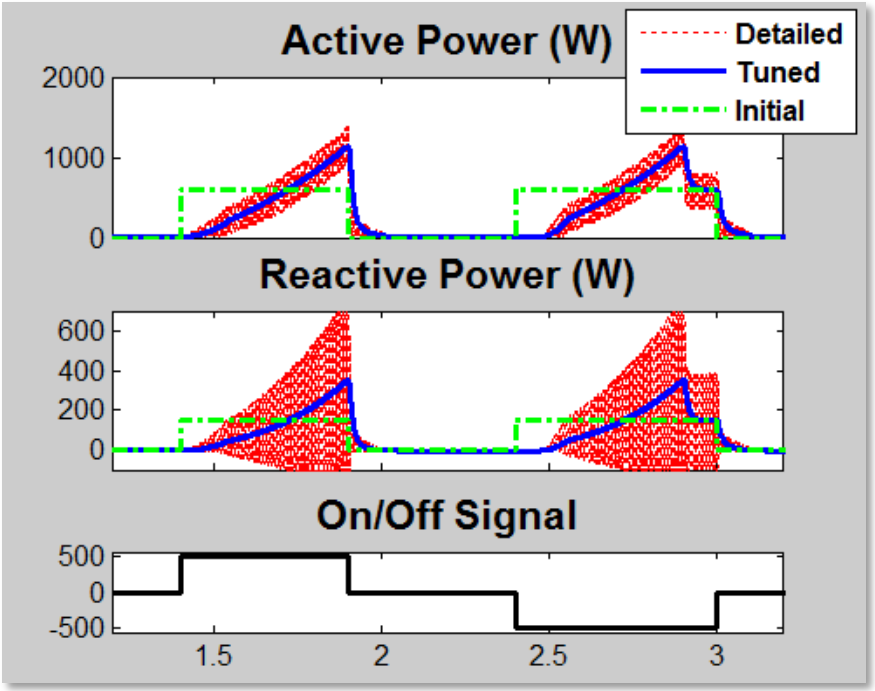
Agenda

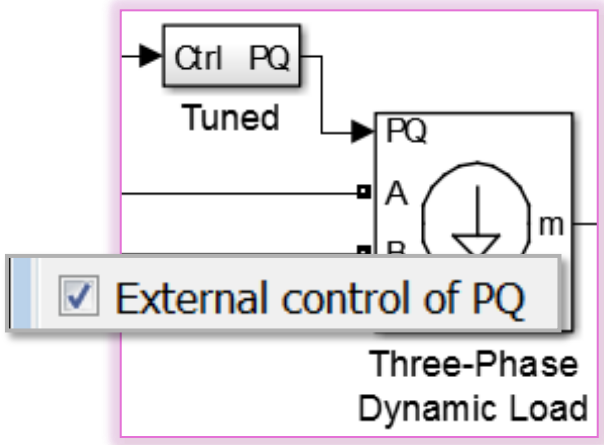
- Overview: Aircraft Power Network Model
  - Simulation goals
  - Development process
- Initial Design
  - Linking to Requirements
  - Refining Requirements
- Detailed Design
  - Generators, Loads
  - Harmonic analysis
  - Integrating other domains
- Tuning Abstract Model
- Documenting Results



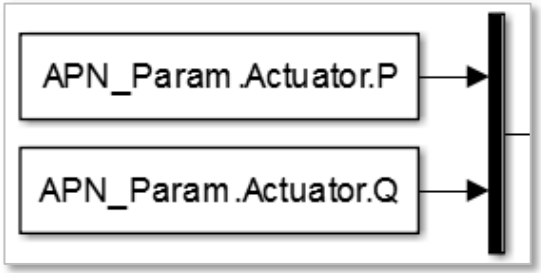
AC Loads
Tune Abstract Model

- Need to refine initial abstract model to match detailed simulation results
  - Specify active and reactive powers using input signal
  - Tune to match behavior of detailed design

