Modeling and Validation of a Variable Frequency Drive-Based HVAC System

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A Quick overview of the problem

- Mechanical/Thermal Engineer
  - Quickly develop the complete HVAC System
  - Gain confidence that the system works fine
  - Arrive at an optimal design of system

- Electrical/Controls Engineer
  - Quickly develop suitable electric drive for the HVAC system
  - Study the behavior of the system
Challenges with Traditional Development Process

- Cannot validate design against requirements
- Cannot test or optimize fully integrated design
- Can only find problems using hardware prototypes
Benefits of Model-Based Design Process

- Detect errors right away with continuous verification
- Optimize design in a single simulation environment
- Lower costs using HIL tests
What are we doing today?
Key challenges in designing a multi-domain system

- Understanding the interaction of different systems
- Having a single environment for modeling and simulating a multi-domain system
- Optimizing the system design
- Reducing the time spent in system analysis and report generation
- Re-using the models for real-time testing
Agenda

- Introduction to Physical Modeling
- Modeling Electrical Systems
- Modeling Thermal Systems
- Defining new physical domains and creating new components
- Logging and exploring simulation data
- Performing design studies and optimizations
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Modeling Physical Systems With MathWorks Products

Modeling Approaches

First Principles Modeling

- Programming (MATLAB, C)
- Block Diagram (Simulink)
- Modeling Language (Simscape language)
- Symbolic Methods (Symbolic Math Toolbox)

Physical Networks (Simscape and other Physical Modeling products)

Data-Driven Modeling

- Statistical Methods (Model Based Calibration Toolbox)
- System Identification (System Identification Toolbox)
- Neural Networks (Neural Network Toolbox)
- Parameter Tuning (Simulink Design Optimization)
Introduction to Physical Modeling

DC Motor

\[ v = K_e \omega + i_m R_{\text{wind}} + L_{\text{wind}} \frac{di_m}{dt} \]

\[ T = K_t i_m - D \omega - J \frac{d\omega}{dt} \]
Let’s build DC motor model from scratch using Simscape
Introduction to Physical Modeling

- Simscape model advantages
  - Easier to read than equations
  - Quicker to create
  - More intuitive – easier to explain to other engineers

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- **Modeling Electrical Systems**
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Problem: Build a modular, intuitive model of a 3-phase electric motor without deriving equations.

Solution: Use SimPowerSystems to model the device.
Model Electric Drives

- Combine power electronics, machine, and control algorithm
  - GUI to assign key parameters
  - Common strategies for speed and torque control
  - Adjustable level of fidelity (detailed, averaged)

- Common machine types can be used as motors or generators:
  - Permanent magnet
  - Synchronous, asynchronous
  - Induction
  - Single phase or 3-phase
Calculate Model Parameter Values
Asynchronous or PMSM Models

- Calculates parameters for equivalent circuit directly from data sheet values
  - Plot torque speed relationship
  - Automatically update machine model

<table>
<thead>
<tr>
<th>Data</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line to Line RMS Voltage</td>
<td>400 V</td>
</tr>
<tr>
<td>Nominal Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Full Load Current</td>
<td>194 A</td>
</tr>
<tr>
<td>Full Load Torque</td>
<td>352 N.m</td>
</tr>
<tr>
<td>Synchronous Speed</td>
<td>2982 rpm</td>
</tr>
</tbody>
</table>
Completed Model of Variable Frequency Drive

AC3 - Field-Oriented Control Induction 200 HP Motor Drive
What’s Next?
Agenda

- Introduction to Physical Modeling
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HVAC Component

Variable Frequency Drive

HVAC Plant Model

This example shows how the Simscape™ language can be used to define a custom thermal fluid domain. In the model, blocks representing components of a fluid-sealed system are implemented. A thermally sealed compressor is linked to a shaft driven by an engine through the circuit. RT FTROP from NIST was used to populate the fluid property data in the tables lookup in the Fluid Properties block.
Creating HVAC Domain using Simscape Language

```matlab
% Thermal Fluid Domain for Refrigeration Example

% Copyright 2012-2013 The MathWorks, Inc.

domain HVAC

% Parameters for properties table lookup - Initial values given for R134a at p = 1 atm, T = 293.15K
% The size of the vectors and matrices are fixed at the time the library is built.
TTLU = linspace(200, 450, 11)', 'K'; % Temperature vector
pTLU = linspace(1e5, 4e6, 12), 'Pa'; % Pressure vector
uTLU = 8*ones(11,12), 'J/kg'; % Internal energy
rhoTLU = 998.2*ones(11,12), 'kg/m^3'; % Density
nuTLU = 1e-6*ones(11,12), 'm^2/s'; % Kinematic viscosity
CTLU = 4.16*ones(11,12), 'J/(g*K)'; % Thermal capacity
kTLU = 0.5*ones(11,12), 'W/(m*K)'; % Thermal conductivity
betaTLU = 2e9*ones(11,12), 'Pa'; % Bulk modulus
alphaTLU = 1e-3*ones(11,12), '1/K'; % Thermal expansion coefficient

end

variables

p = 1e5, 'Pa'; % Pressure
T = 293.15, 'K'; % Temperature

end

variables(Variables = true)

mdot = 0, 'kg/s'; % Mass flow rate
Phi = 0, 'J/s'; % Heat flux

end

end
```
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Logging and Exploring Simulation Data

Variable Frequency Drive

HVAC Plant Model

Simscape Logging & Simulink Data inspector
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Performing design studies and optimizations

**Problem:** Design and tune the Reference speed in this system to meet condenser pressure requirements

**Solution:** Use Simulink Design Optimization to design, tune, and test the system

<table>
<thead>
<tr>
<th>Speed</th>
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<tr>
<td>3555</td>
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Thank You