A Study on the Influence of Induction Motor Models on Power System Stability

Sudarshan Dahal, Pathom Attaviriyanupap, Yoshihiko Kataoka

Tokyo Institute of Technology

Kumamoto University, Japan
August 6, 2008

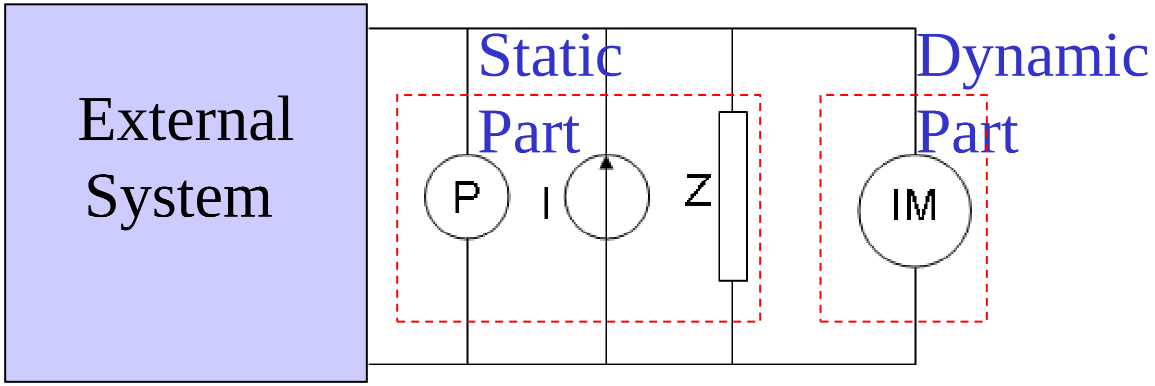
Outline

- Background
- Objective
- Induction motor modeling issue
  - Introduction of rotor speed based frame model
  - Implementation for stability study
- Comparative study of PS Stability
  - Transient stability
  - Steady state stability
- Conclusion

Background

- Stability Analysis: Modeling and Simulation

- Power System Loads



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

Objective

- Modeling in Rotor Speed Based Frame
- Comparison of Accuracy
- Comparative Analysis of PS Stability

- Background
- Objective
- Induction Motor Modeling Issue
  - Introduction of rotor speed based frame model
  - Implementation for stability study
- Comparative study of PS Stability
  - Transient stability
  - Steady state stability
- Conclusion

Induction Motor Modeling

➢ Different frames

- ω_e-frame
- ω_r -frame (proposed)

ω_o : Nominal Frequency

ω_e :System Frequency

ω_r :Rotor Speed

➢ Different orders

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

Simulation in ω_e-frame

v_s

Stator equations

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

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

Dynamic Equations

Algebraic Equations

Flux to currents

$$\begin{bmatrix}\psi_{qs}^e\\ \psi_{ds}^e\\ \psi_{qr}^{'e}\\ \psi_{dr}^{'e}\end{bmatrix} = \begin{bmatrix} x_{ls}+x_m & 0 & x_m & 0\\ 0 & x_{ls}+x_m & 0 & x_m\\ x_m & 0 & x_{lr}^{'}+x_m & 0\\ 0 & x_m & 0 & x_{lr}^{'}+x_m\end{bmatrix}\begin{bmatrix} i_{qs}^e\\ i_{ds}^e\\ i_{qr}^{'e}\\ i_{dr}^{'e}\end{bmatrix}$$

Rotor inertia equations

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

$$T_{em} = \frac{3}{2}\frac{P}{2\omega_b}\left(\psi_{qr}^{'e} i_{dr}^{'e} - \psi_{dr}^{'e} i_{qr}^{'e}\right),\quad T_{mech} = K\left(\frac{\omega_r}{\omega_b}\right)$$

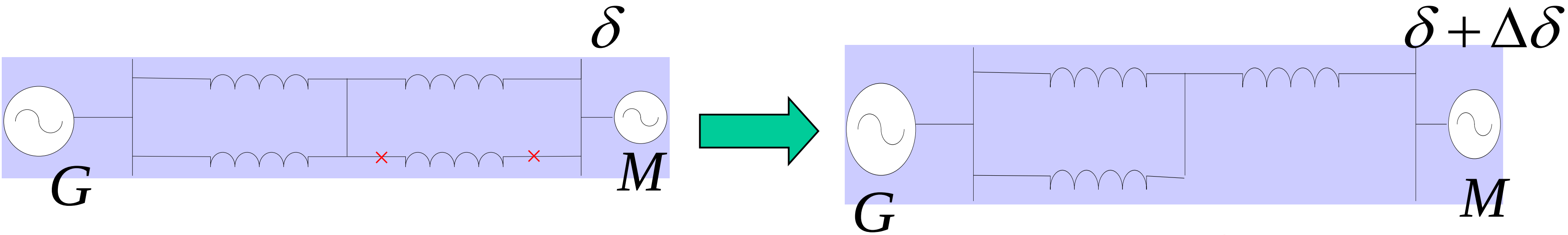
$$v_{qr}^{'e} = 0 = \frac{1}{\omega_b}\frac{d\psi_{qr}^{'e}}{dt} + \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{dr}^{'e} + r_r^{'} i_{qr}^{'e}$$

$$v_{dr}^{'e} = 0 = \frac{1}{\omega_b}\frac{d\psi_{dr}^{'e}}{dt} - \left(\frac{\omega_e - \omega_r}{\omega_b}\right)\psi_{qr}^{'e} + r_r^{'} i_{dr}^{'e}$$

$v_r = 0$

Rotor equations

Existence of Discontinuity



Opening of a line

ω_e Unbounded $\left[\lim_{\Delta t \to 0} \frac{\Delta\delta}{\Delta t} = \frac{d\delta}{dt} = \omega_e\right]$ ← $\Delta\delta$ discontinuous