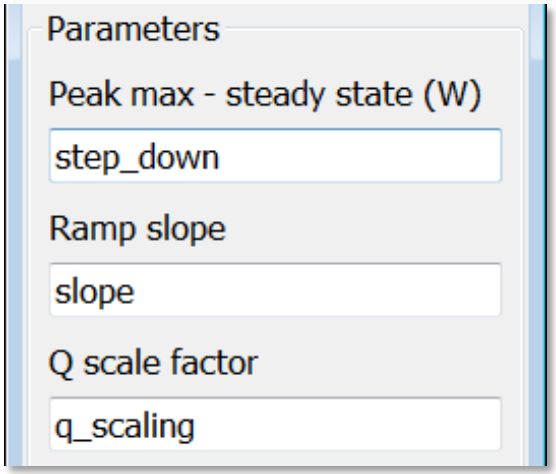




Initial Abstract Model

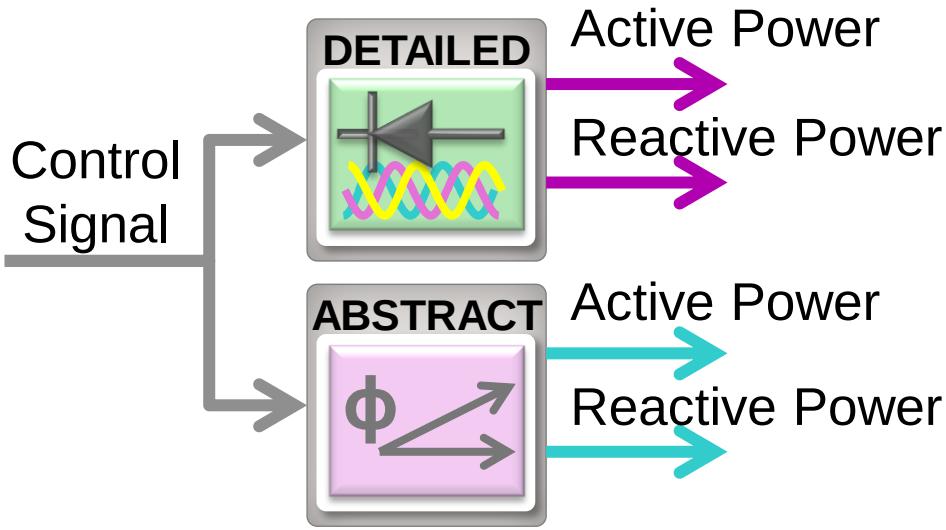


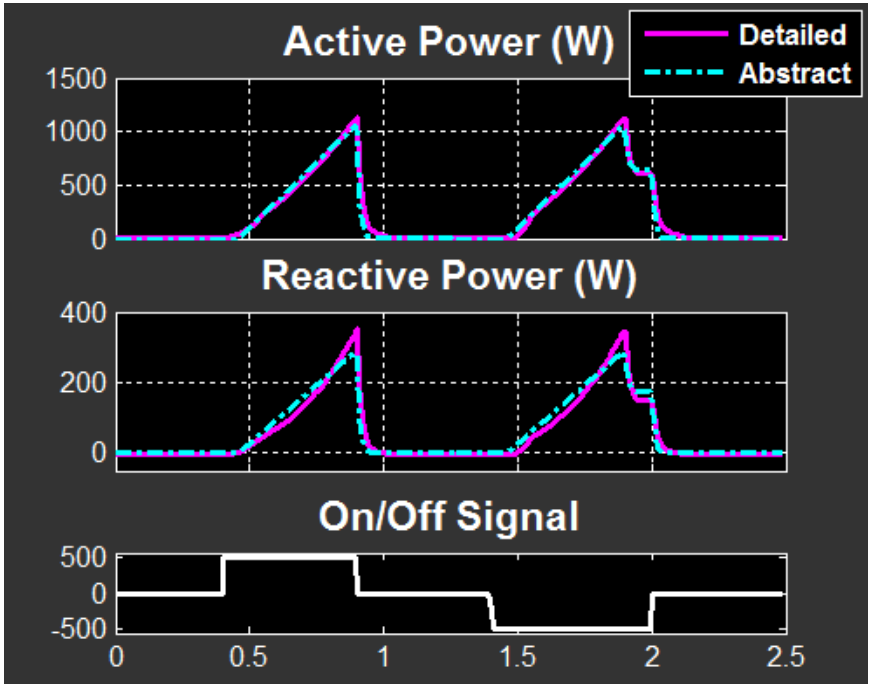
Tuned Abstract Model



Tuning Abstract Models to Match Detailed Results

Situation:





