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

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ICEE2008, Okinawa, Japan
July 7, 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

- ➢ Load Modeling for Stability Assessment

- ➢ Dynamic loads → Induction Motors

- ➢ Issues of Induction Motor Modeling
  - Properness of the available models
  - Choice of coordinate system
  - Selection of proper model

Objective

- Modeling in rotor speed based frame
- Comparison of accuracy
- Transient stability analysis
- Steady state stability analysis

Induction Motor Modeling Issue

Induction motor modeling

➢ Different frames

- ω_e-frame
- ω_r -frame (proposed)

➢ 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

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

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

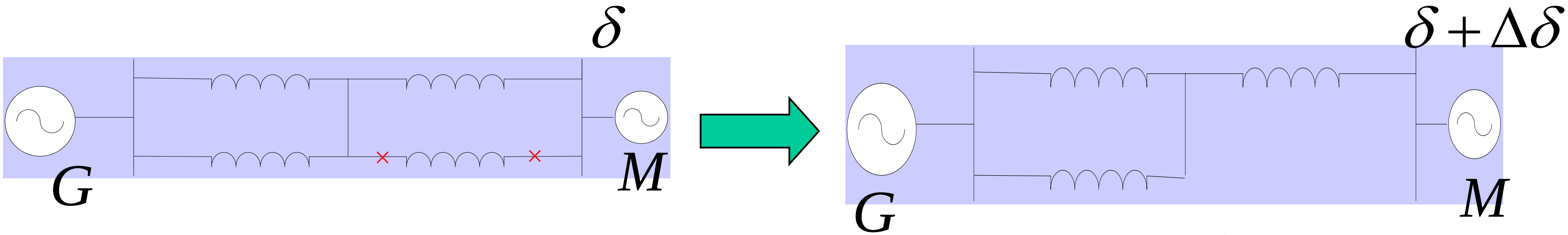
Rotor equations

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

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

$v_r = 0$

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

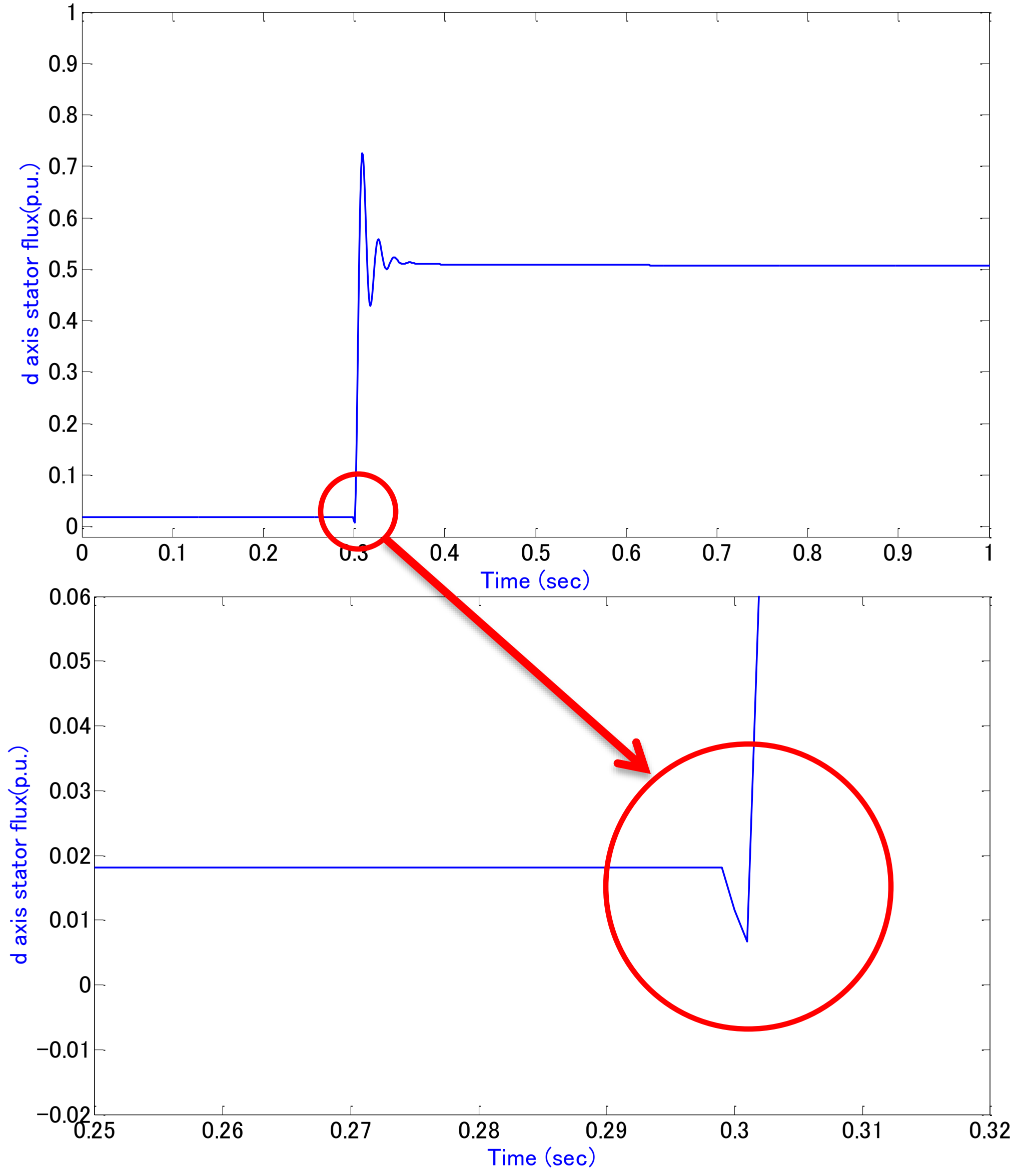
ψ discontinuous $\left[\boldsymbol{v} = \frac{1}{\omega_b}\frac{d\boldsymbol{\psi}}{dt} + \frac{1}{\omega_b}\omega_e \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \boldsymbol{\psi} + r\boldsymbol{i} \right]$