↓

Stator equations

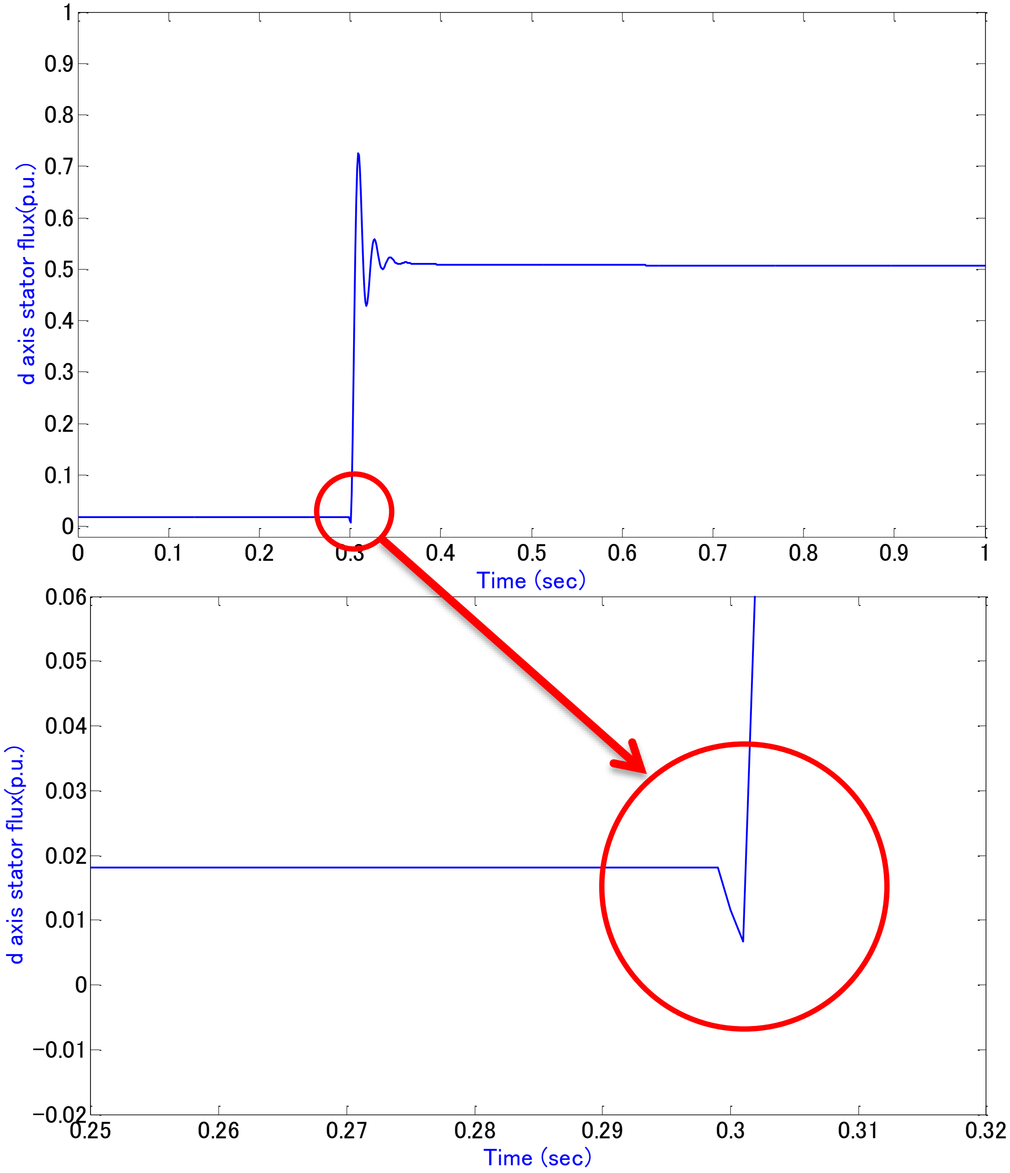
ψ discontinuous $\left[\boldsymbol{v} = \frac{1}{\omega_b}\frac{d\boldsymbol{\psi}}{dt} + \frac{1}{\omega_b}\omega_e \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \boldsymbol{\psi} + r\boldsymbol{i}\right]$

