

Study of the Influence of Induction Motor Models on Dynamic Stability of a Power System

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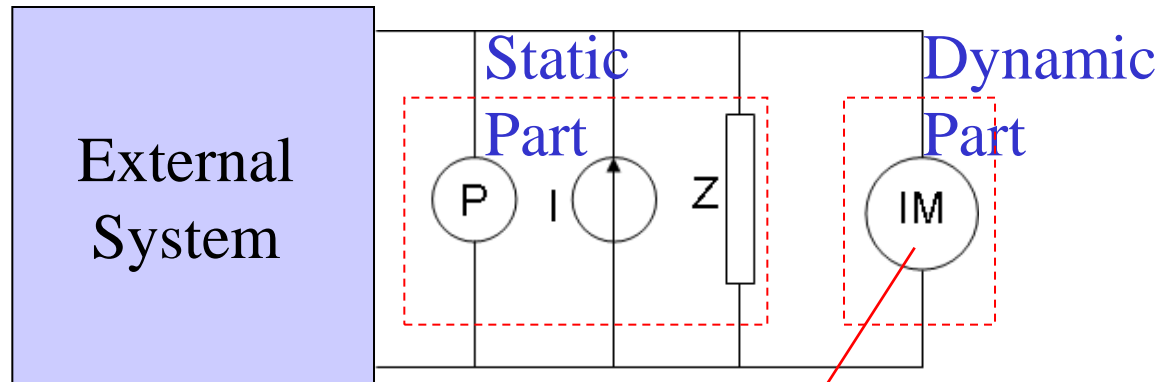
August 11, 2008

Outline of the Thesis

- **Introduction**
- X ➤ Singular Perturbation Issues
- **Induction Motor Modeling Issue**
 - **Introduction of rotor speed based frame models**
 - **Comparison of Accuracy**
- X ➤ Construction of Stability Simulator
- **Comparative Study of PS Stability**
 - **Transient stability**
 - X - Steady state stability
- **Load Modeling Considerations**
- **Conclusion & Future Works**

Background

- Phasor Based Modeling for PS Simulation
- Load Models Represent the Load Behaviors



➤ Issues of Induction Motor Modeling

- Properness of the available models
- Choice of appropriate model

Objective

- Modeling in Rotor Speed Based Frame
- Accuracy Assessment of Proposed Models
- Comparison of IM behaviors on PS Stability
- Identify the Required Inputs to the Load Models

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Induction Motor Modeling

➤ Different Frames

- ω_e -frame
- ω_r -frame (proposed)