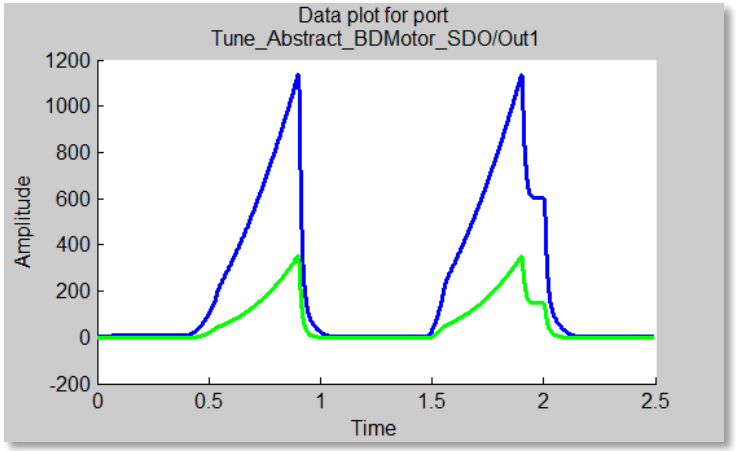
Problem: Result from abstract model do not match detailed simulation results

Solution: Use Simulink Design Optimization to automatically tune model parameters

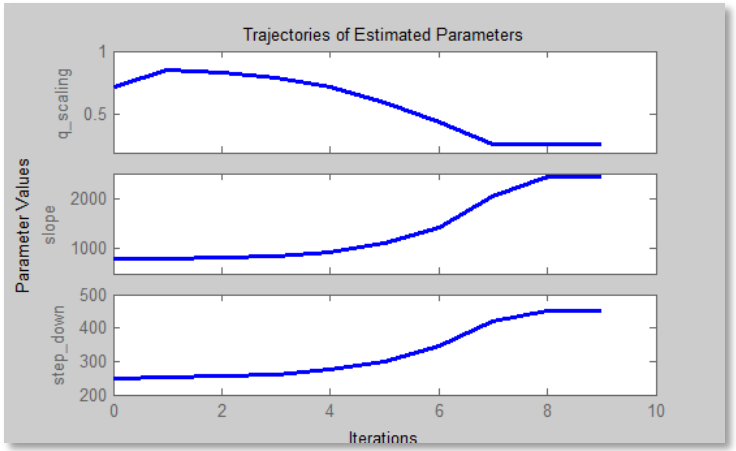
slope	step_down	q_scaling
2432	452.3	0.2713

Tuning Abstract Models to Match Detailed Results

- Steps to Estimate Parameters
  1. Import measurement data and select estimation data
  2. Identify parameters and their ranges
  3. Perform parameter estimation
  4. Validate estimation

