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Modeling and Analysis of the System Dynamics of Electrical Power Networks

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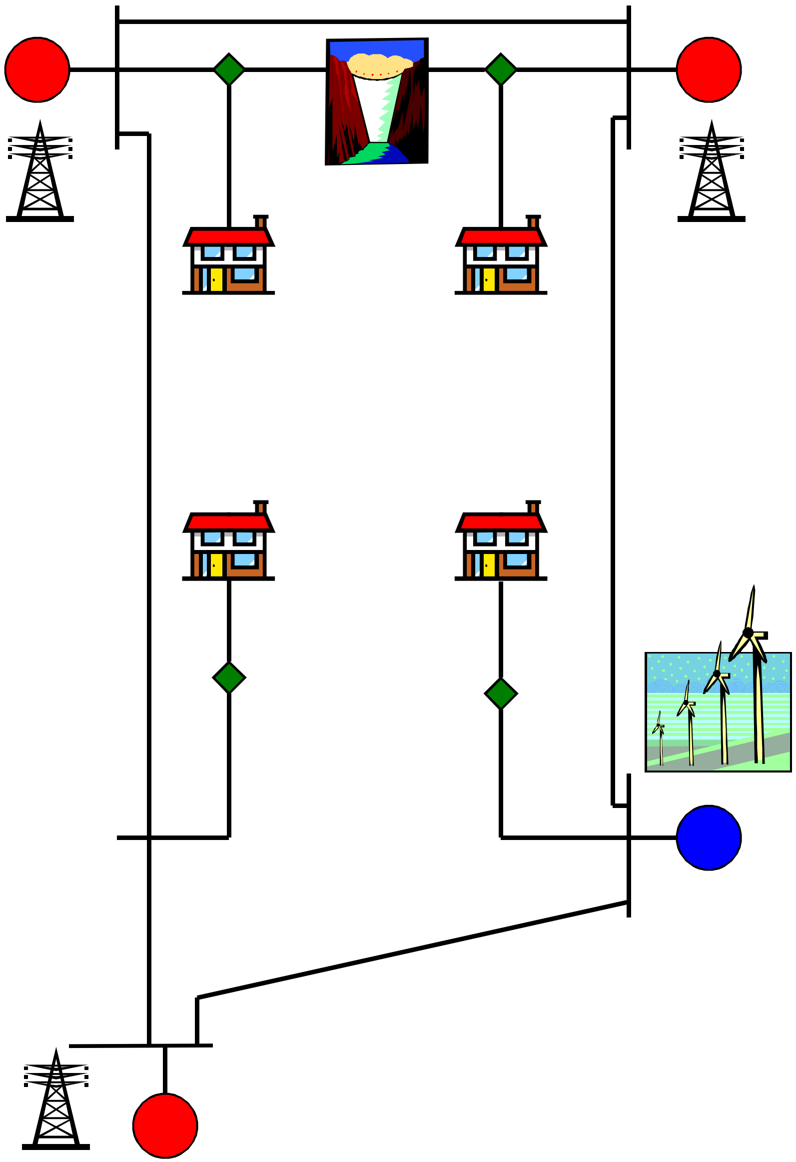
Motivation

- Large dynamic systems emerge from networks of interacting components
  - Dynamics at multiple time scales
  - Multiple sources of uncertainty (i.e. model parameters, network structure, external forcing)
- Power flow and transient stability analyses are necessary for power planning, operation, economic scheduling and utility exchange

Goals

- Develop multiple power system models with increasing levels of complexity that can be used in the investigation of new Uncertainty Quantification (UQ) techniques