ω_o : Nominal Frequency

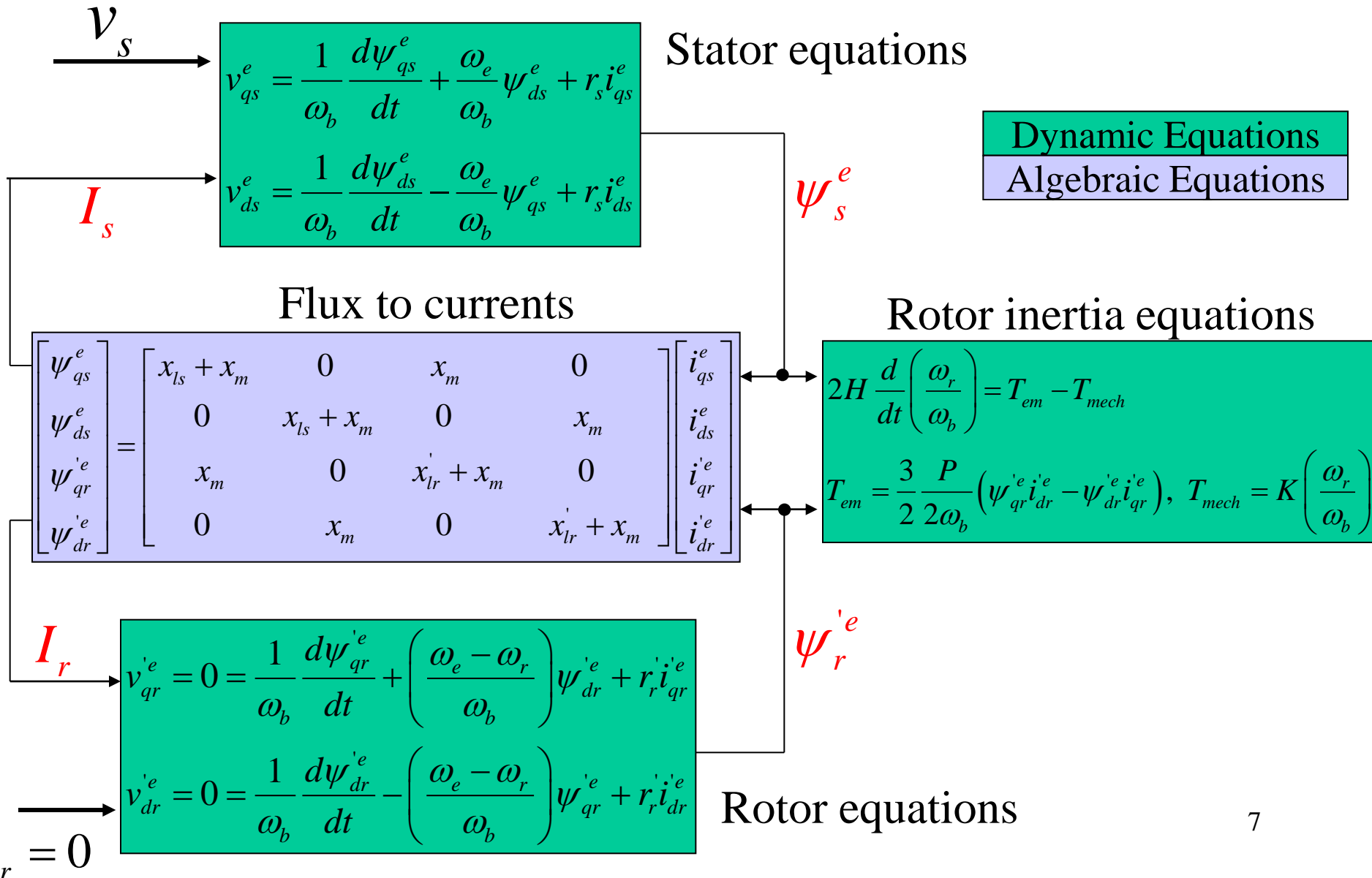
ω_e : System Frequency

ω_r : Rotor Speed

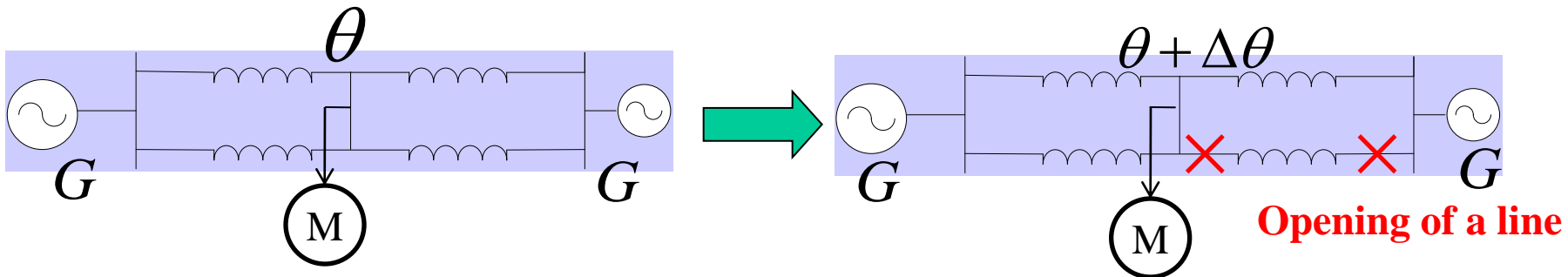
➤ Different Orders

- 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



The Discontinuity Problem



ω_e unbounded $\left[\lim_{\Delta t \rightarrow 0} \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt} = \omega_e \right]$ $\Delta\theta$ discontinuous