This means the discontinuity of state variables

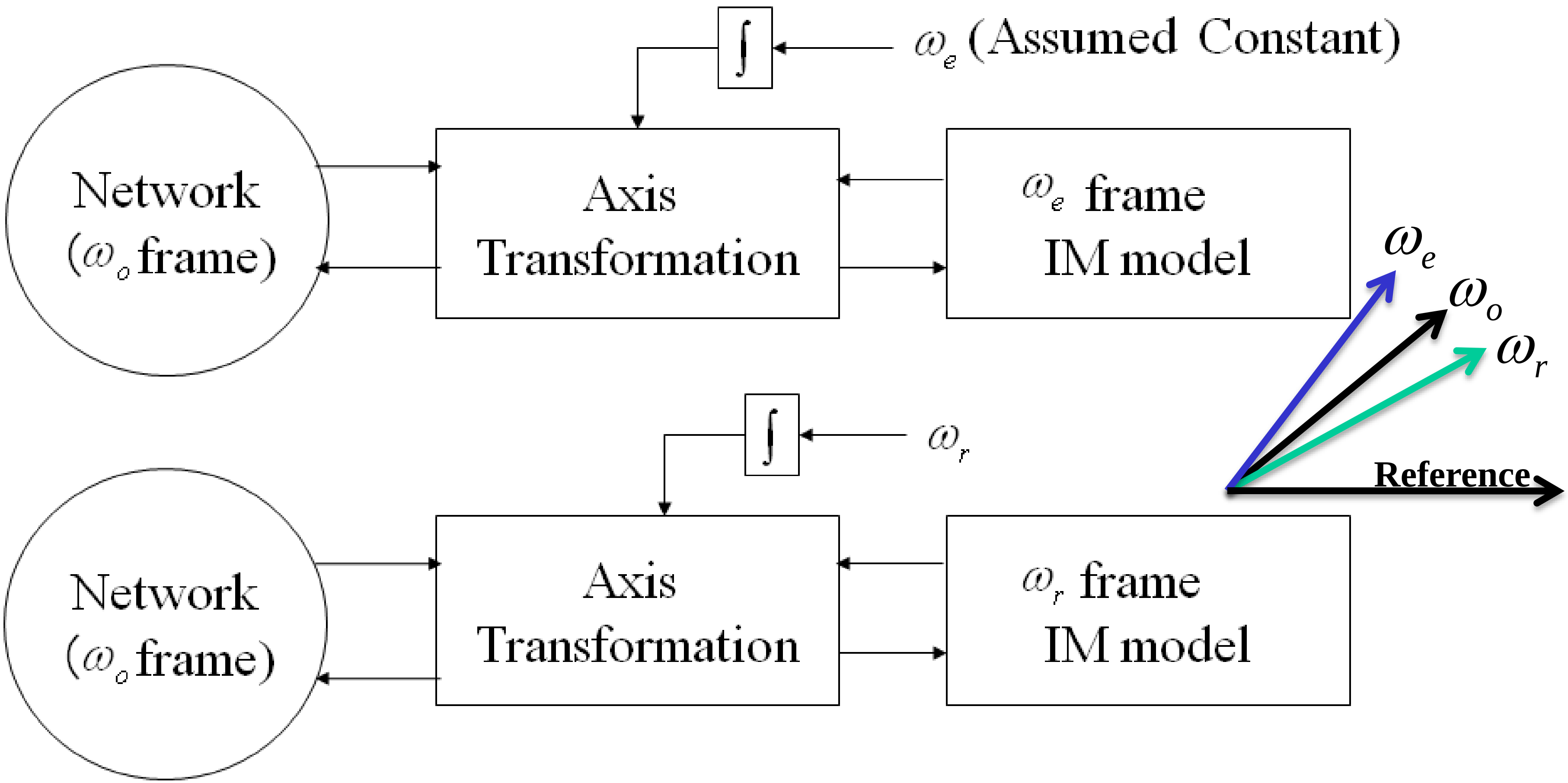
This situation should be avoided

An Example of Discontinuity

- ➢ Phase angle step
- ➢ At t = 0.3 second
- ➢ By 30 degree

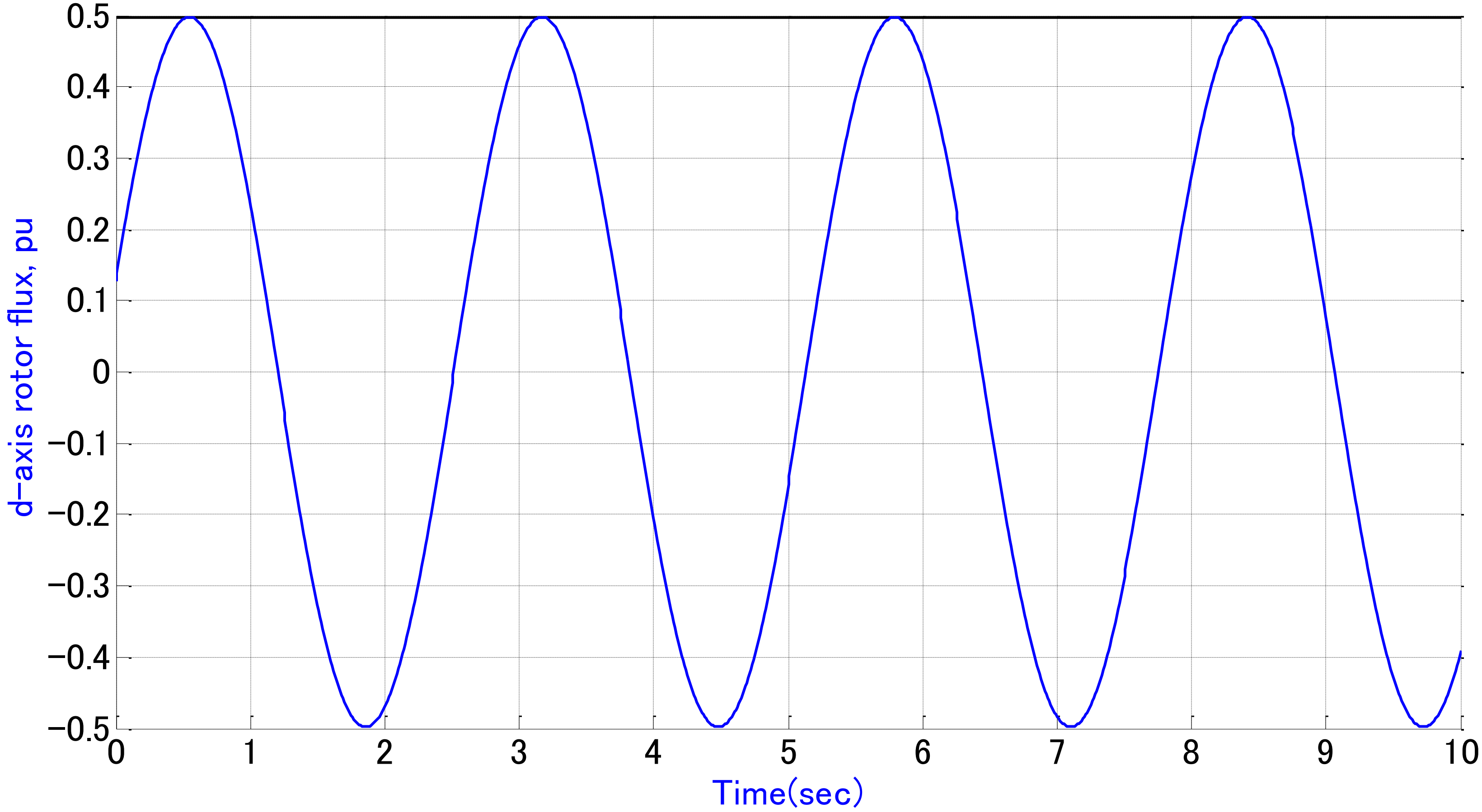


Proposed Implementation



- Similar to the synchronous machine implementation

$\omega_{\bar{r}}$-Frame State Variables