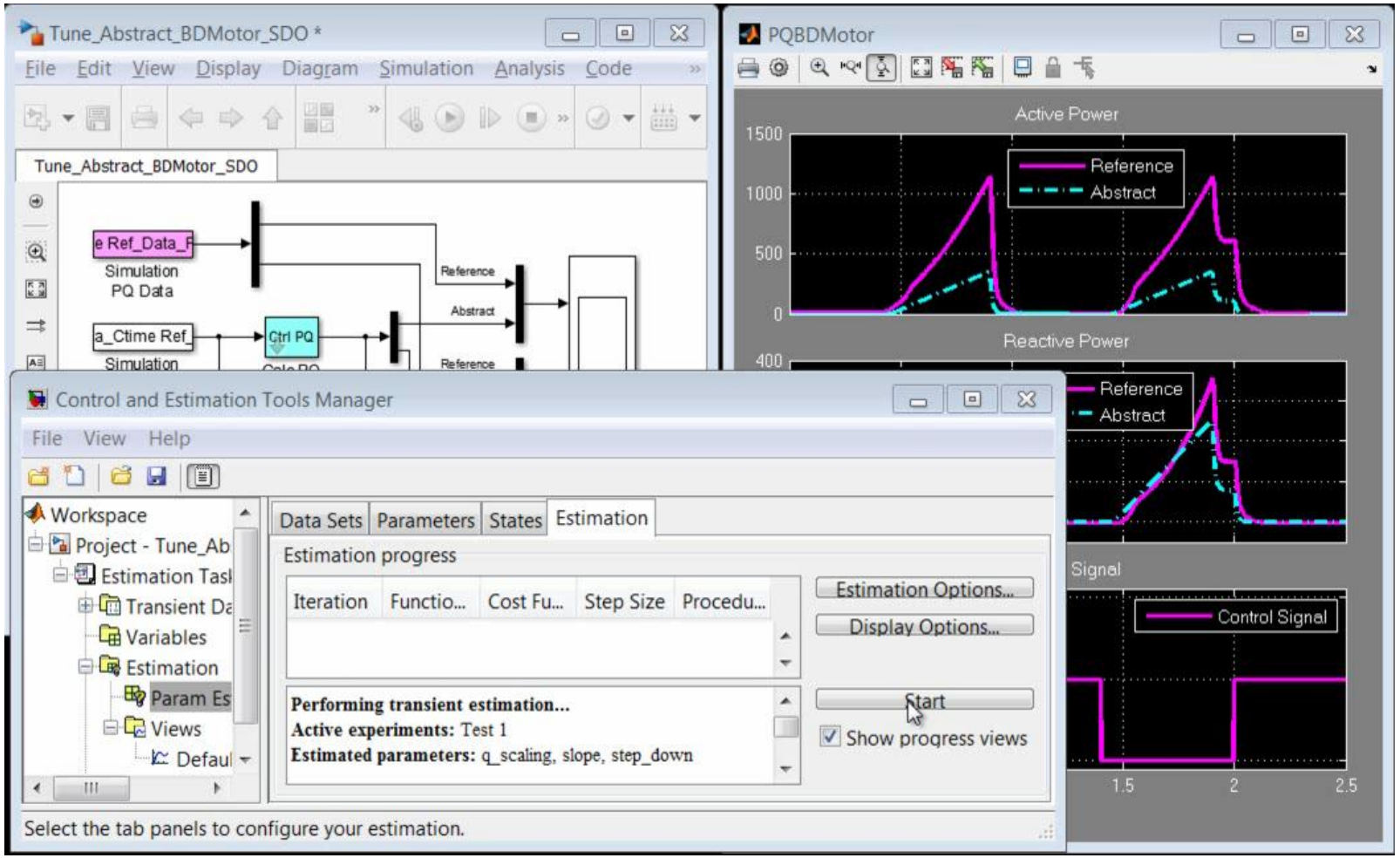


slope	step_down	q_scaling
792	250	0.72



Tuning Abstract Model

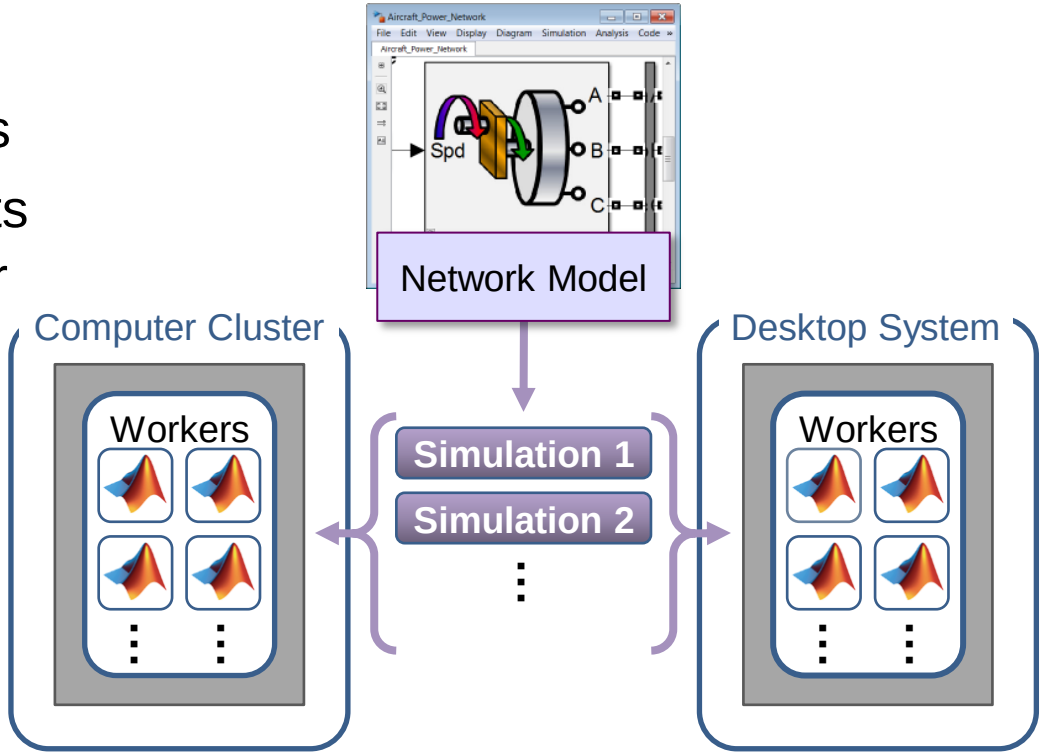
Video of Parameter Tuning



Distributing Simulations with Parallel Computing

- Simulating in parallel
  - Distribute simulations to multiple cores/processors