Stator equations

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

This means the discontinuity of state variables

This situation should be avoided

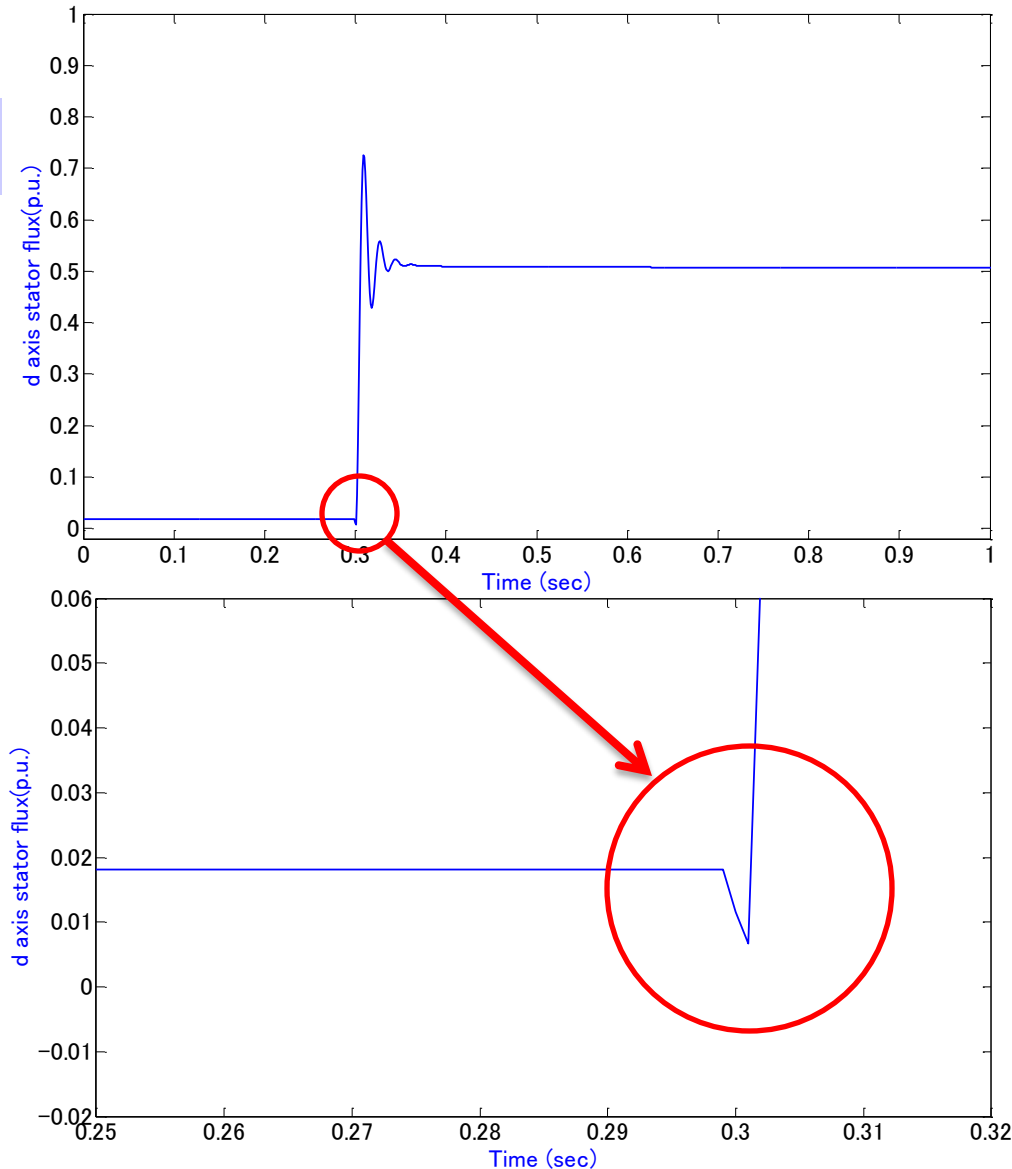
An Example of Discontinuity

➤ Phase angle step

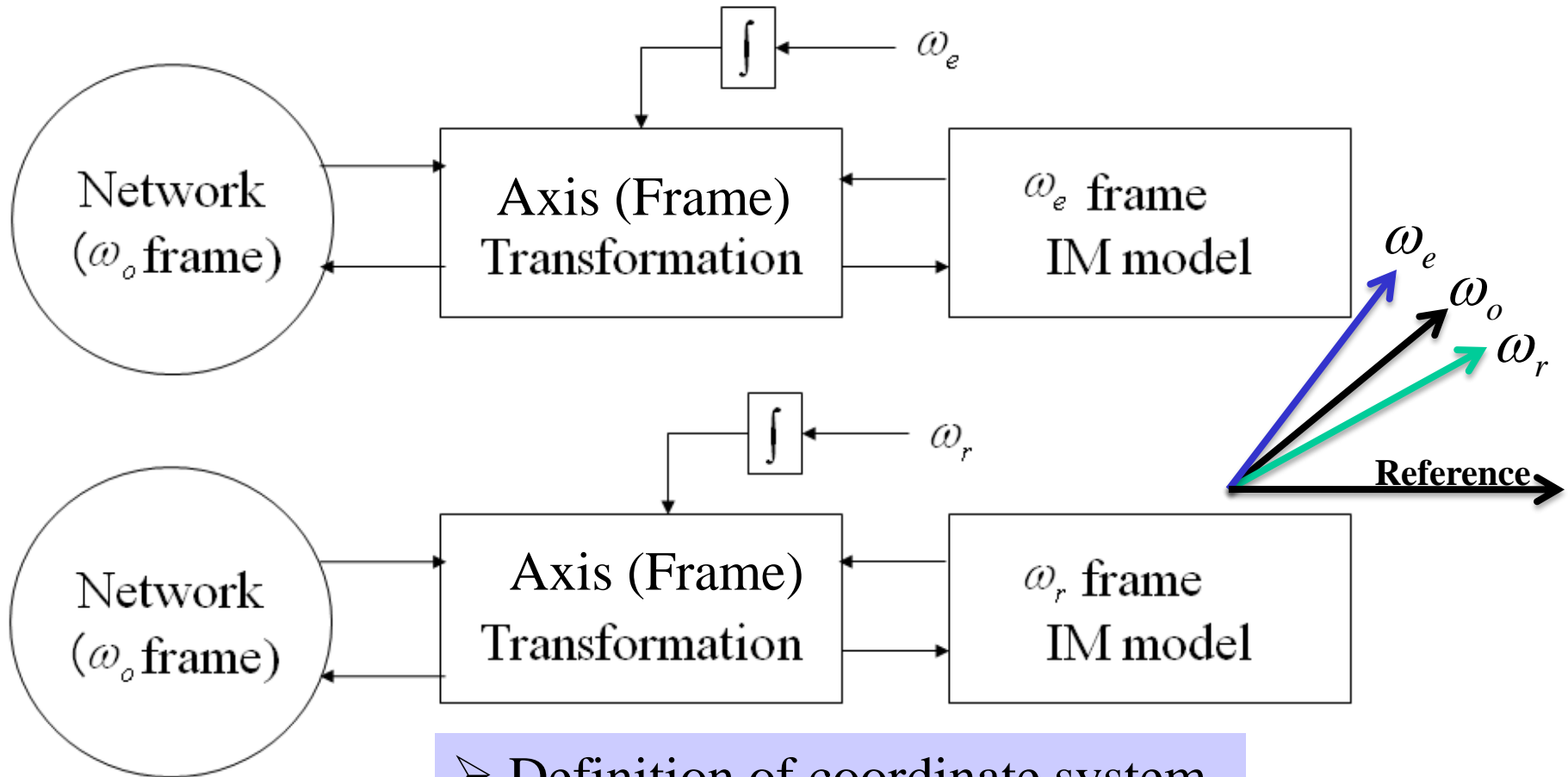