This means the discontinuity of state variables

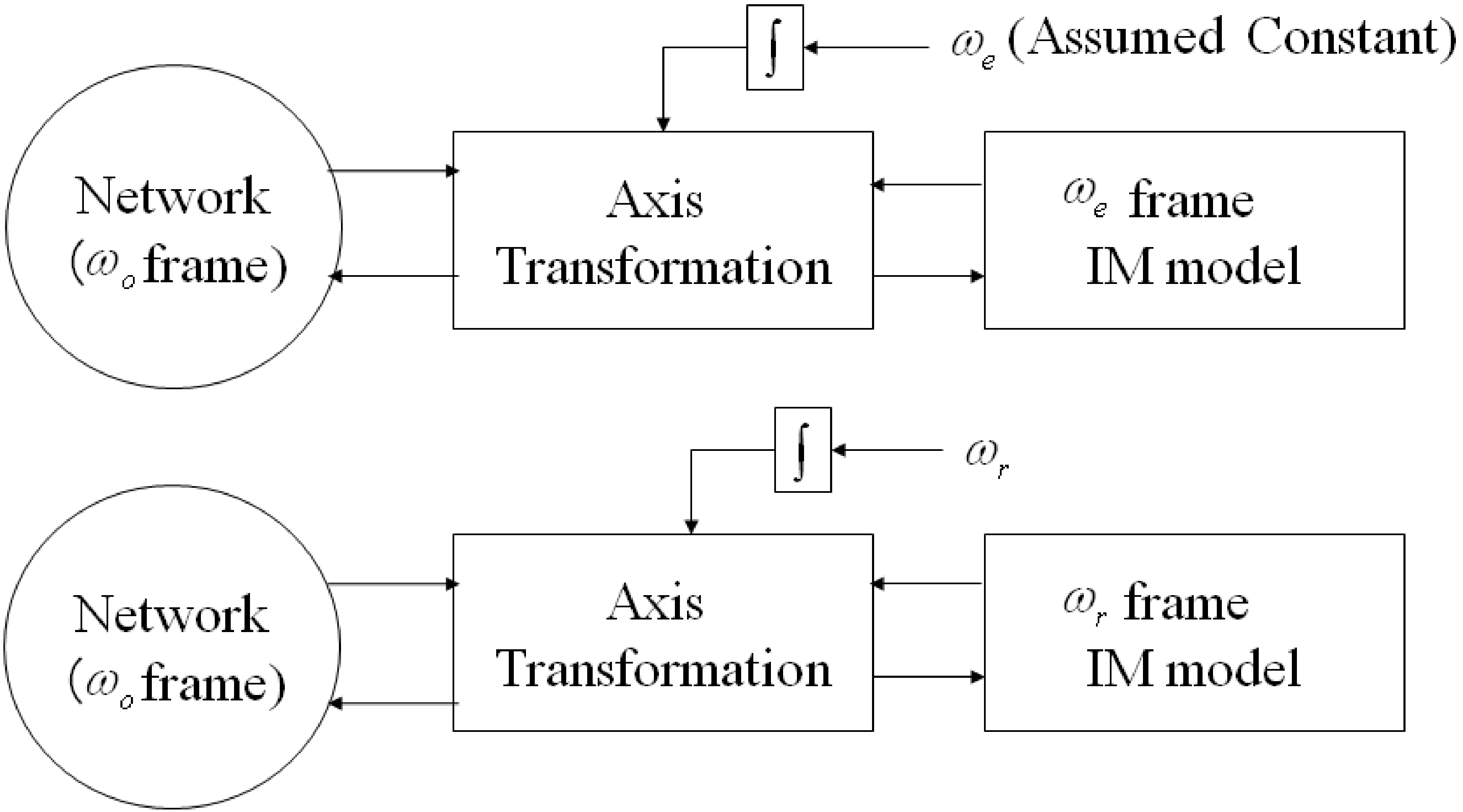
This situation should be avoided

An Example of Discontinuity

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



Implementation techniques



➢ Similar to the synchronous machine implementation

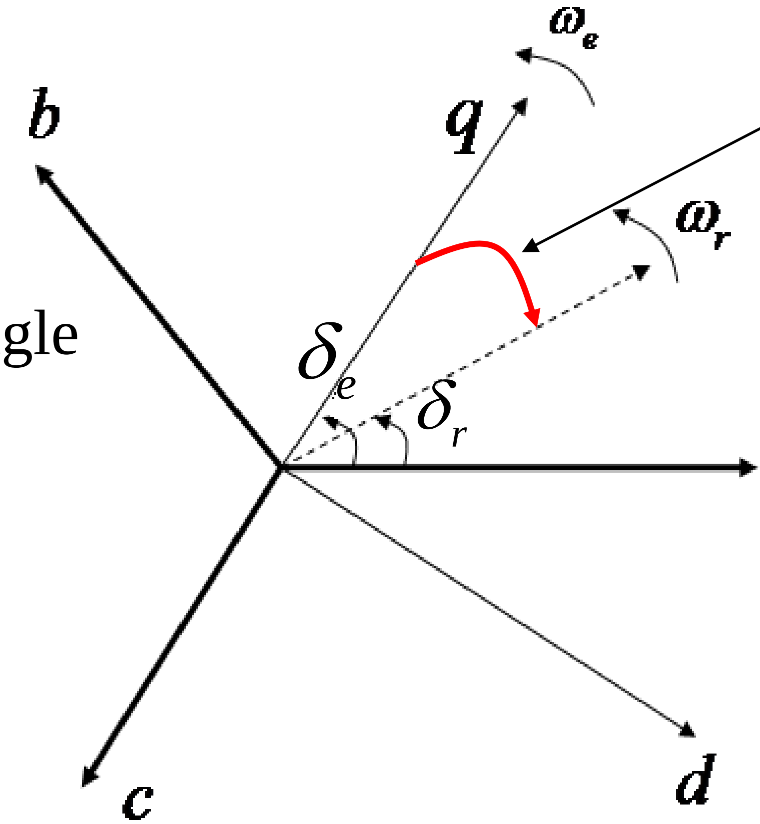
Axis transformation

