Effects of Induction Machine Dynamics on Power System Stability

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Outline

- Background
- Objective
- Induction motor modeling issue
  - Modeling in rotor speed based frame
  - Implementation issue for stability study
- Comparative study of PS Stability
- Conclusion

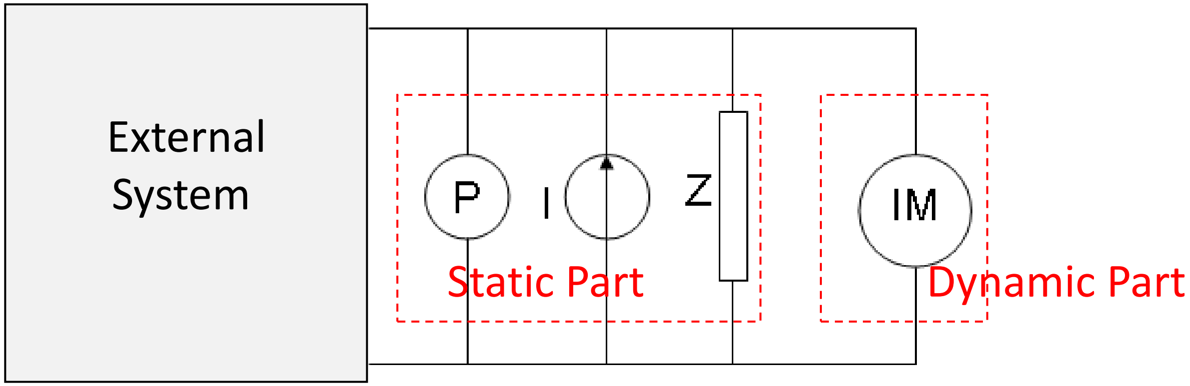
Objective

- Modeling in Rotor Speed Based Frame
- Validation of Models
- Comparison of IM behaviors in system stability

Background

- Category of Loads : static and dynamic

- Static Loads : ZIP
  Dynamic Loads : Induction motor



- Issues of Induction Motor Modeling
  - Properness of the available models
  - Choice of appropriate model

Induction Machine Models

➢ Different Frames

- System frequency (ω_e)
- Rotor speed(ω_r)
- Stationary

➢ Different Orders

- First order
  - rotor inertia dynamics considered
- Third order
  - rotor flux & inertia dynamics considered
- Fifth order
  - stator/rotor flux, inertia dynamics considered

Simulation in ω_e-frame

$$v_{qs}^e = \frac{1}{\omega_b}\frac{d\psi_{qs}^e}{dt} + \frac{\omega_e}{\omega_b}\psi_{ds}^e + r_s i_{qs}^e$$

$$v_{ds}^e = \frac{1}{\omega_b}\frac{d\psi_{ds}^e}{dt} - \frac{\omega_e}{\omega_b}\psi_{qs}^e + r_s i_{ds}^e$$

Stator Dynamic Equations

$$v_{qr}^{'e} = \frac{1}{\omega_b}\frac{d\psi_{qr}^{'e}}{dt} + \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{dr}^{'e} + r_r' i_{qr}^{'e}$$

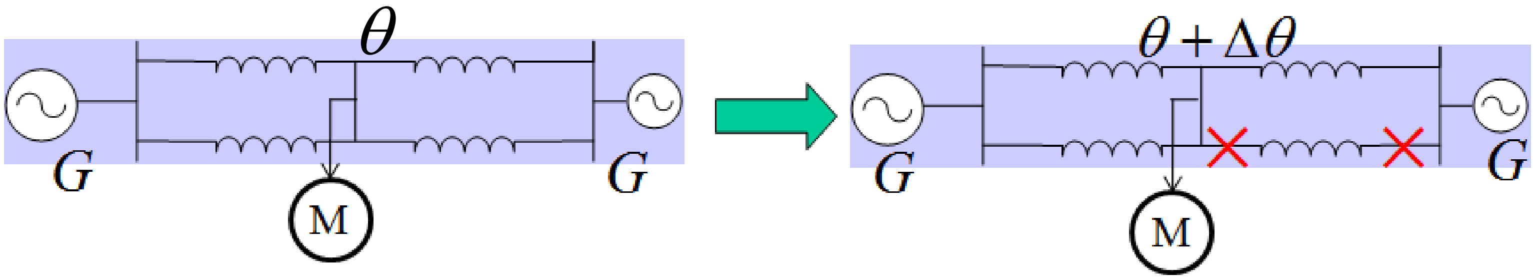
$$v_{dr}^{'e} = \frac{1}{\omega_b}\frac{d\psi_{dr}^{'e}}{dt} - \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{qr}^{'e} + r_r' i_{dr}^{'e}$$