➤ At $t = 0.3$ second

➤ By 30 degree

➤ Practical problem shown later



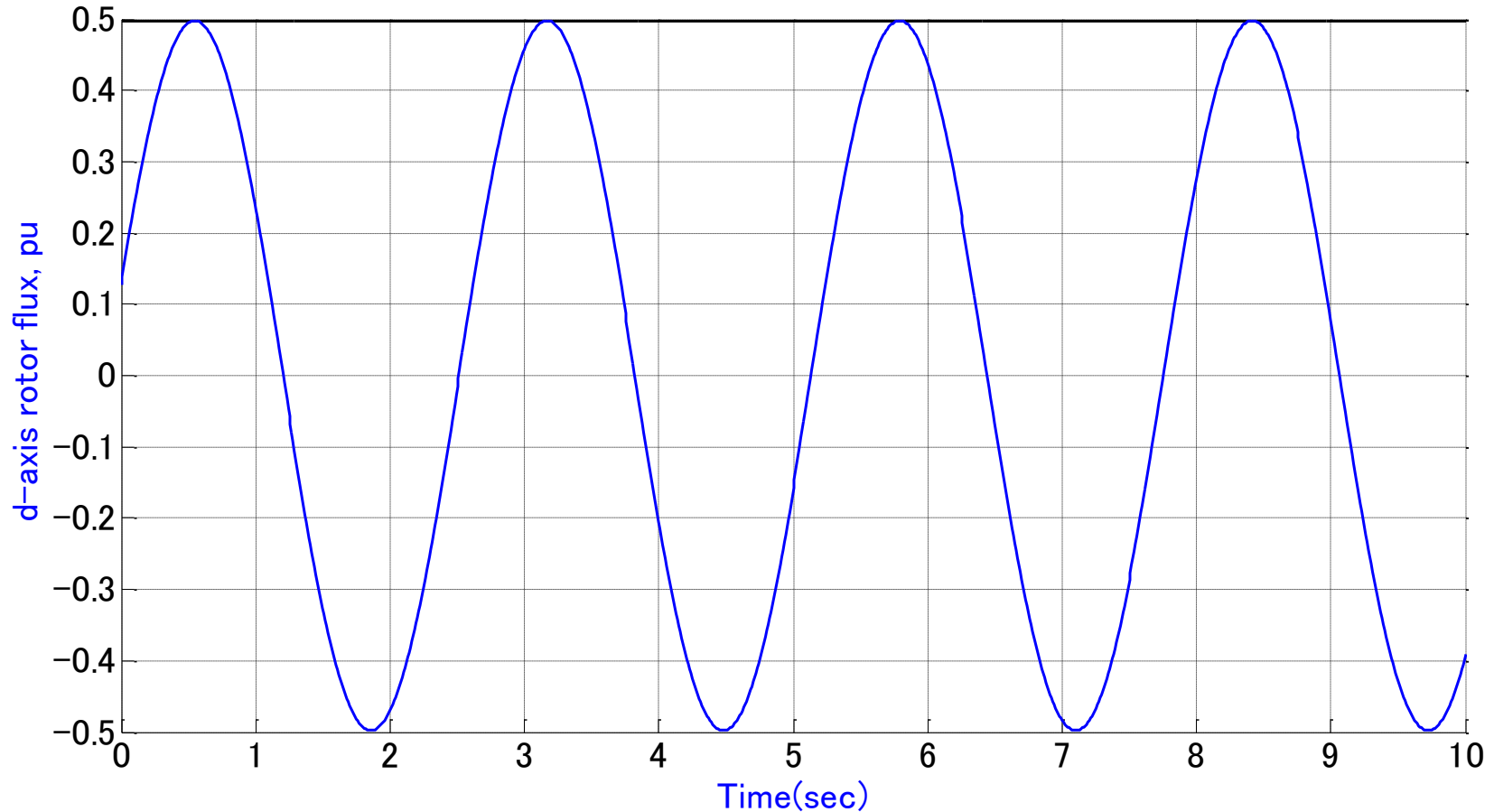
Proposed Implementation



➤ Definition of coordinate system

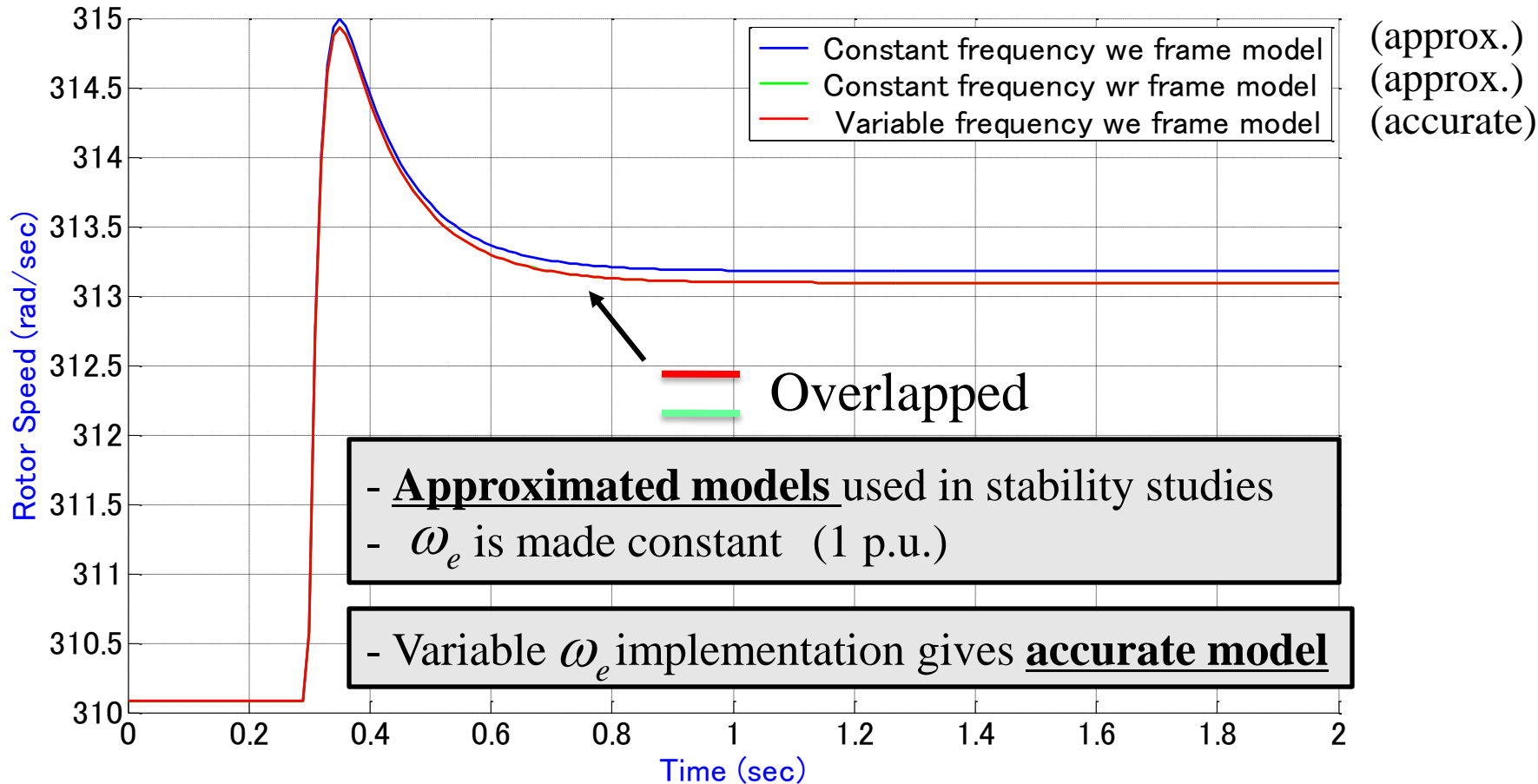
➤ Similar to the synchronous machine implementation