- Shifting the axis of rotating q-d frame
- Eliminates ω_e from equations

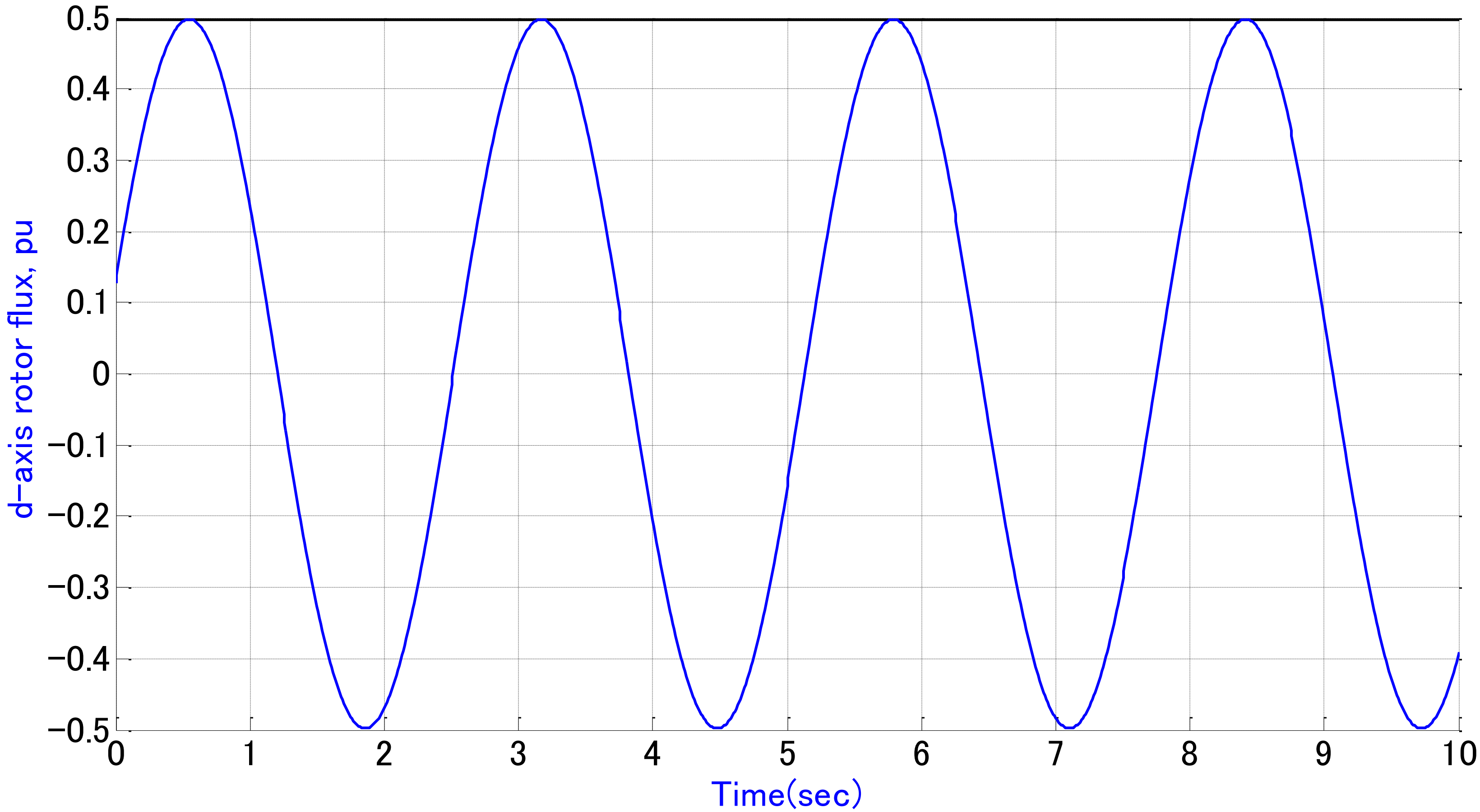
shifting angle
$(\delta_e - \delta_r)$

δ_e = bus voltage angle

δ_r = rotor angle



ω_r-Frame state variables



➢ Oscillating in a slip frequency

Reduction into 3rd Order Model

- Stator flux dynamics neglected