- Oscillating in a slip frequency

Reduction into 3rd Order Model

- Stator flux dynamics neglected

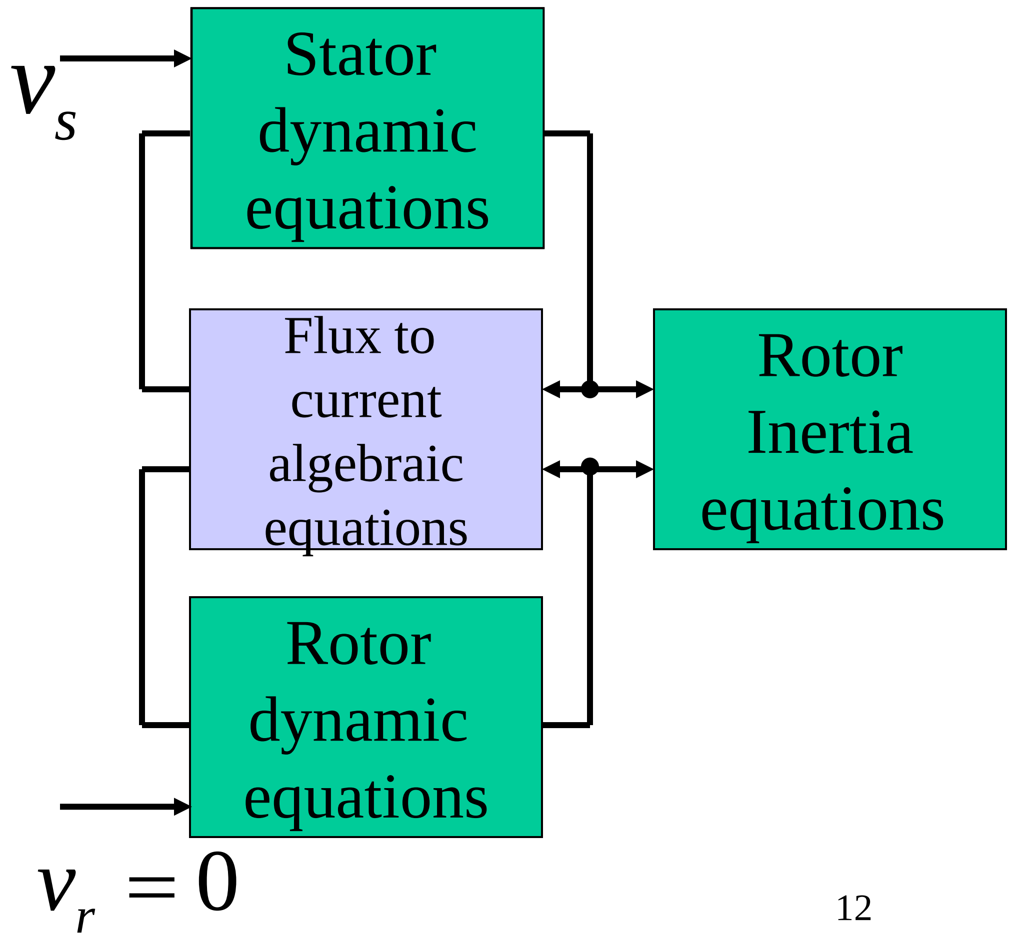
Fifth Order Model

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

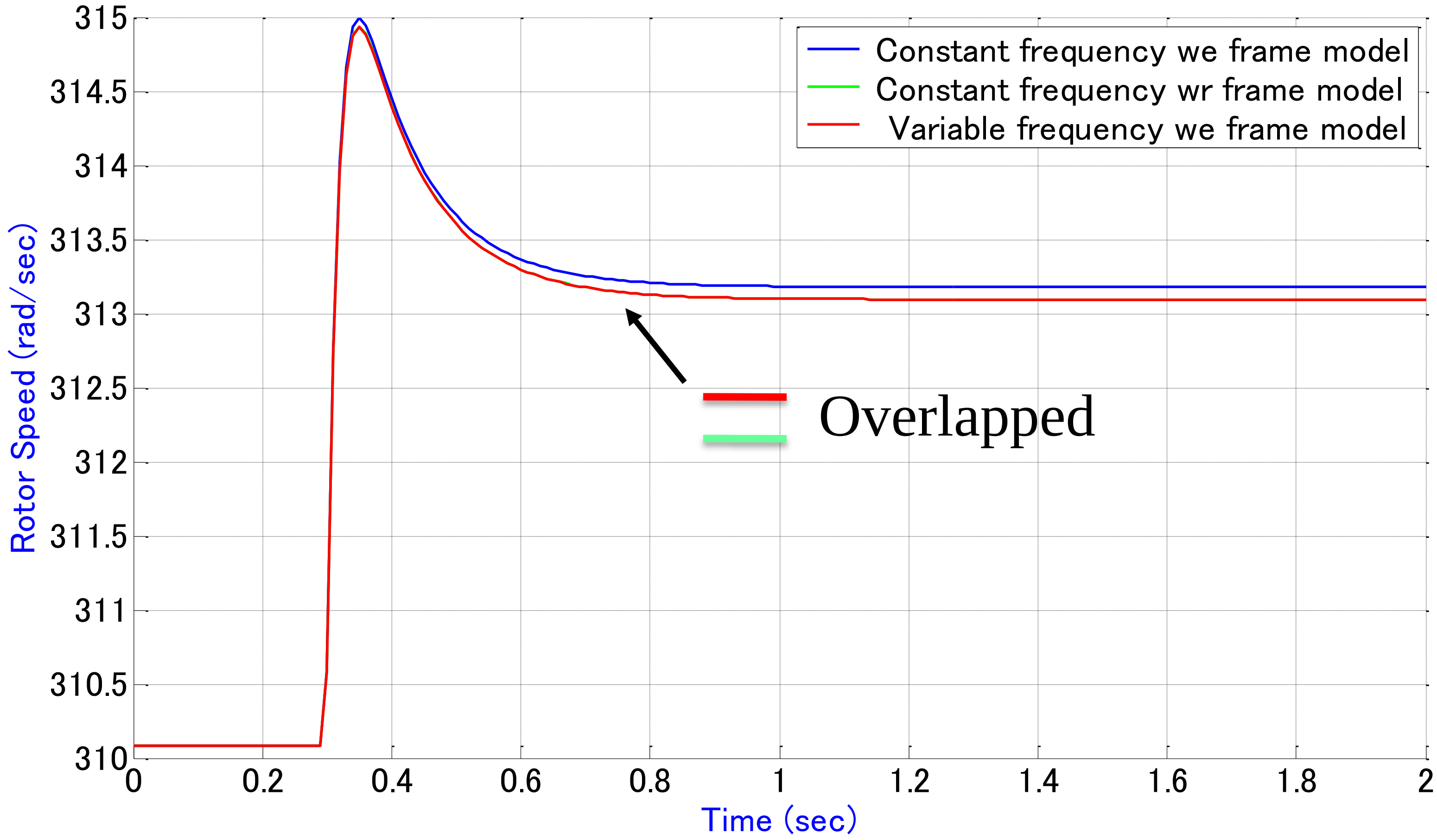
$$v_{ds}^{e} = \frac{1}{\omega_b}\frac{d\psi_{ds}^{e}}{dt} - \frac{\omega_e}{\omega_b}\psi_{qs}^{e} + r_s i_{ds}^{e}$$