ω_r -frame state variables



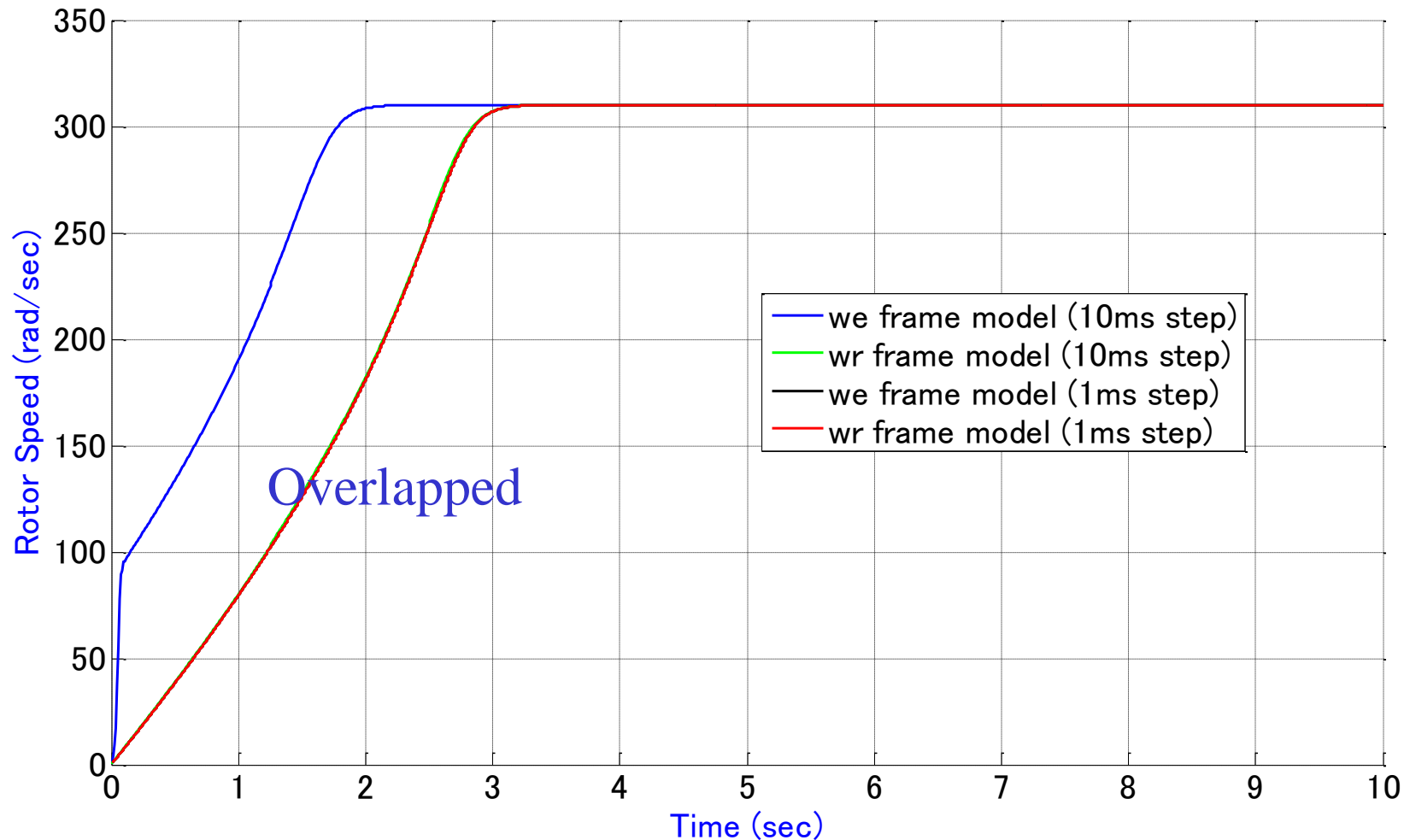
➤ ω_r frame state variable is oscillating in a slip frequency

Comparison (Steady-State)



➤ ω_r frame model is better

Comparison (Startup)