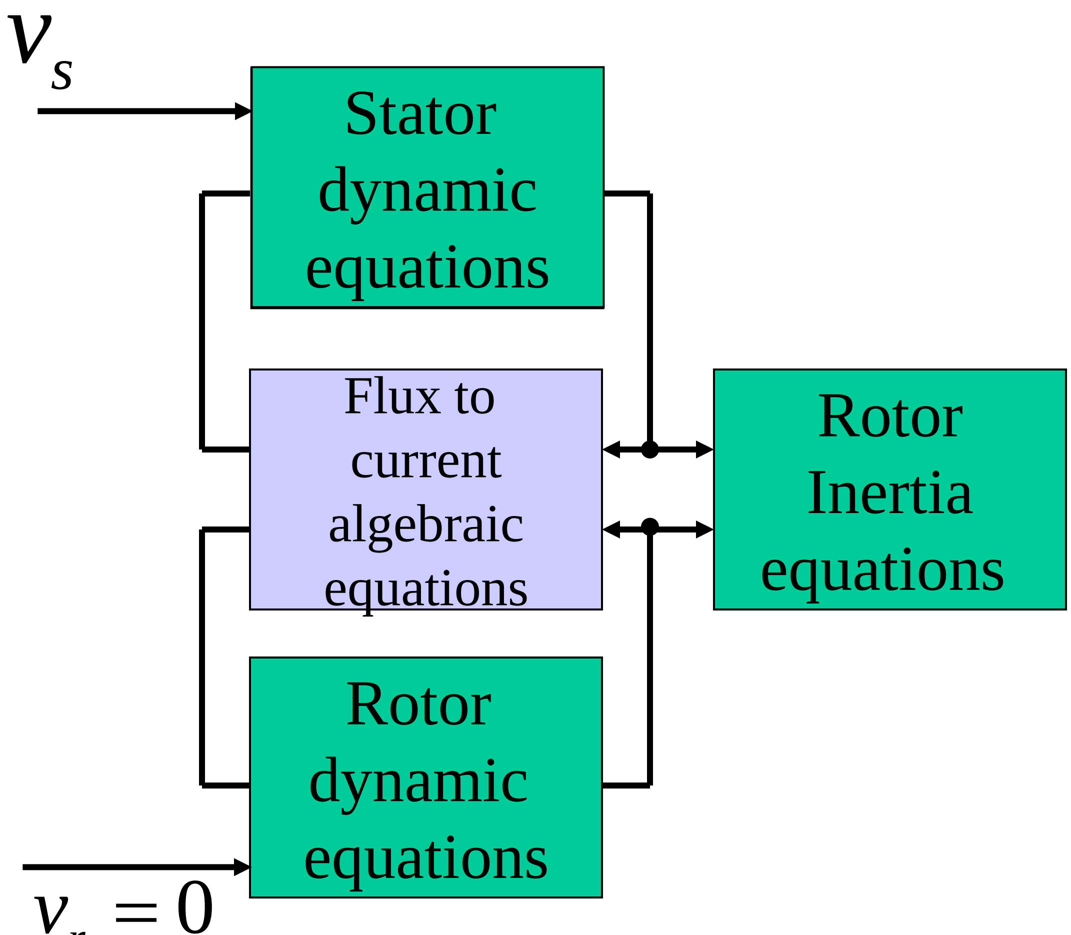
$$v_{qs}^e = \frac{1}{\omega_b}\frac{d\psi_{qs}^e}{dt} + \frac{\omega_e}{\omega_b}\psi_{ds}^e + r_s i_{qs}^e$$

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

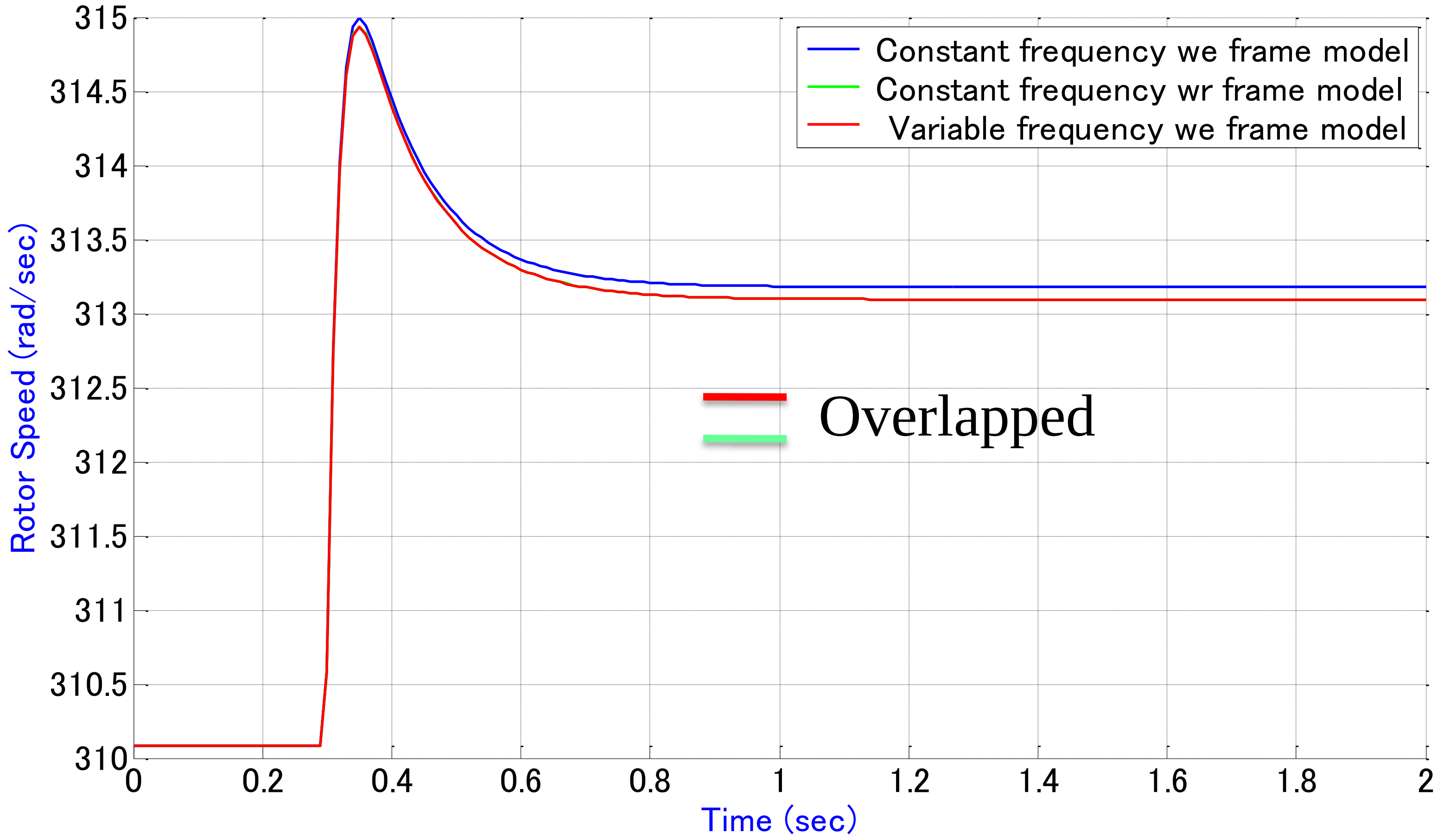
$$v_{qs}^e = \frac{1}{\omega_b}\frac{d\psi_{qs}^e}{dt} + \frac{\omega_e}{\omega_b}\psi_{ds}^e + r_s i_{qs}^e$$