Power Network



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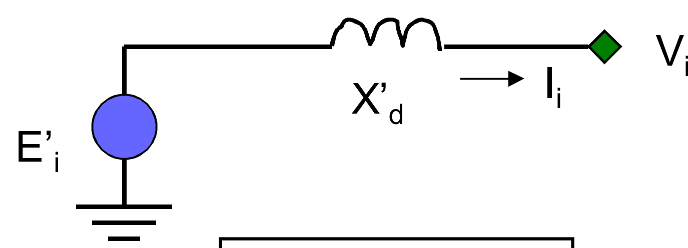
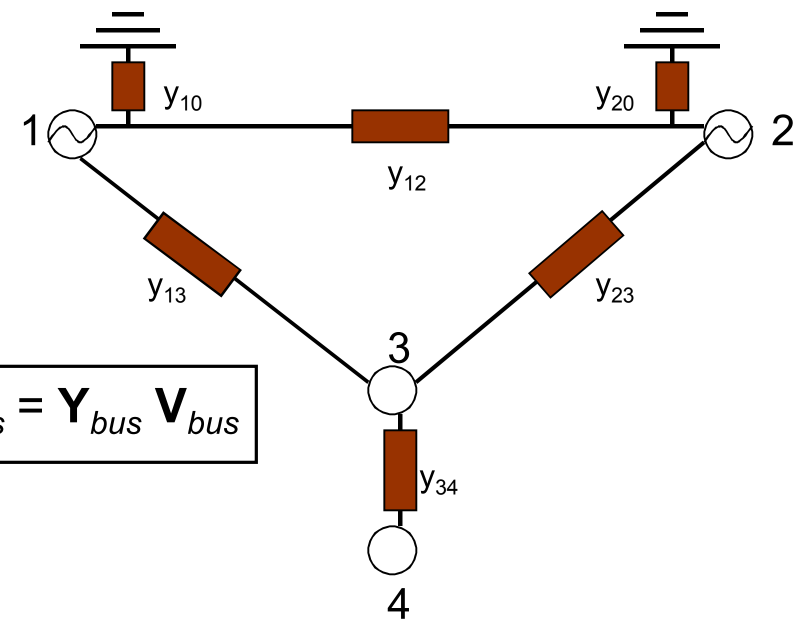
Classic Generator Model



$$E'_i = V_i + j\,X'_d I_i$$

Transmission Network



$$\mathbf{I}_{bus} = \mathbf{Y}_{bus}\,\mathbf{V}_{bus}$$

Power Flow

$$P_i + jQ_i = V_i I_i^*$$

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \qquad i \neq j$$

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \qquad i \neq j$$

P: Real power
Q: Reactive power
I: Current
V: Voltage
n: Number of nodes in transmission network
y_{ij}: Admittance

Generator Dynamics

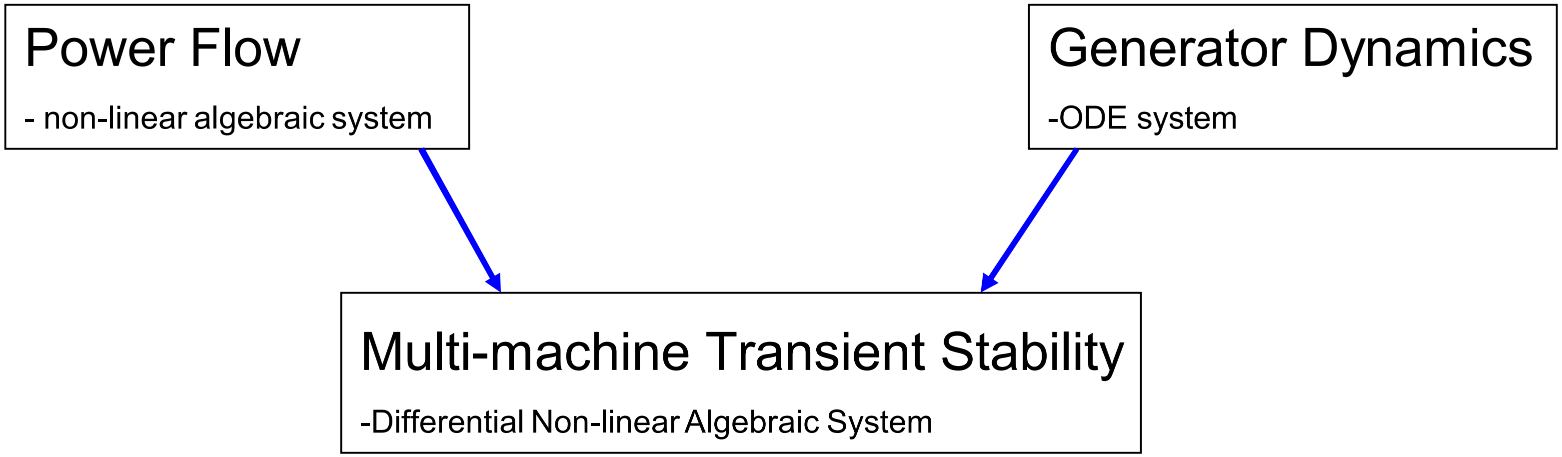
$$\frac{d\delta_i}{dt} = \Delta\omega_i$$