Rotor Dynamic Equations

$$2H\frac{d}{dt}\left(\frac{\omega_r}{\omega_b}\right) = T_{em} - T_{mech}$$

Equation of motion

The Discontinuity Problem



➢ When a line is disconnected suddenly, step change in phase angle ($\Delta\theta$) occurs

ω_e unbounded

ψ discontinuous

$$\left[\lim_{\Delta t \to 0} \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt} = \omega_e \right]$$

$\Delta\theta$ discontinuous

$$\left[\boldsymbol{v} = \frac{1}{\omega_b}\frac{d\boldsymbol{\psi}}{dt} + \frac{1}{\omega_b}\omega_e \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \boldsymbol{\psi} + r\boldsymbol{i} \right]$$

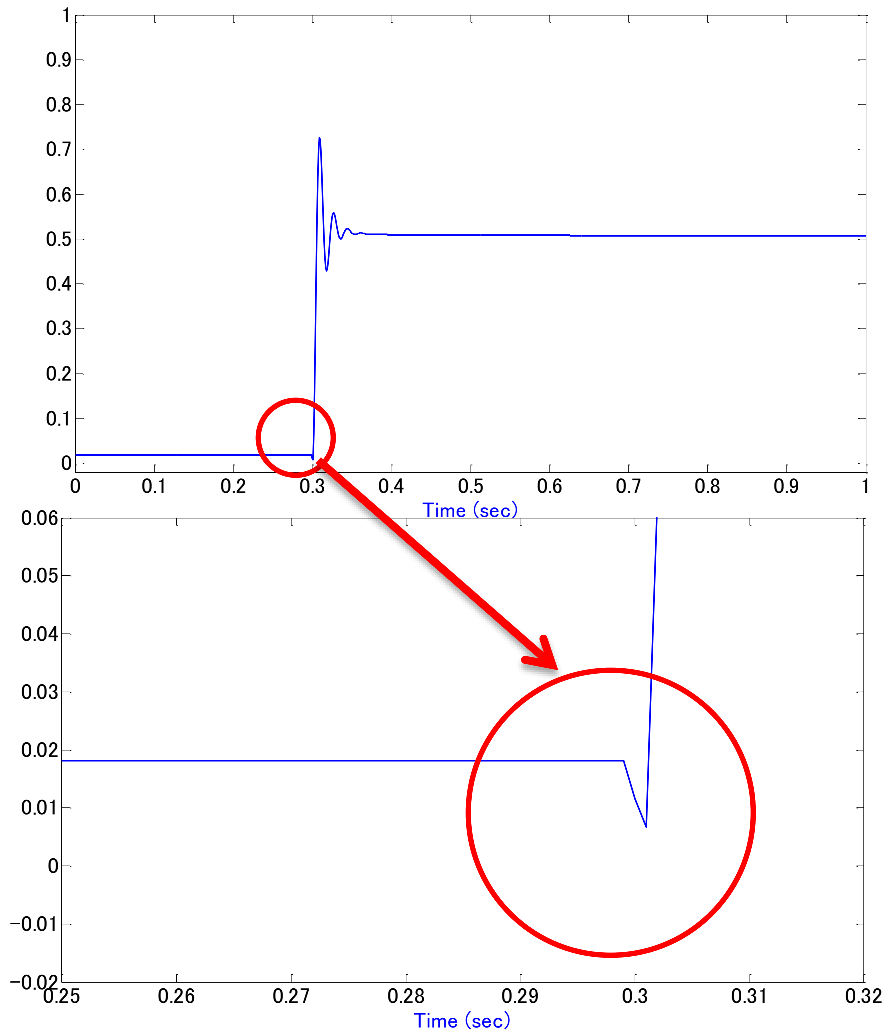
Stator equations

➢ This means the discontinuity of state variables

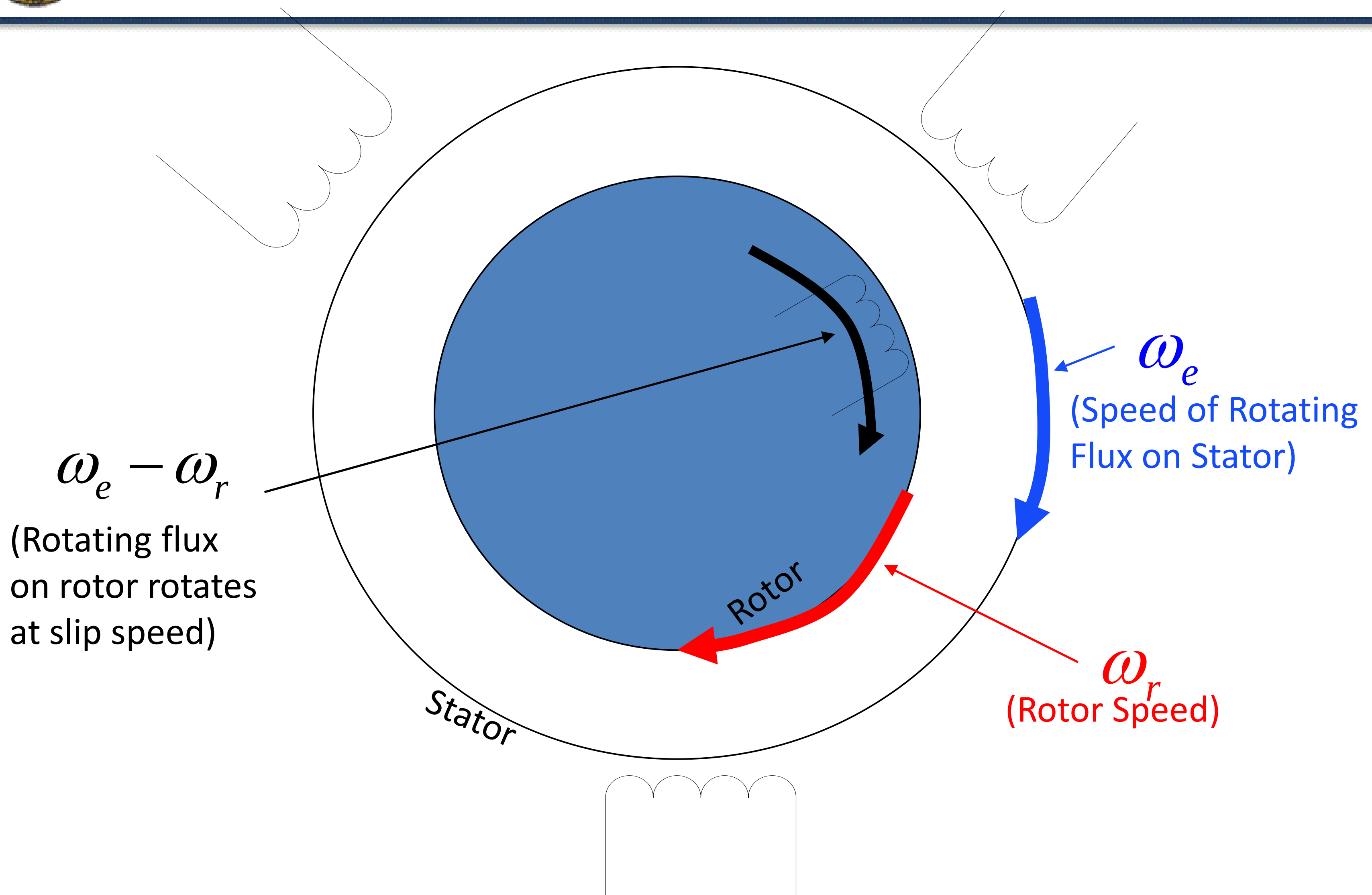
➢ This situation should be avoided

An example of discontinuity

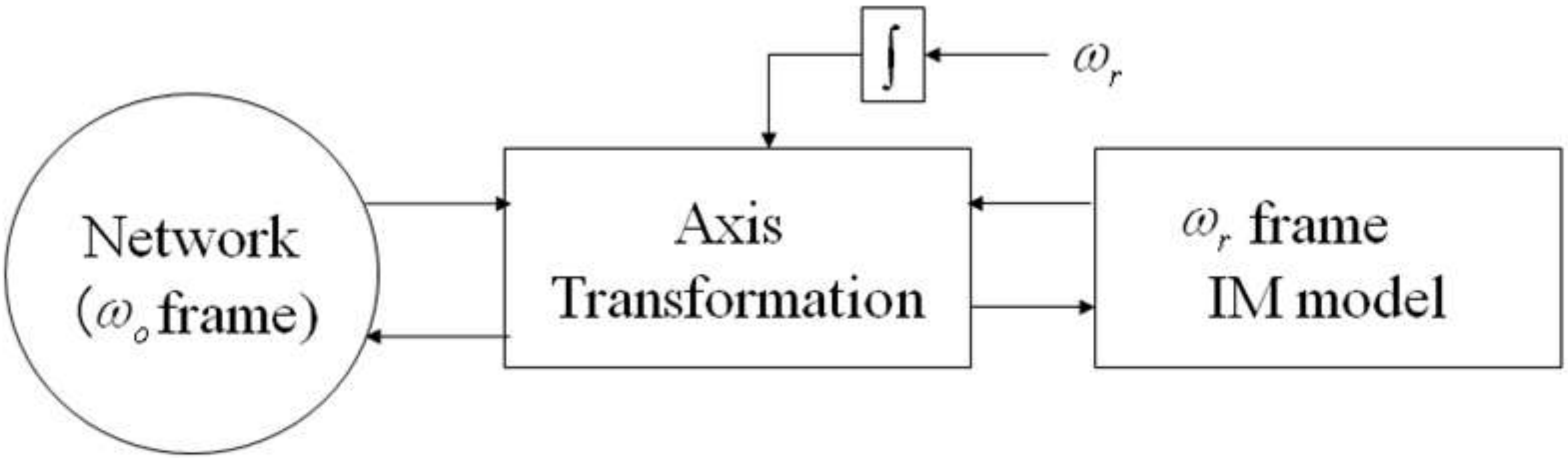
- 30 degree phase angle step applied at 0.3 seconds
- d-axis rotor flux was observed
- The enlarged view shows the existence of discontinuity



Introduction of "ω_r-frame"