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

Fifth Order Model

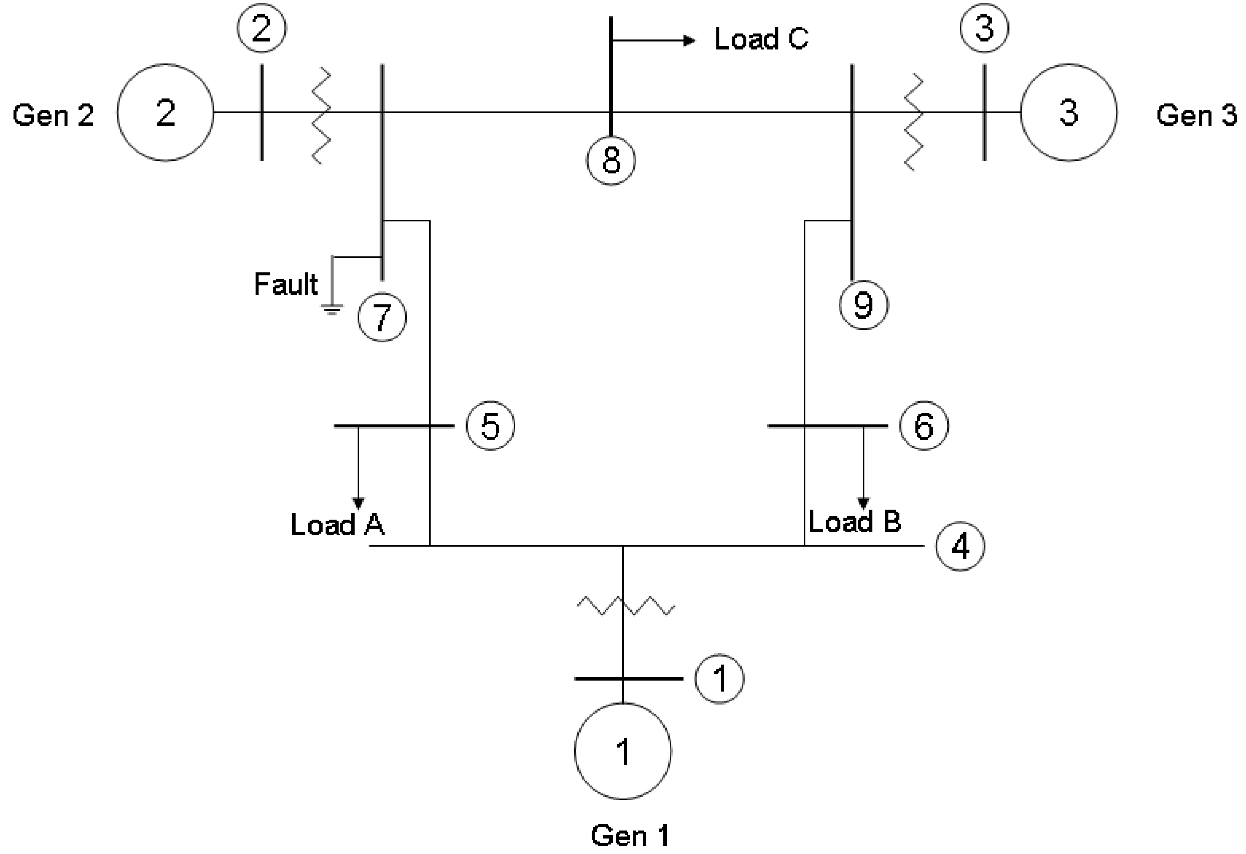


Comparison(different frames)