  - Dramatic speedup for sets of simulations (parameter sweeps, flight cycles optimizations, and more)

```
for  ⟶  parfor
```

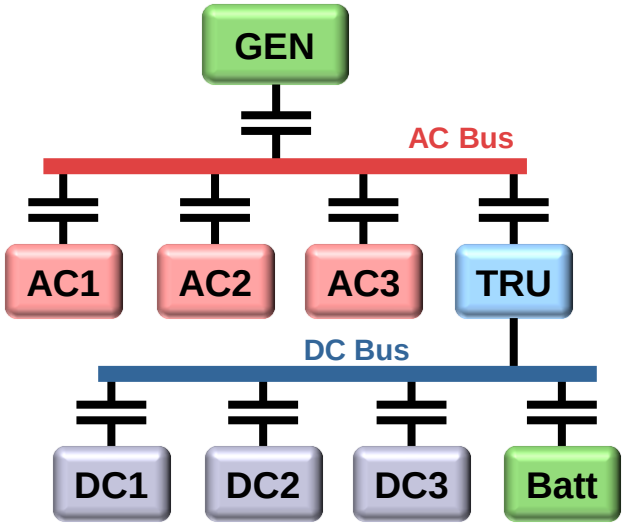


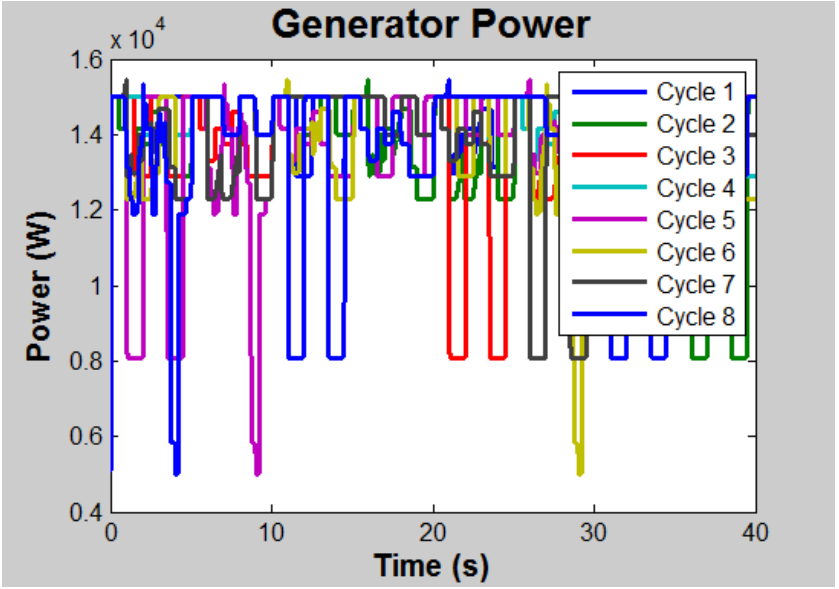
Running simulations in parallel speeds up your testing process.