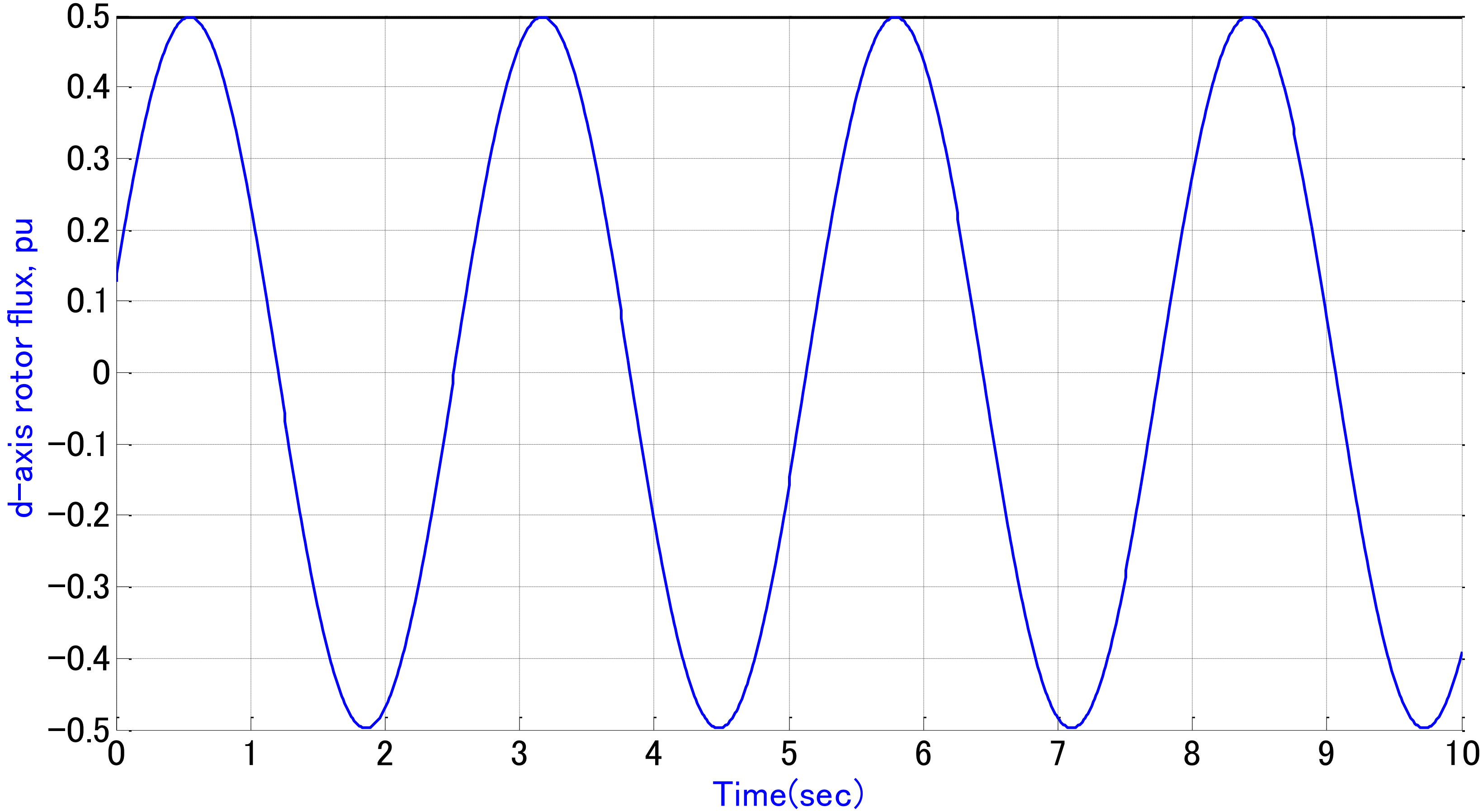


Implementation in ω_r Frame



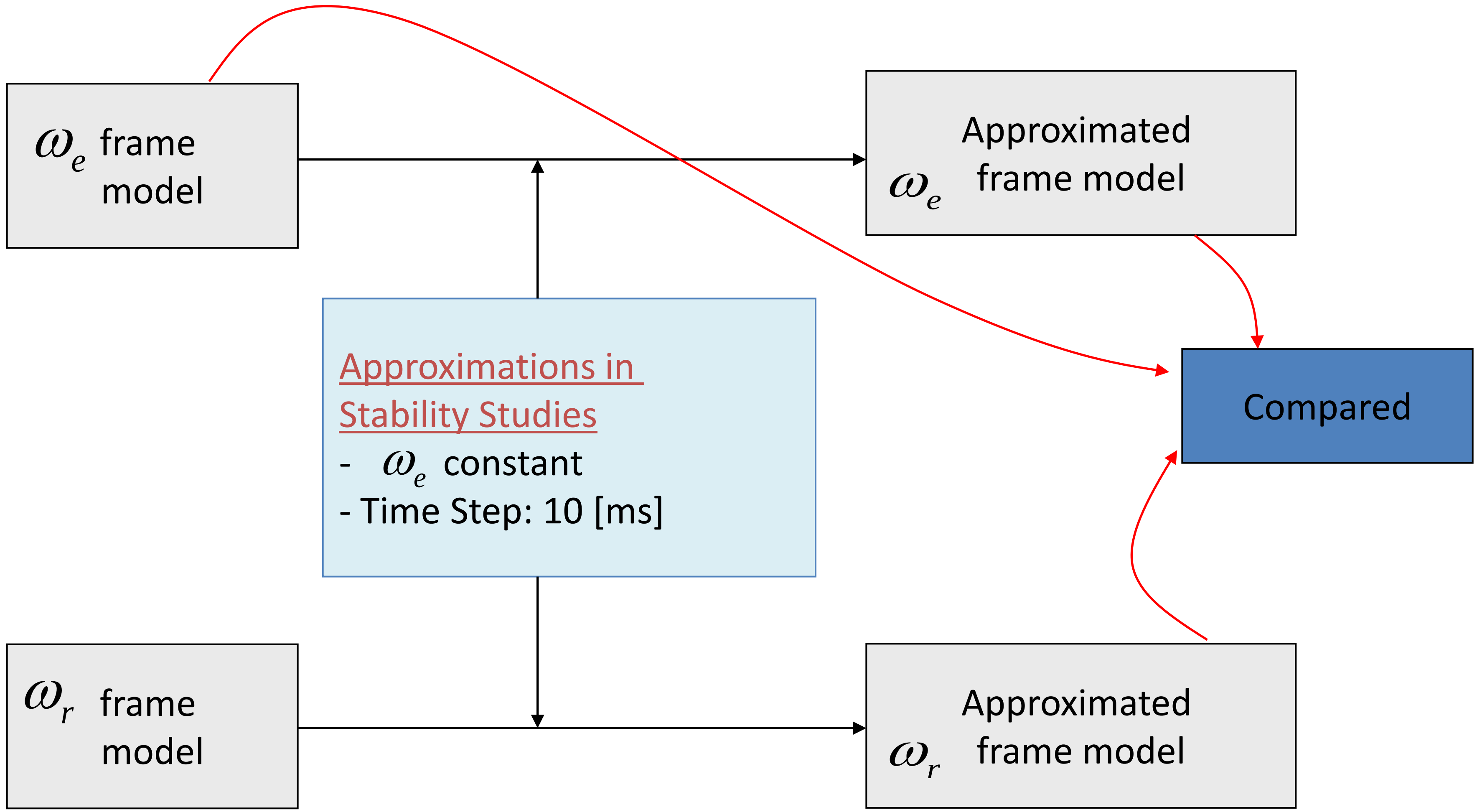
- Similar to the synchronous machine implementation
- Eliminates ω_e term from equations → eliminates discontinuity