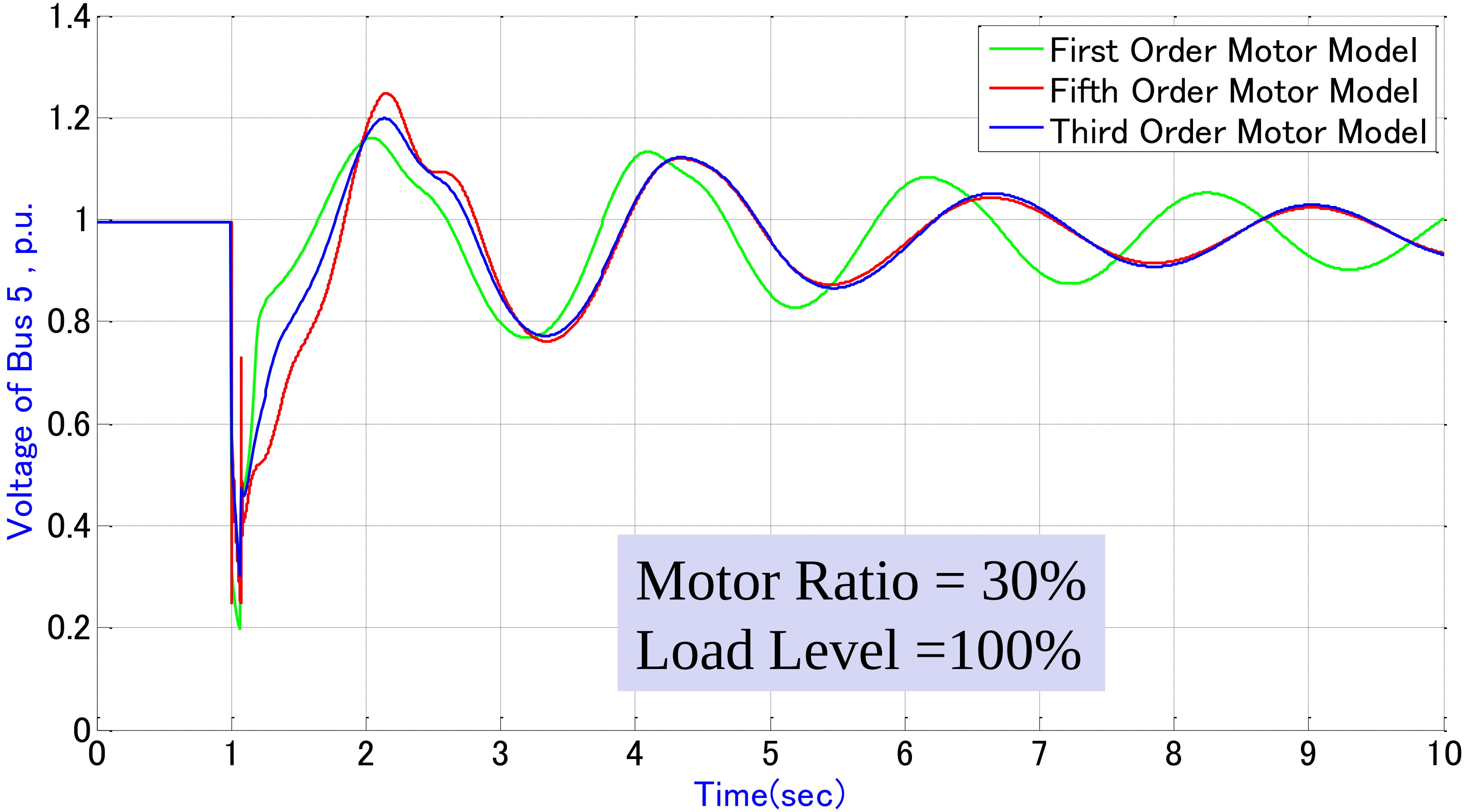


- ω_r frame model is better

Comparative study of PS stability

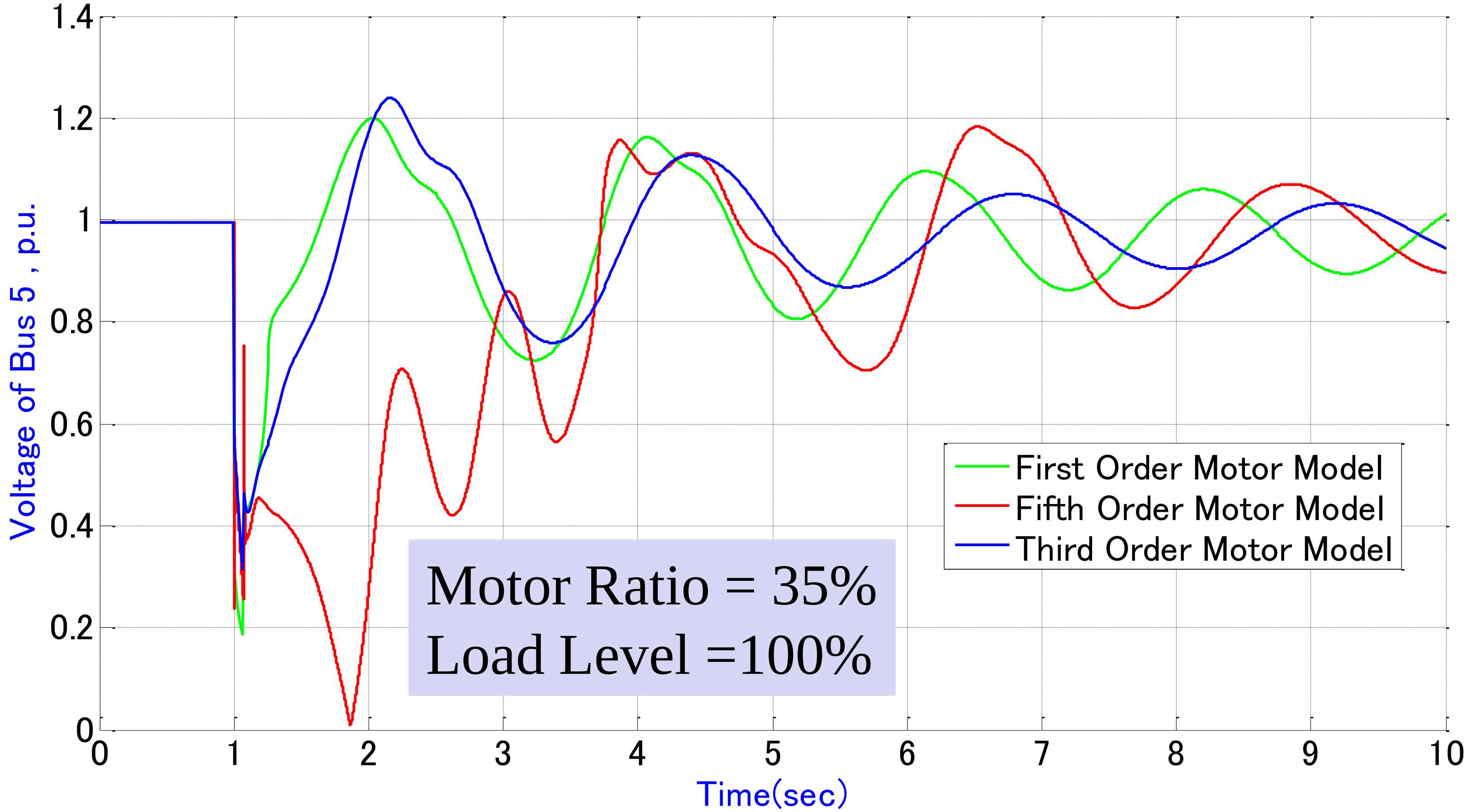


Comparison of Responses



➢ Third and Fifth order models have similar responses

Comparison of Responses



➢ Fifth order shows unstable condition

Transient stability Analysis

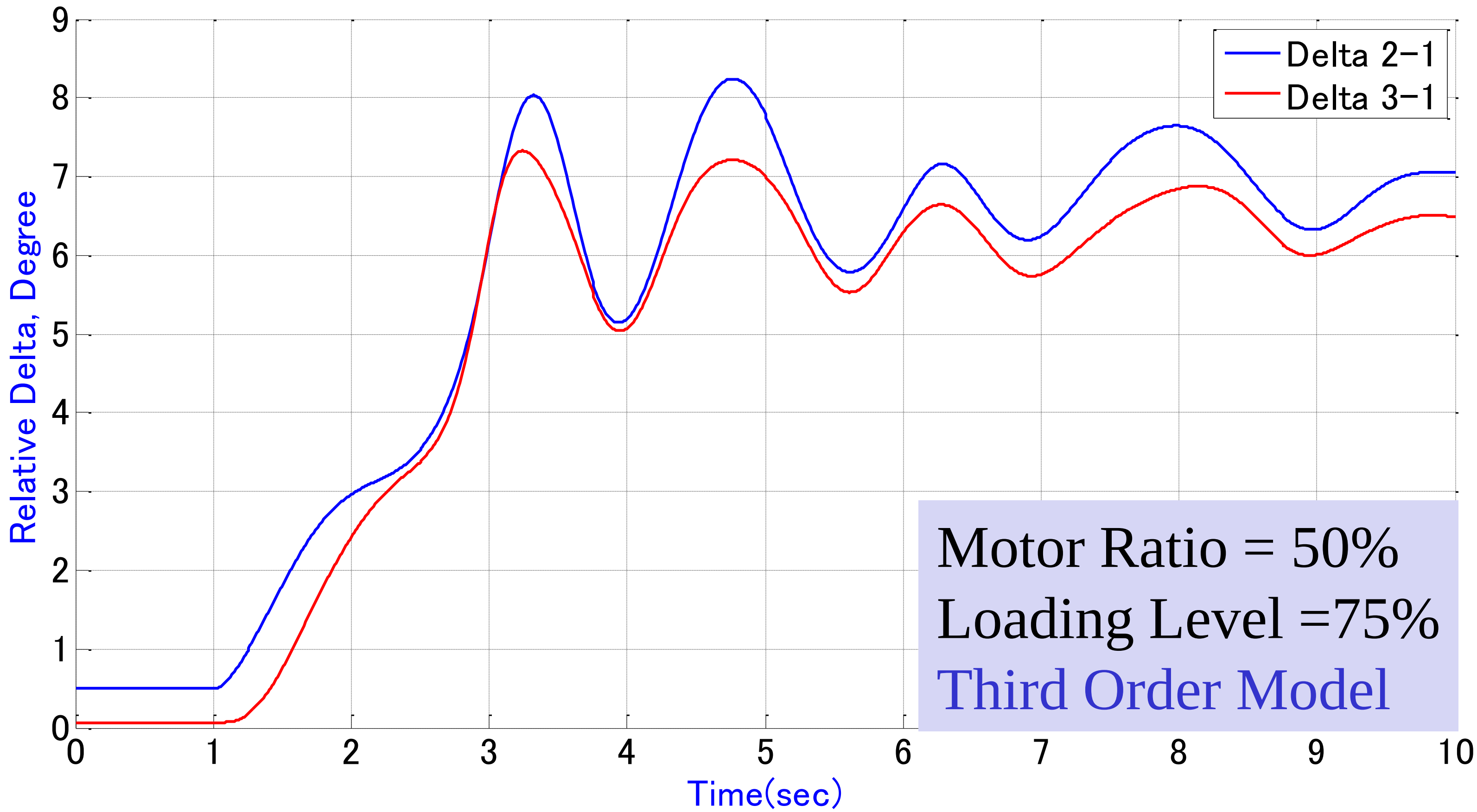
Loading Level

- 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	