Accelerate Flight Cycle Tests Using Parallel Computing

Model:

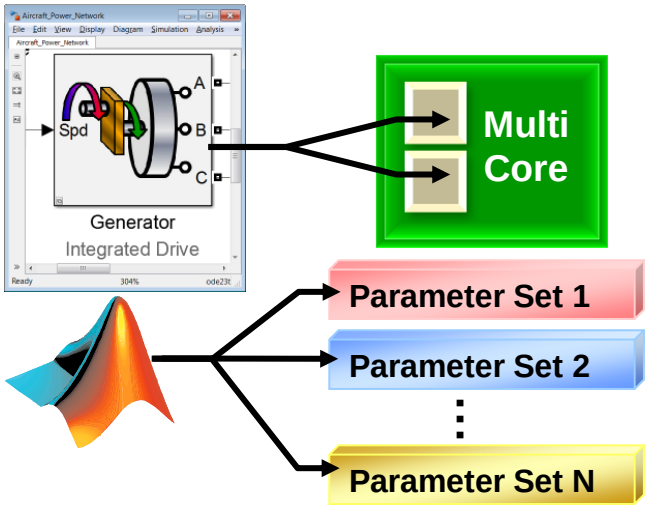
Flight Cycles
Faults
Equipment
Weather
…





Problem: Test system performance under a range of conditions (flight cycles, faults, weather, etc.)

Solution: Use Parallel Computing Toolbox™ to speed up the set of tests



Accelerate Flight Cycle Tests Using Parallel Computing

- Steps to compare simulation methods

1. Open pool of MATLAB sessions

```
>> matlabpool
```

2. Generate parameter sets

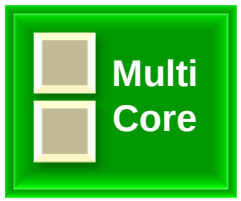
```
Flight_Cycle_array = [1:8];
Generate_Sim_Settings
```

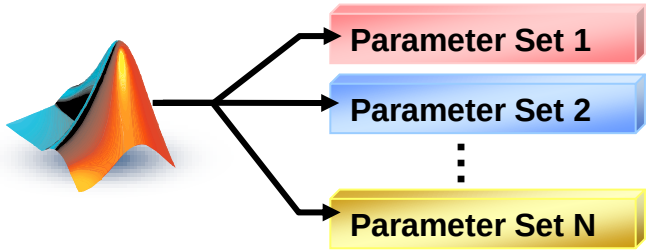
3. Run simulations **serially**

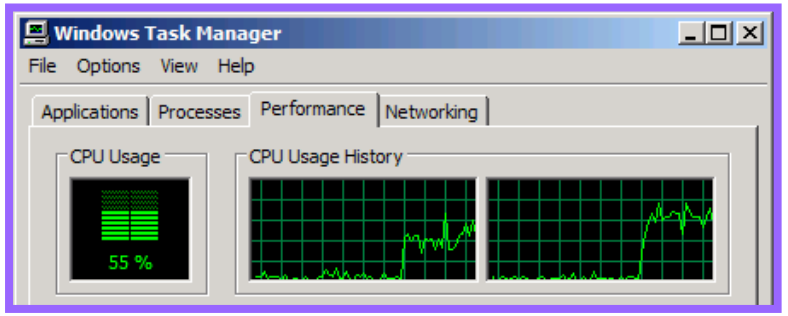
```
for i = 1:numSims
    out{i} = sim(mdl, SimSettings{i});
end
```