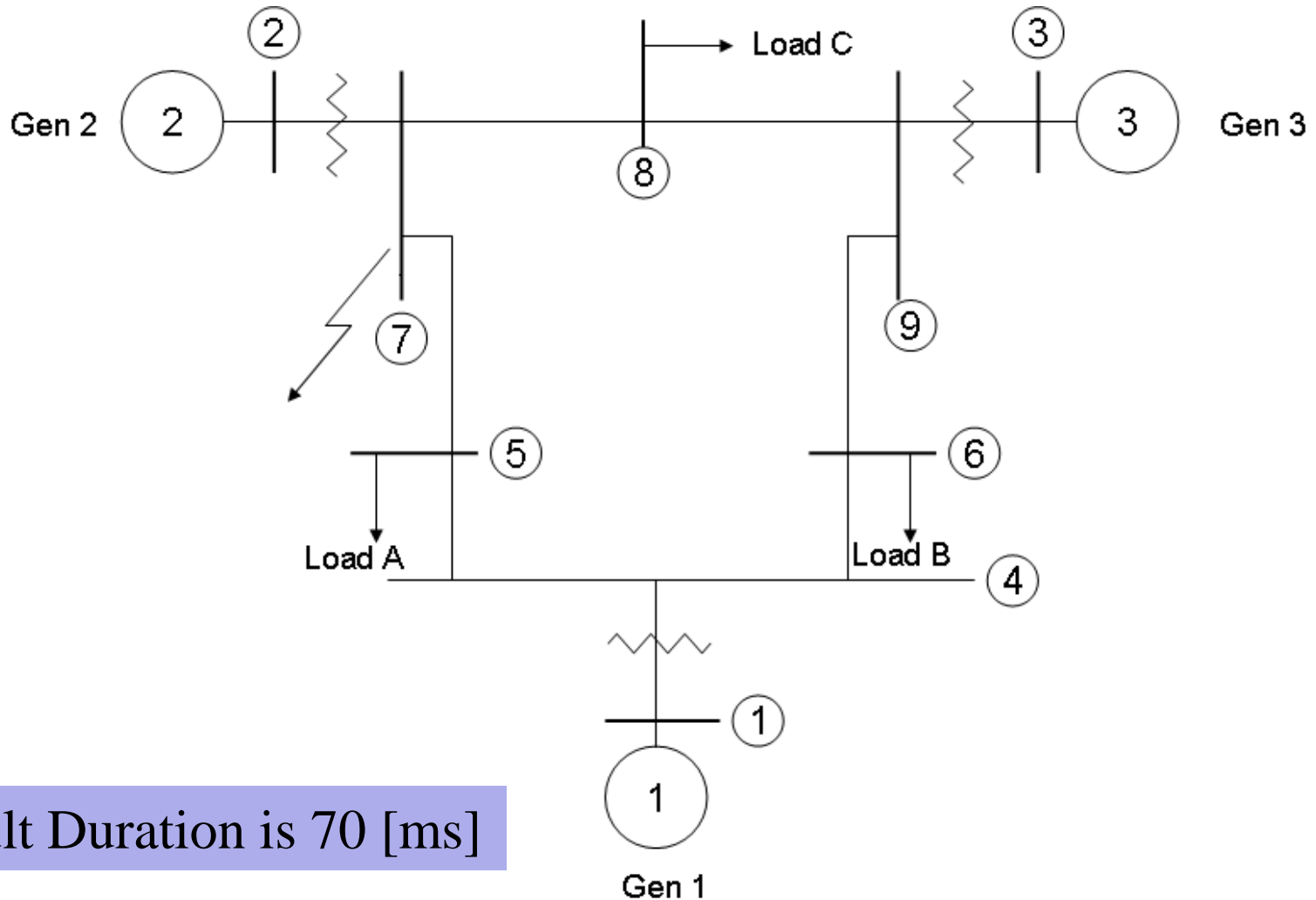


ω_e frame model has numerical problem with different time steps

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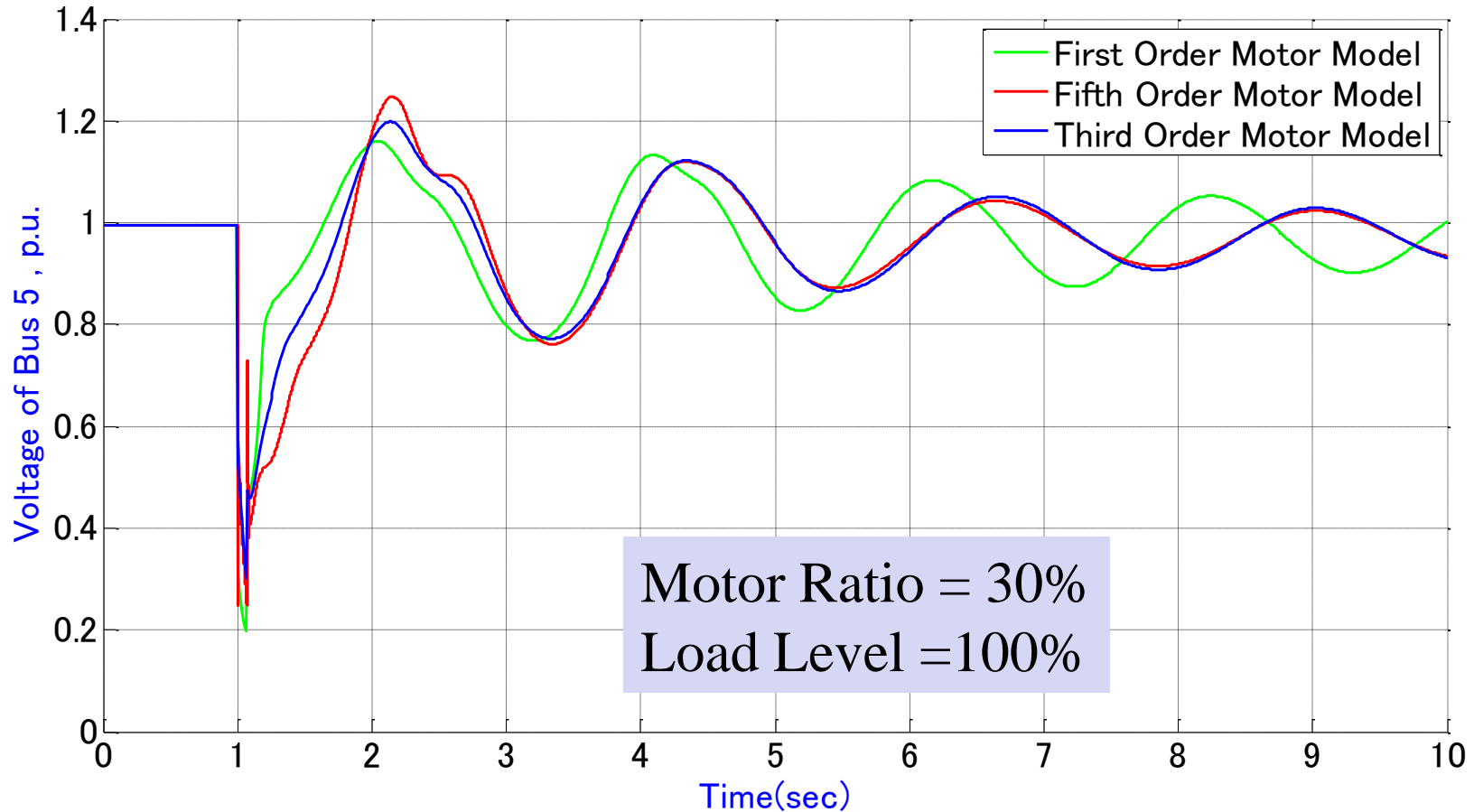
Study System



➤ Fault Duration is 70 [ms]

➤ Fault cleared by opening the line 5-7

Responses to a Disturbance



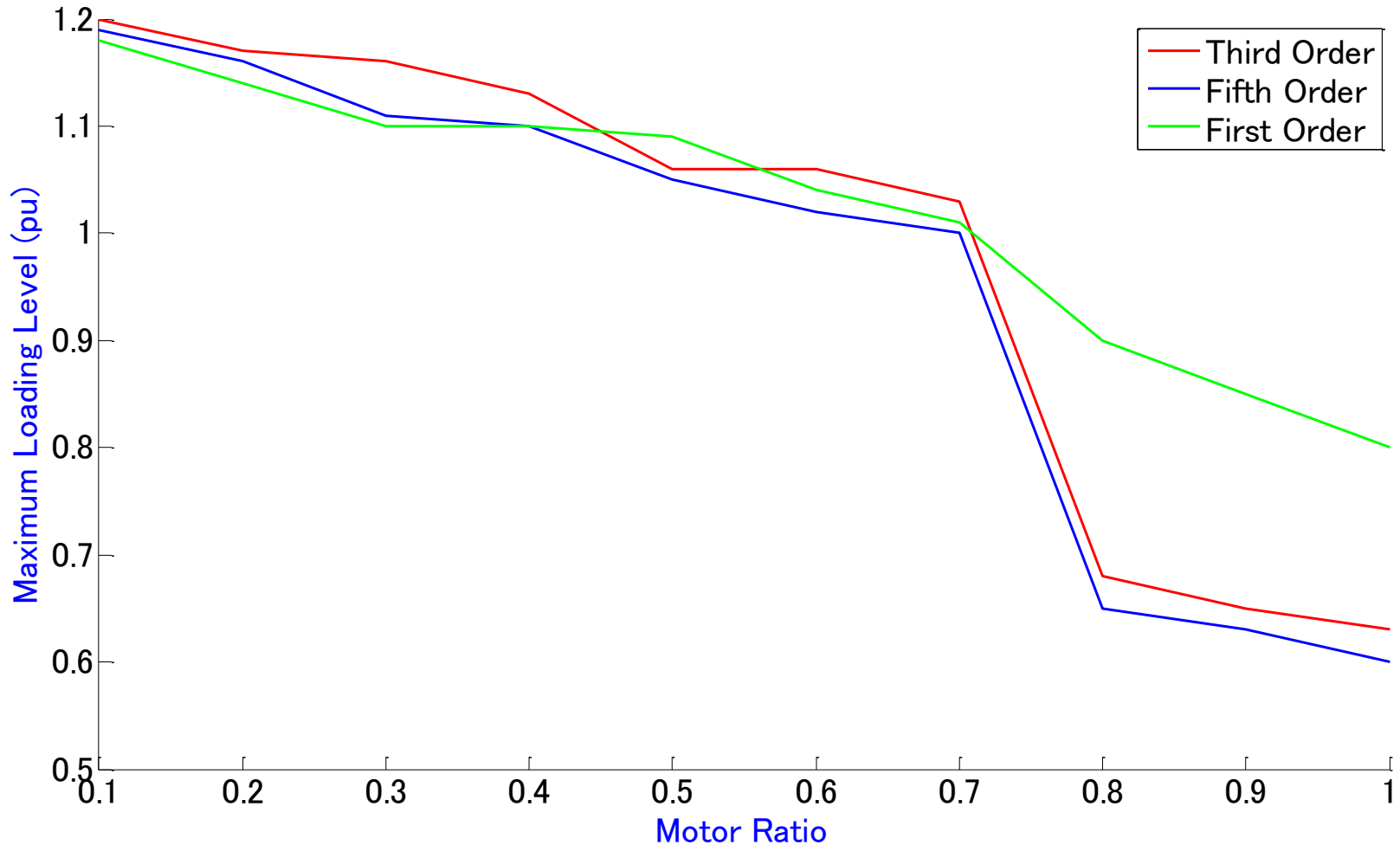
➤ 3rd and 5th order models have similar responses