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

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



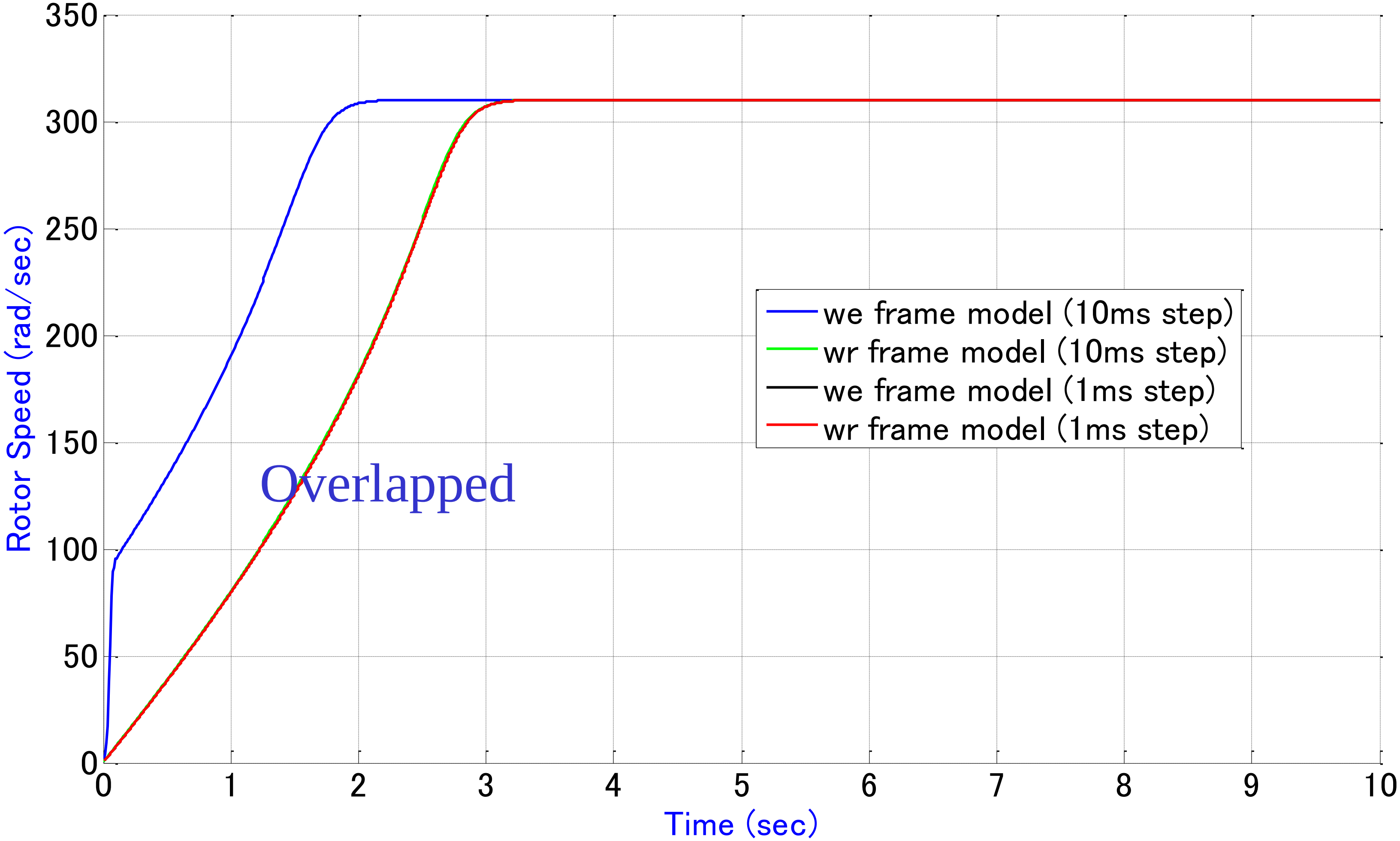
Comparison(different frames)



(approx.)
(approx.)
(accurate)