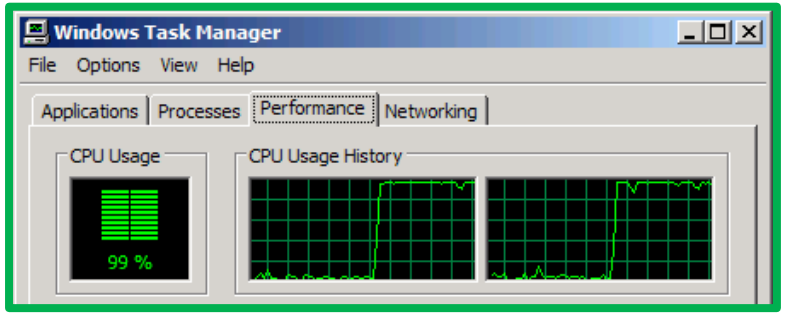
4. Run simulations in **parallel**

```
parfor i = 1:numSims
    out{i} = sim(mdl, SimSettings{i});
end
```









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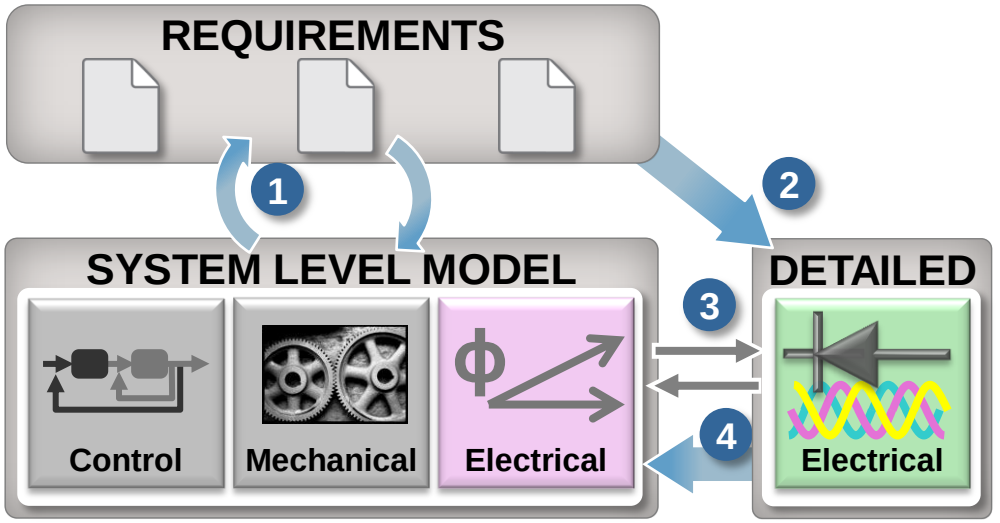
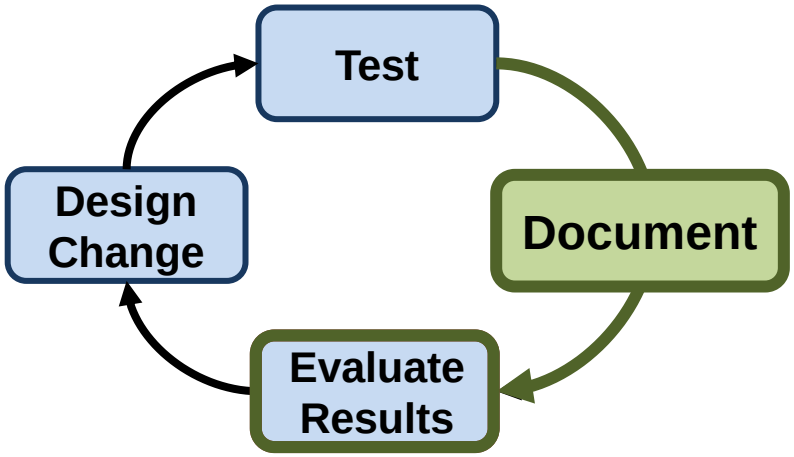