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	Increase ↓ 1.198	Increase ↓ 0.869
First Order	Increase ↓ 1.271	Increase ↓ 0.882
Static Loads	1.781	

Nonlinearity



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

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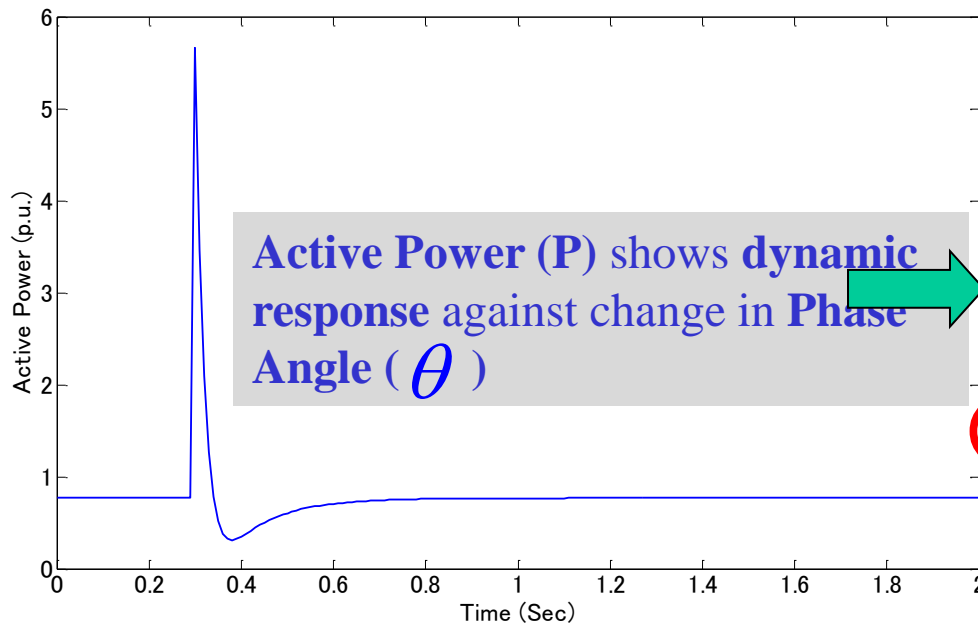
Load Modeling Issues

- Third order IM model is recommended

Similar to the 5th order responses

Balance of approximation (Generators and Motors)

- Two-input load model is required



Active Power (P) shows dynamic response against change in Phase Angle (θ)

×

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} G_{PV}(s) \\ G_{QV}(s) \end{bmatrix} \Delta |V|$$

1-Input Load Model

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} F_{PV}(s) & F_{P\theta}(s) \\ F_{QV}(s) & F_{Q\theta}(s) \end{bmatrix} \begin{bmatrix} \Delta |V| \\ V_o \Delta \theta \end{bmatrix}$$