ω_r-frame state variables

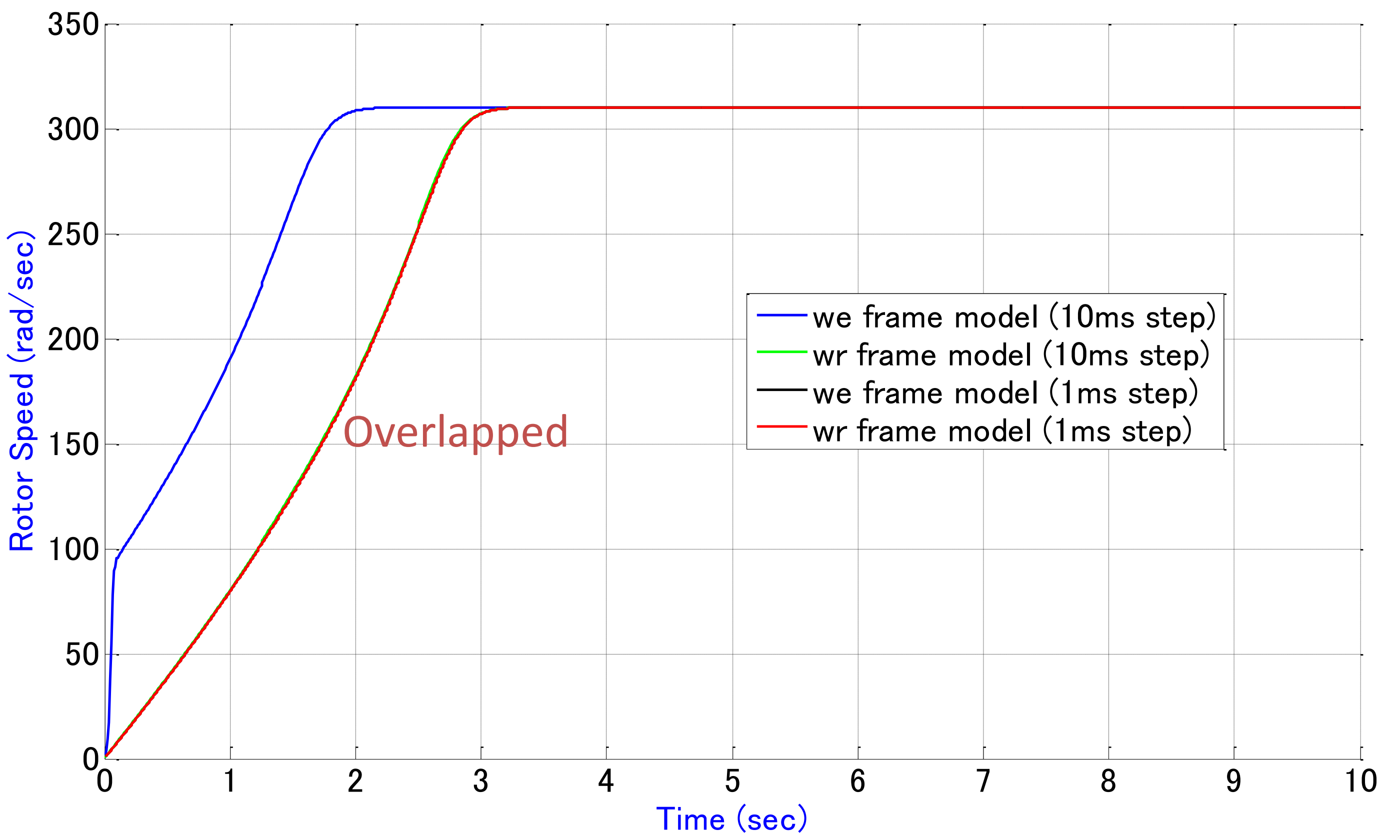


- ω_r frame state variables are oscillating in a slip frequency

Models for Stability Simulation

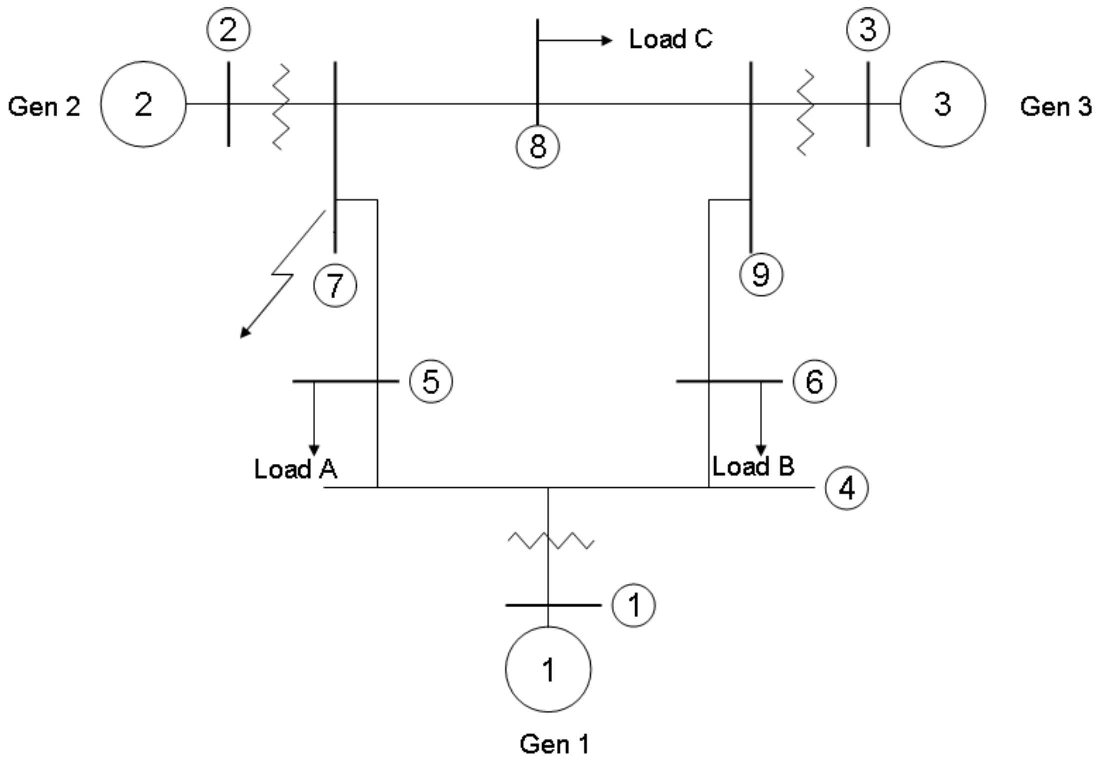


Comparison of Models



ω_e frame model has numerical problem with different time steps

Study System



- A three machine 9-bus power system was chosen
- Impact of order of model on stability assessment will be presented