- ω_r frame model is better

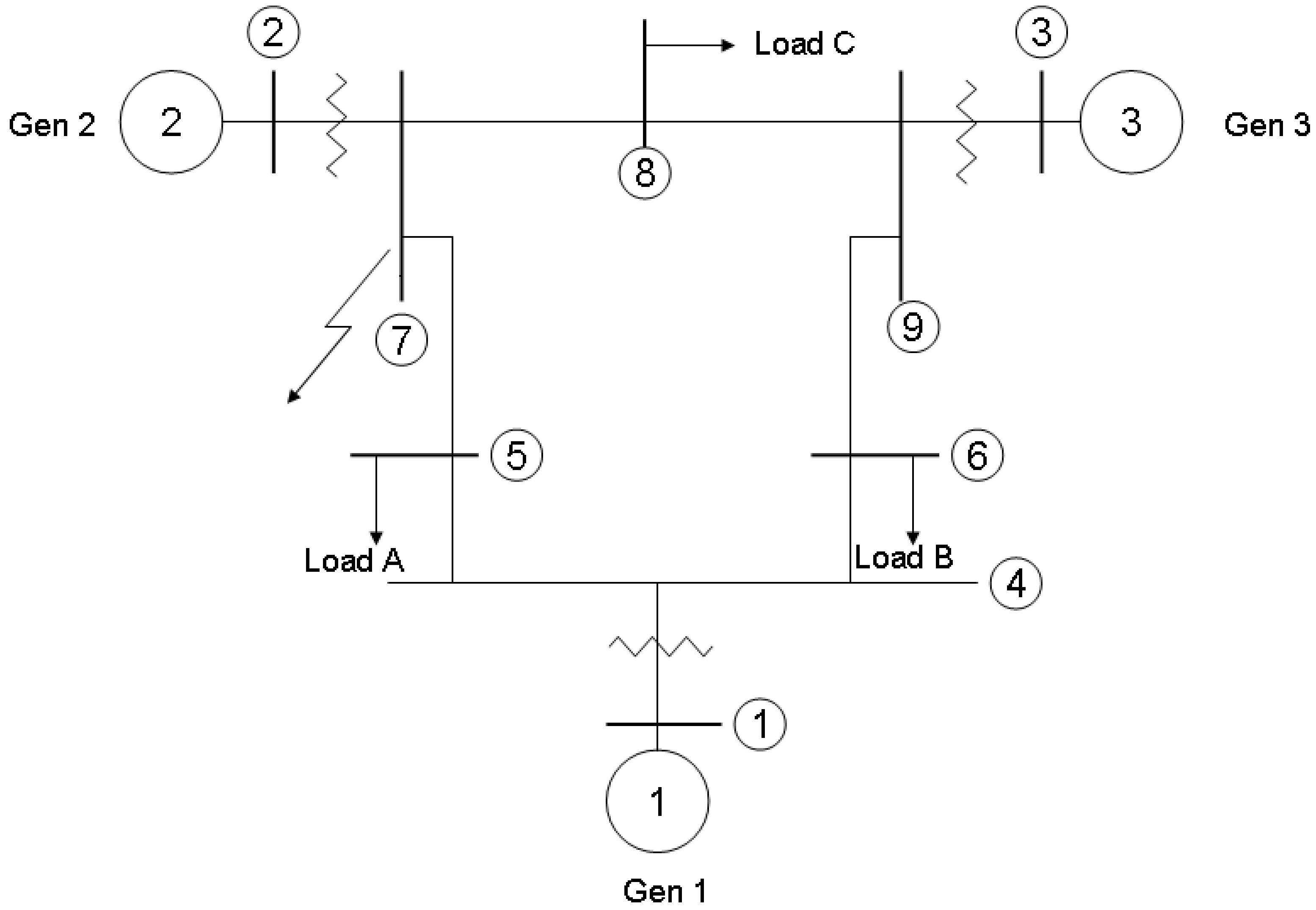
Comparison (Startup)



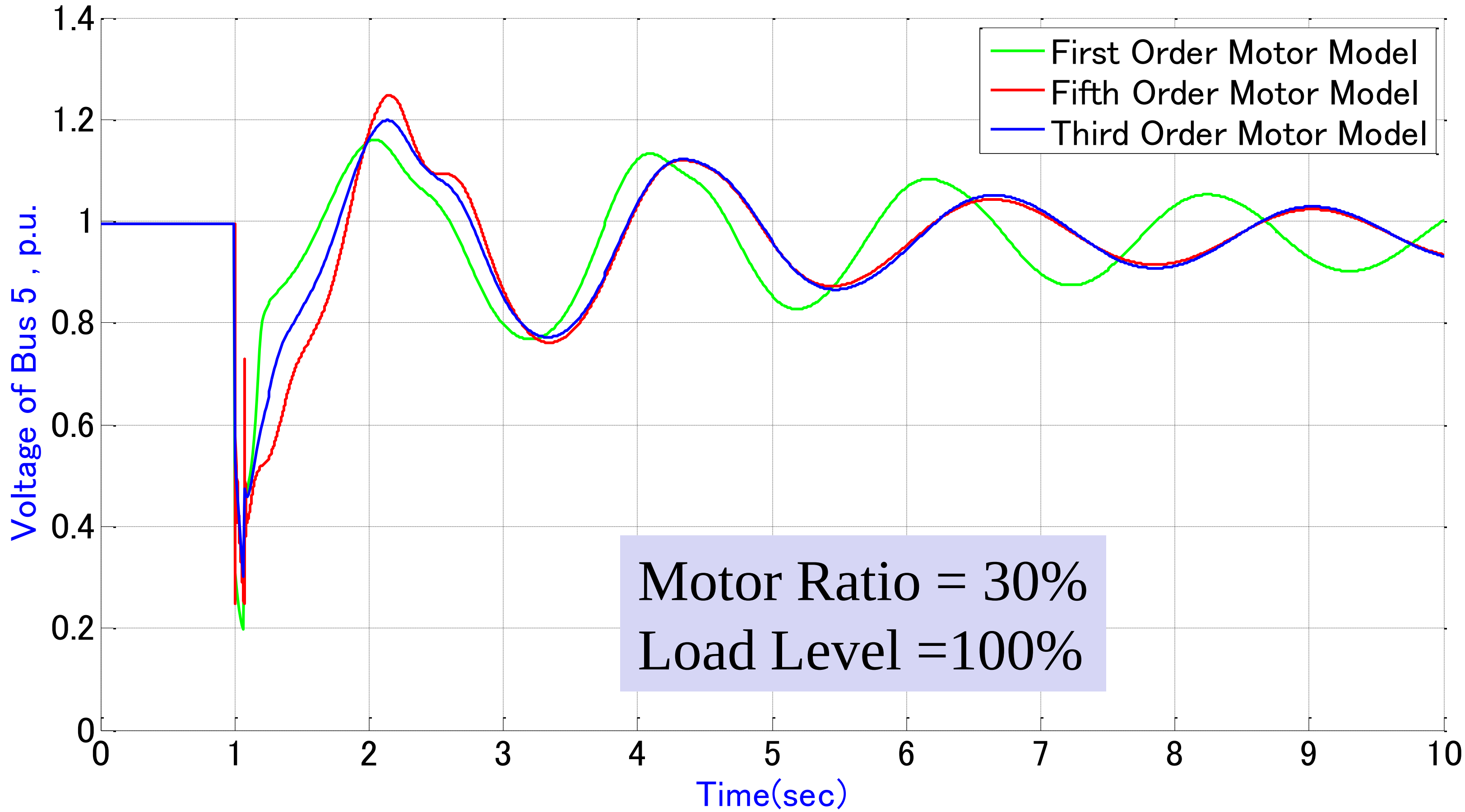
ω_r frame model is numerically stable over different time steps