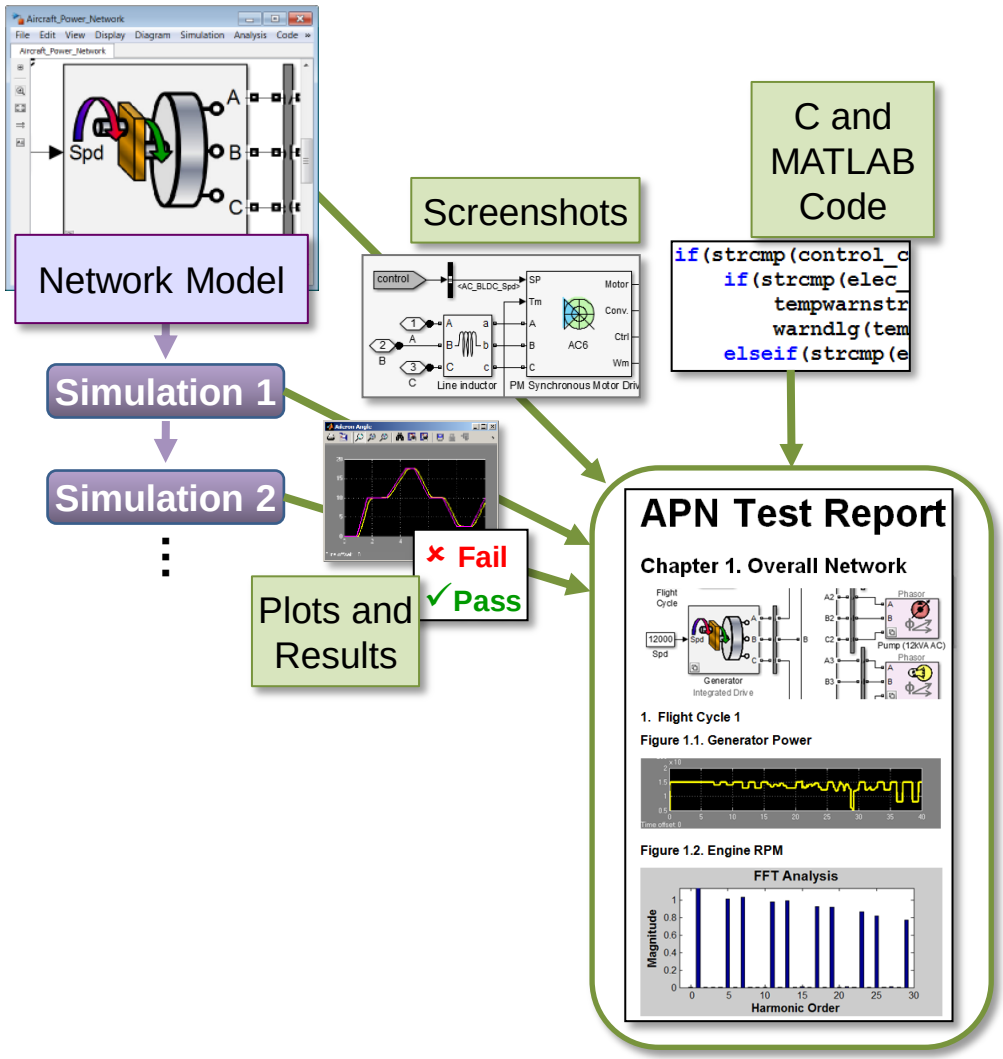
Automatically Run Tests And Document Results

Situation:



Problem: Evaluate test results quickly to make design changes and document the results

Solution: Use Simulink Report Generator to automatically document tests and results



Key Points

- Configure your model to balance model fidelity and simulation speed
- Accelerate your simulations using optimization algorithms and parallel computing
- Accelerate your development by automating simulation and analysis tasks using MATLAB