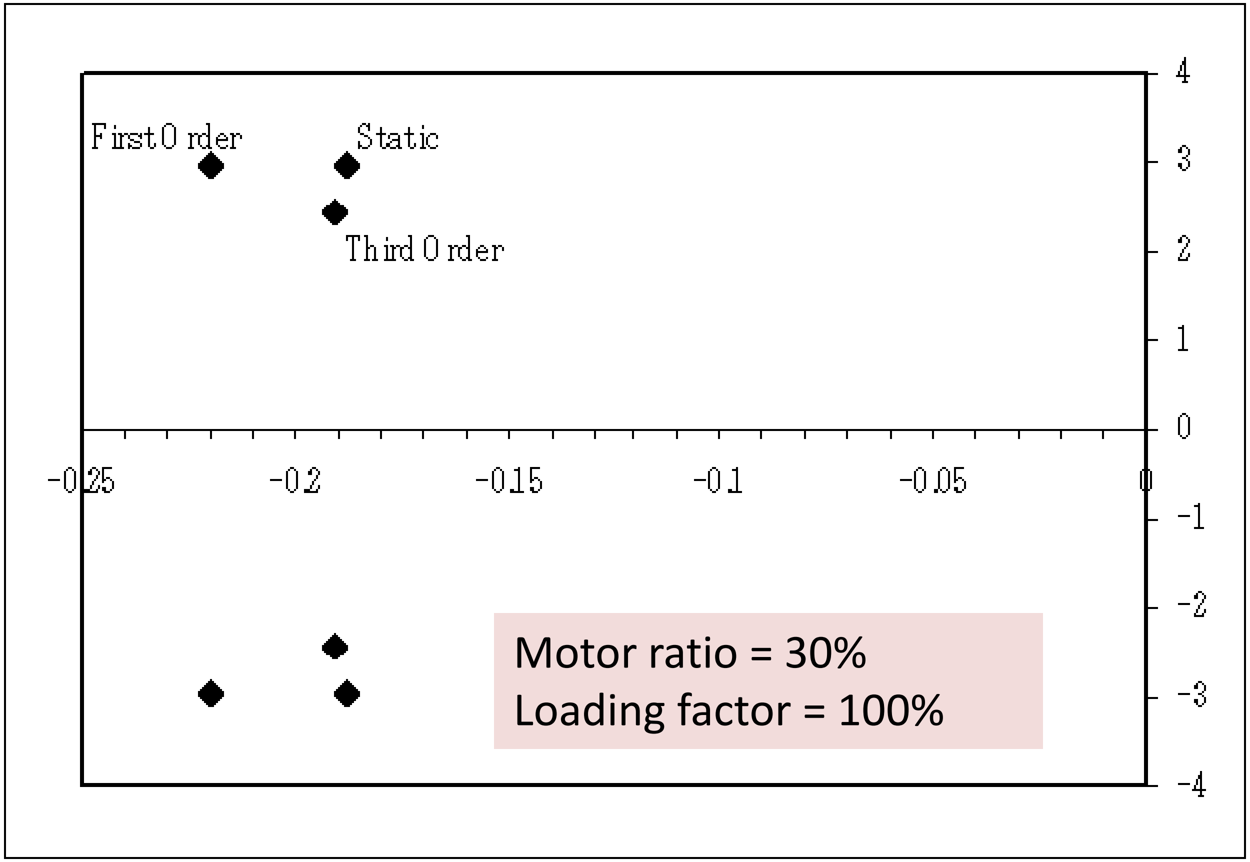
Transfer Capacity Assessment

- Maximum power transfer capability
  - Generator stability limit considered

	Transfer Capacity	
Model	30% Motor Load	50% Motor Load
Third Order	1.198	0.869
First Order	1.271	0.882
Static Loads	1.781	

Increase ↓ (30% Motor Load) Increase ↓ (50% Motor Load)

Comparison of Eigenvalues



➢ First order model gives the most optimistic solution

Conclusion

- Simulation in rotor speed based frame
  - Eliminates the possible discontinuity in flux
  - Good Accuracy
- Transfer Capacity
  - More motor loads results in less power transfer limit
  - First order models give most optimistic result
- Steady state stability
  - Poor damping with static load
  - Higher order models show poorly damped oscillations