- Background
- Objective
- Induction motor modeling issue
  - Introduction of rotor speed based frame model
  - Implementation for stability study
- Comparative study of PS Stability
  - Transient stability
  - Steady state stability
- Conclusion

Study System

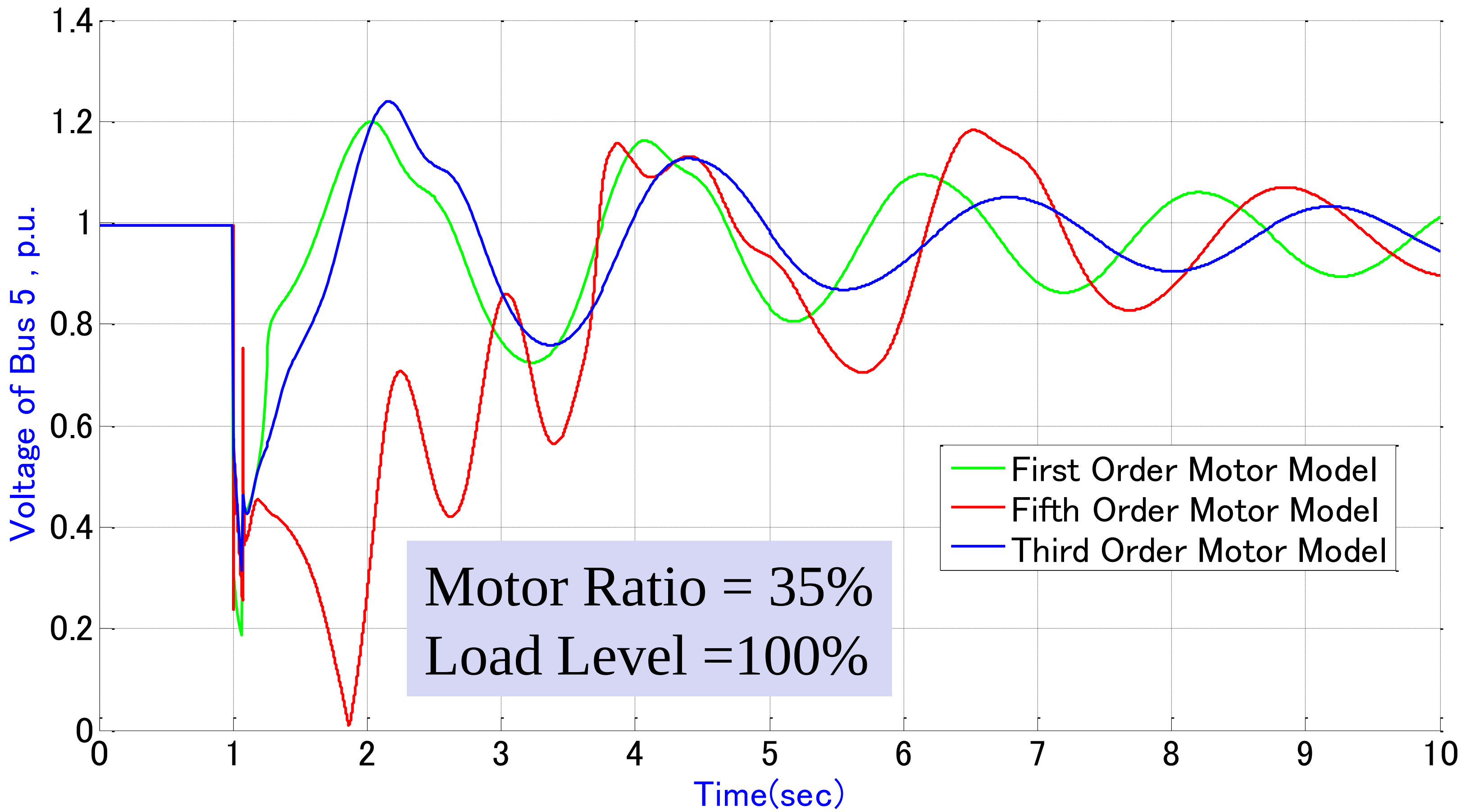


Comparison of Responses



- Third and Fifth order models have similar responses

Comparison of Responses



- Fifth order shows unstable condition

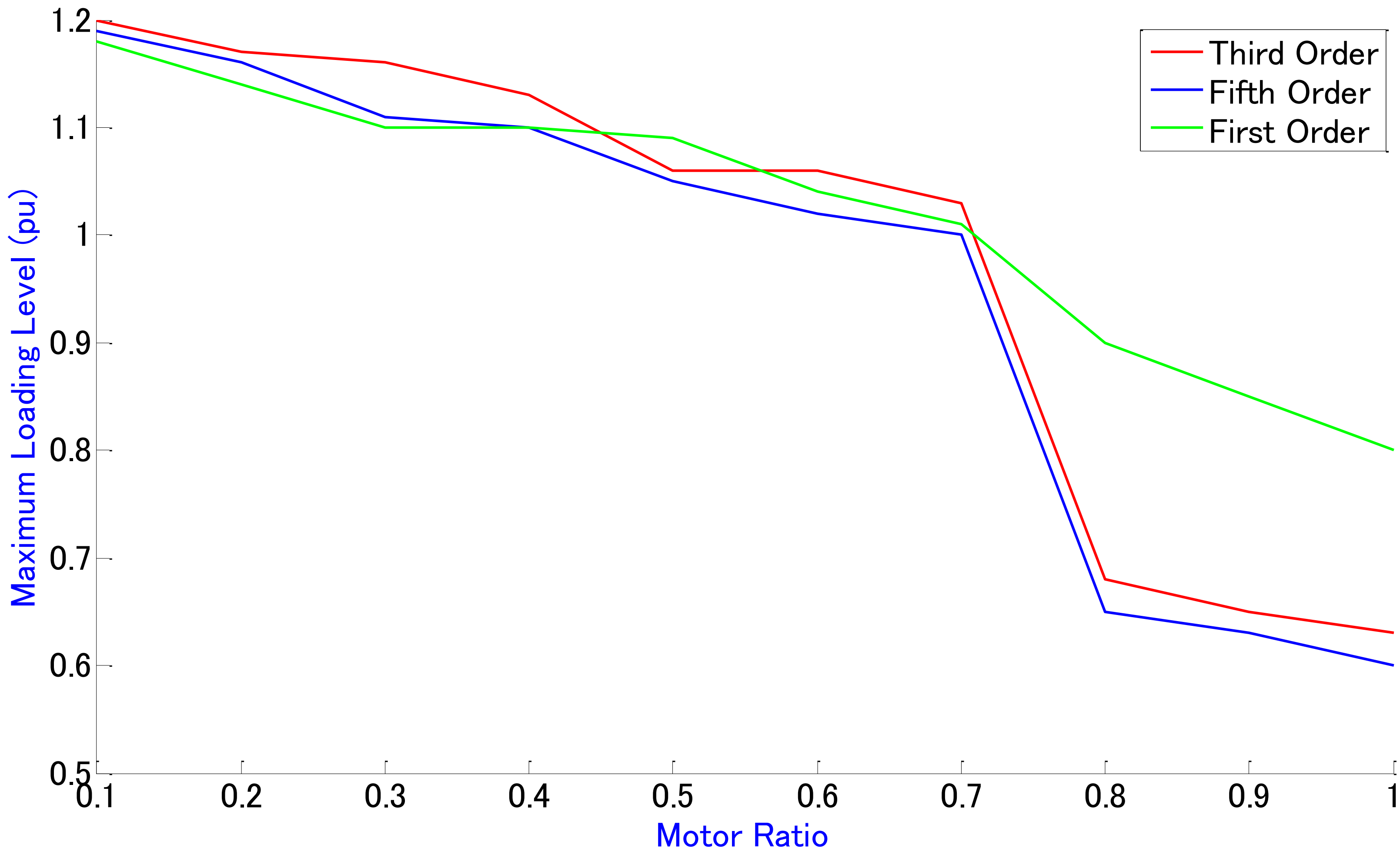
Loading Level

- Maximum power transfer capability
  - Generator stability limit considered