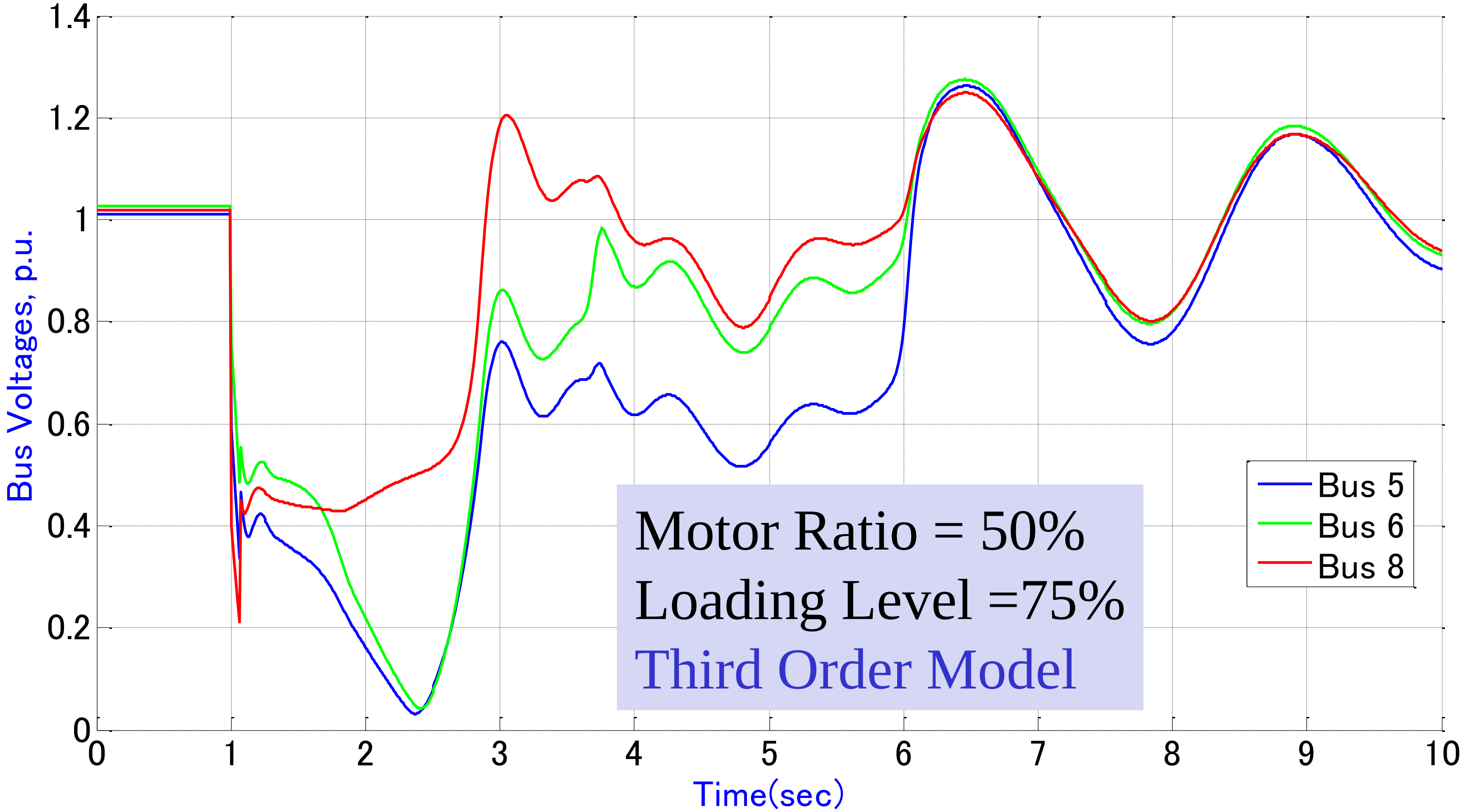
Increase

Rotor-angle Stability



- ➢ Rotor angle at generator stability limit

Voltage Stability



- Bus voltage at generator stability limit

Steady-State Stability Analysis

Oscillation modes

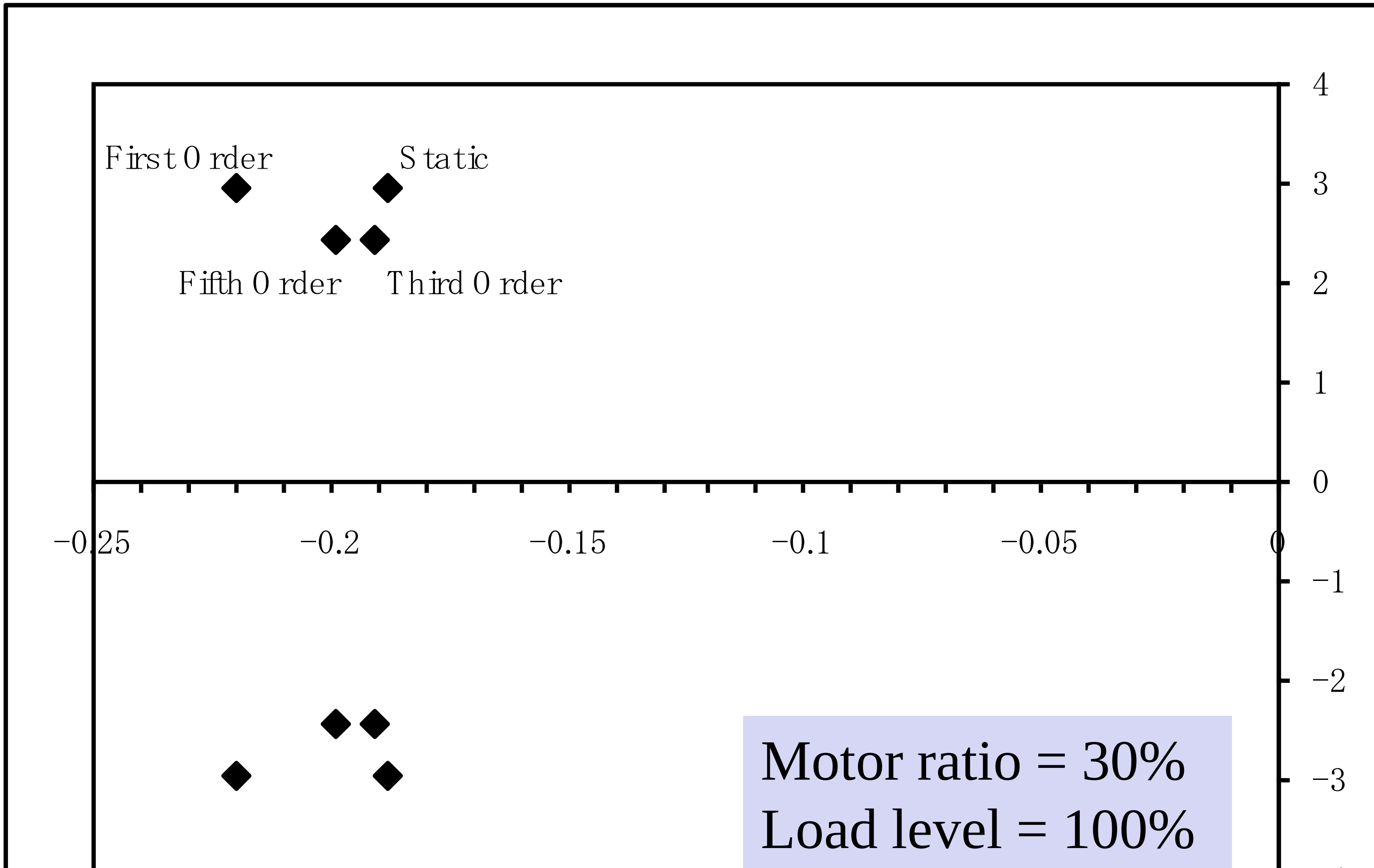
- Fast modes

  - high frequency/high damping coefficients
  - less significant modes

- Slow modes

  - low frequency/low damping coefficients
  - significant modes

Comparison of eigenvalues



- First order model gives the most optimistic solution

Conclusion

- Simulation in rotor speed based frame

  - Eliminates the possible discontinuity
  - Good Accuracy

- Transient stability

  - More motor loads → less power transfer limit
  - First order → most optimistic result

- Steady state stability

  - Higher order → poorly damped oscillations

Thank you for your kind attention!!

Questions/Comments are Welcome!