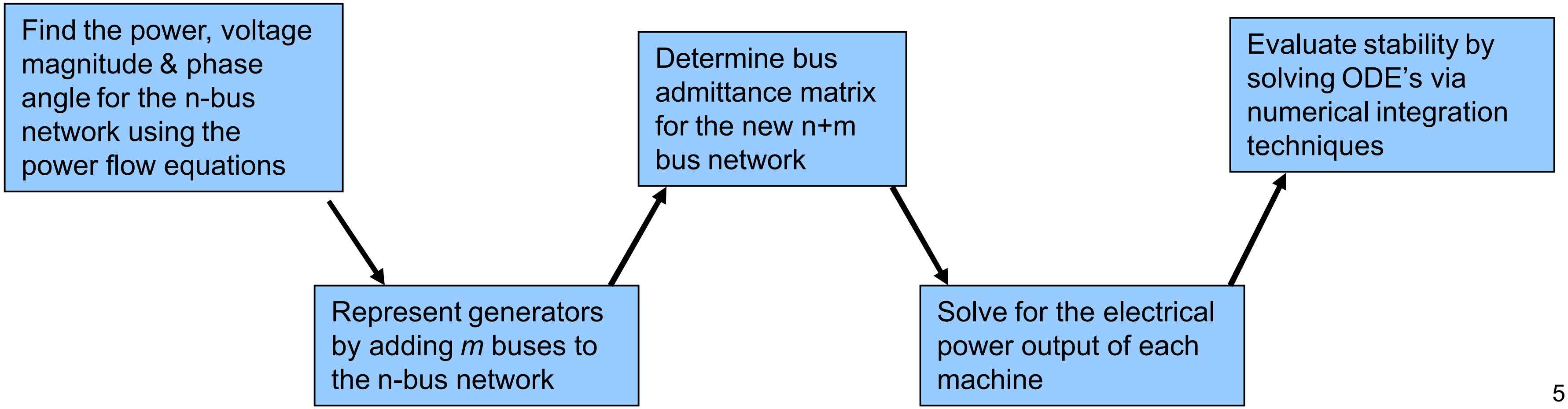
$$\frac{d\Delta\omega_i}{dt} = \frac{\pi f_0}{H_i}\left(P_m - P_e^f\right)$$

$$P_{ei} = \sum_{j=1}^{m} \left|E_i'\right|\left|E_j'\right|\left|Y_{ij}\right| \cos\left(\theta_{ij} - \delta_i + \delta_j\right)$$