	Loading Level	
Model	30% Motor Load	50% Motor Load
Fifth Order	1.073	0.750
Third Order	1.198	0.869
First Order	1.271	0.882
Static Loads	1.781	

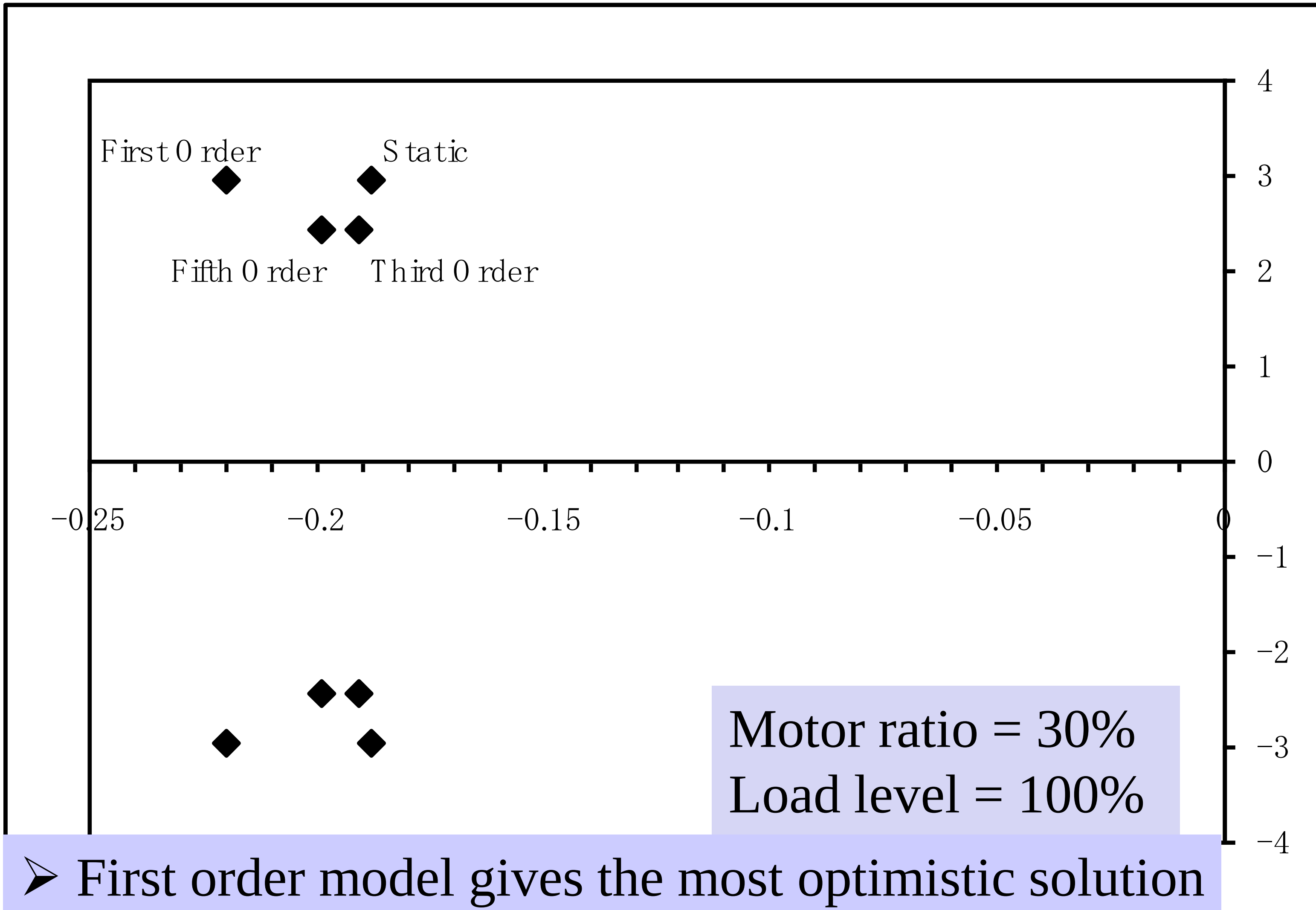
Increase ↓ (from Fifth Order down to Static Loads, in both columns)

Nonlinearity



The 5th order and the 3rd order have similar characteristics

Comparison of eigenvalues



Motor ratio = 30%
Load level = 100%

- First order model gives the most optimistic solution

Conclusion

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

Thank you very much!!

Questions/Comments are Welcome!