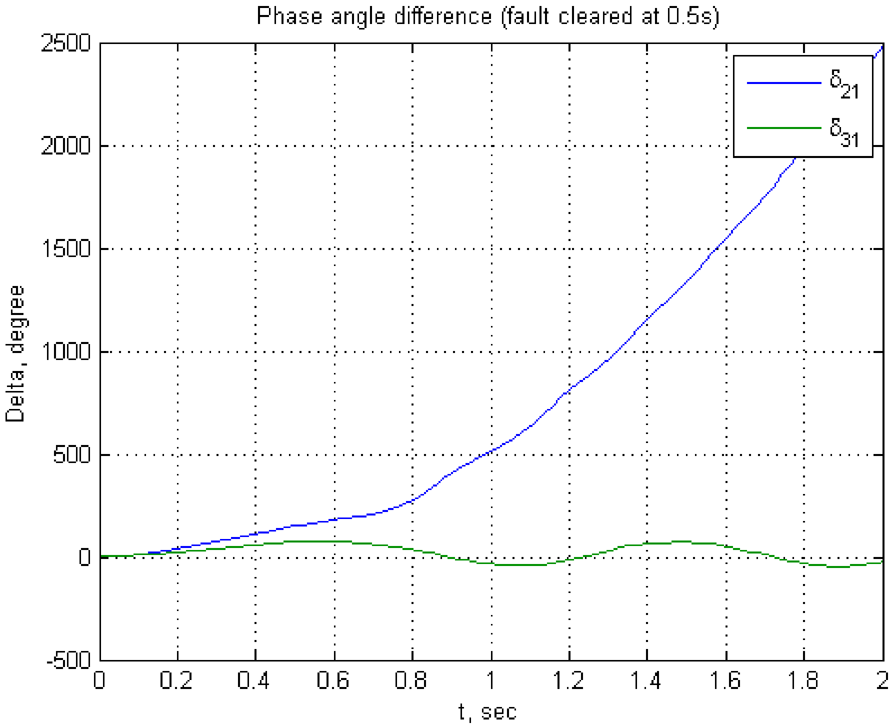
δ: Rotor position in rotating reference frame
ω: Rotor angular velocity
P_m: Mechanical power input
P_e: Electrical power
H: Inertia
f_0: Nominal frequency
θ: Angular displacement w.r.t. stationary stator
E: Generator voltages
m: Number of generators

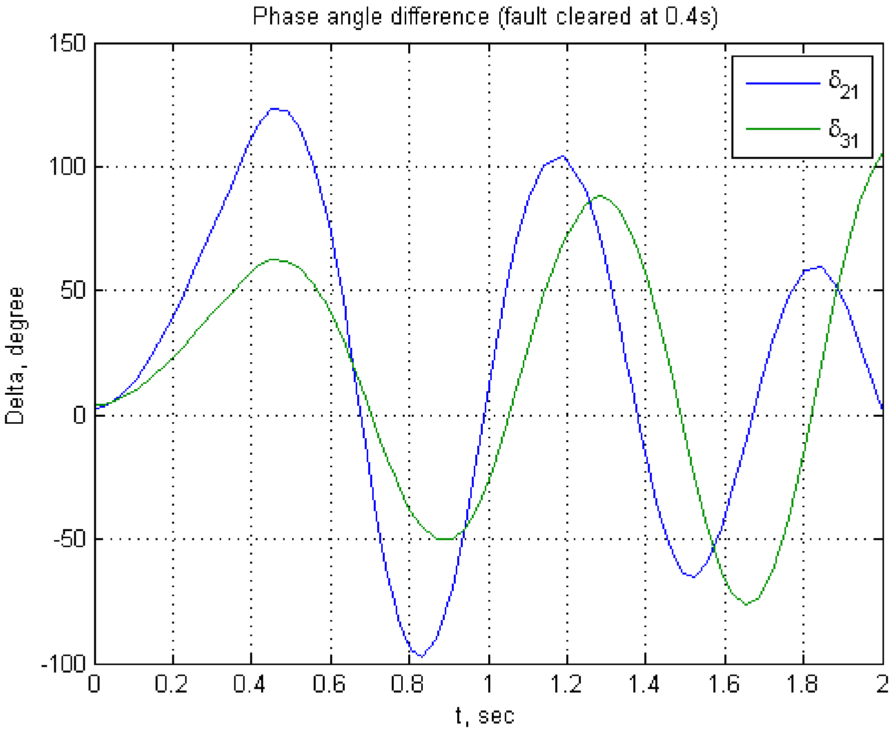
Multi-machine Transient Stability





Simulation Results





Completed Objectives

- Develop electrical power network models at varying degrees of complexity
- Evaluate stability of multi-machine systems with the aid of Matlab

Future Work

- Expand models to include more complexity and more parameters
- Determine which parameters should be modeled as uncertain parameters
- Investigate the use of uncertainty quantification (UQ) techniques for use in electrical power system networks