2-Input Load Model

Response of 3rd order model

Conclusion

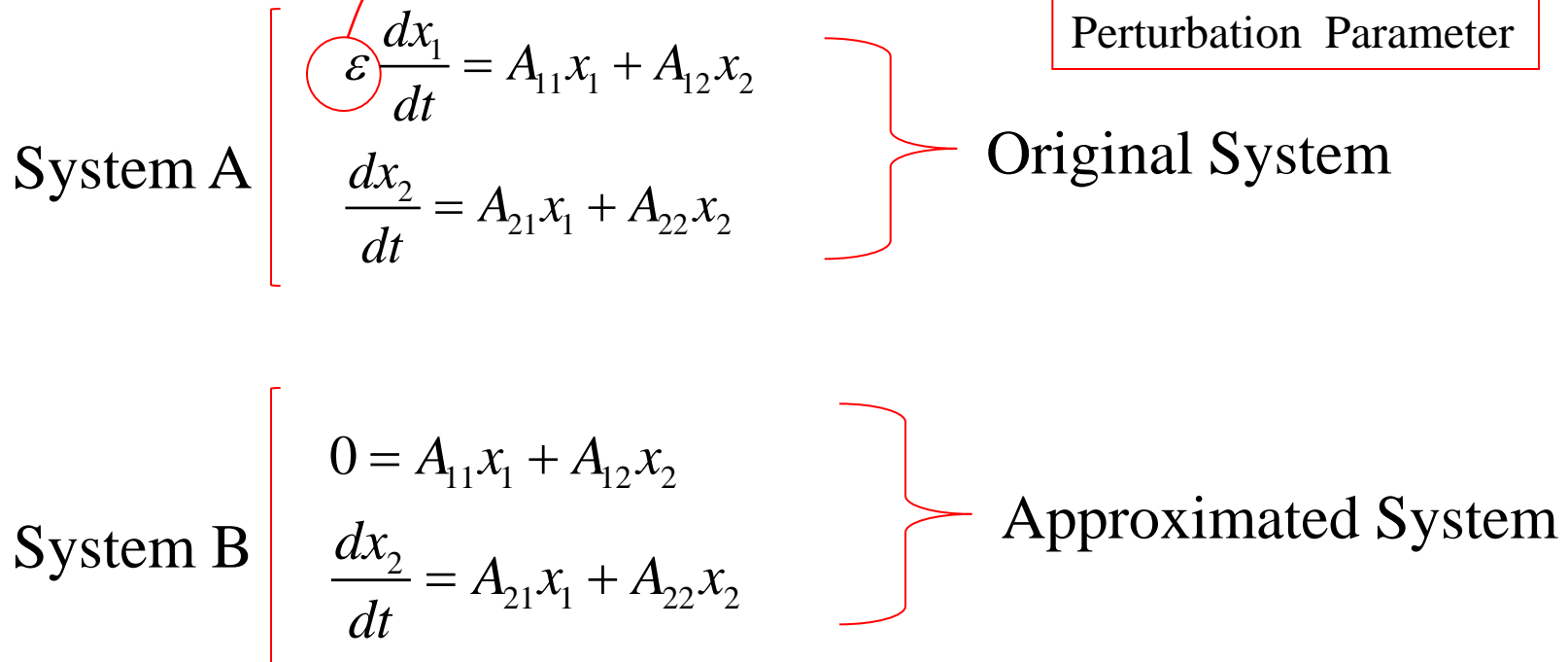
- IM Modeling is better in ω_r -frame
- Lower Order IM Models give Optimistic Results
- 3rd Order Model is best choice for Stability Study
- Two-Input Load Models suggested

Future Works

- Development of two input general load models
- Inclusion of the nonlinearity issue

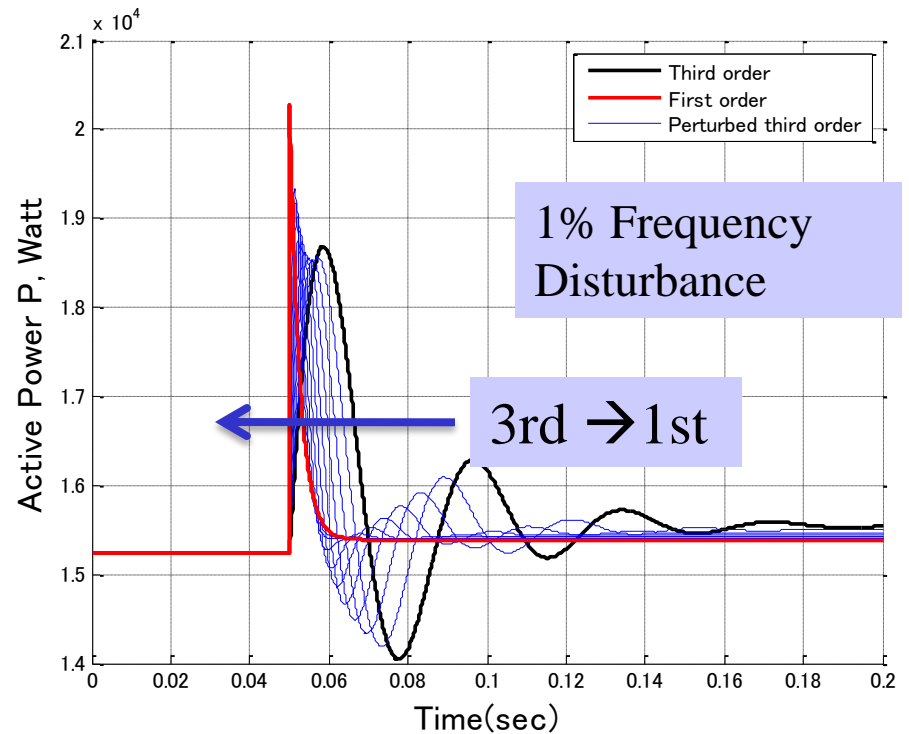
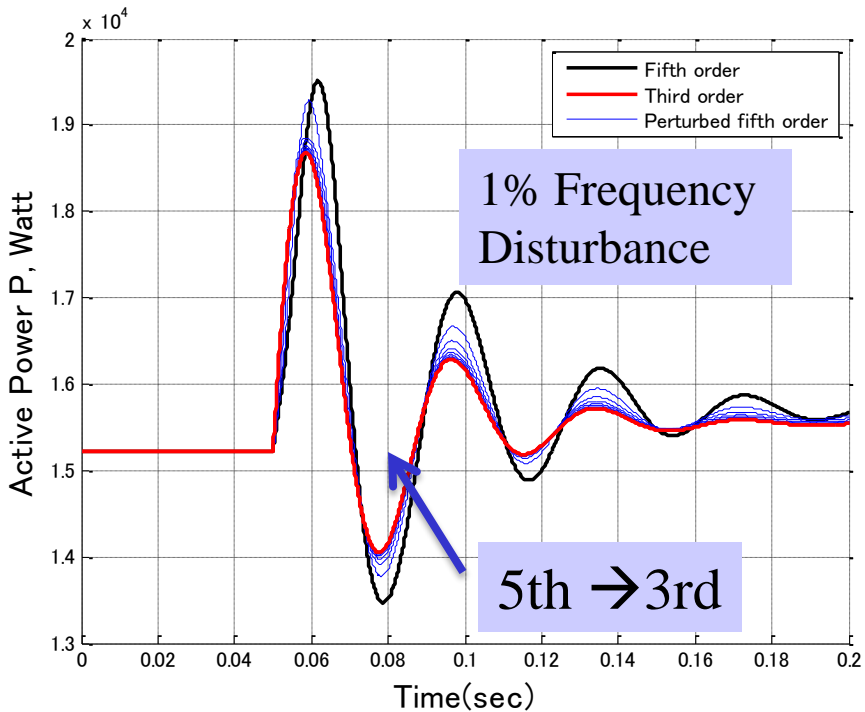
Thank you very much for your
Attention!!

Singular Perturbations(SP)



System B can be an approximation of System A

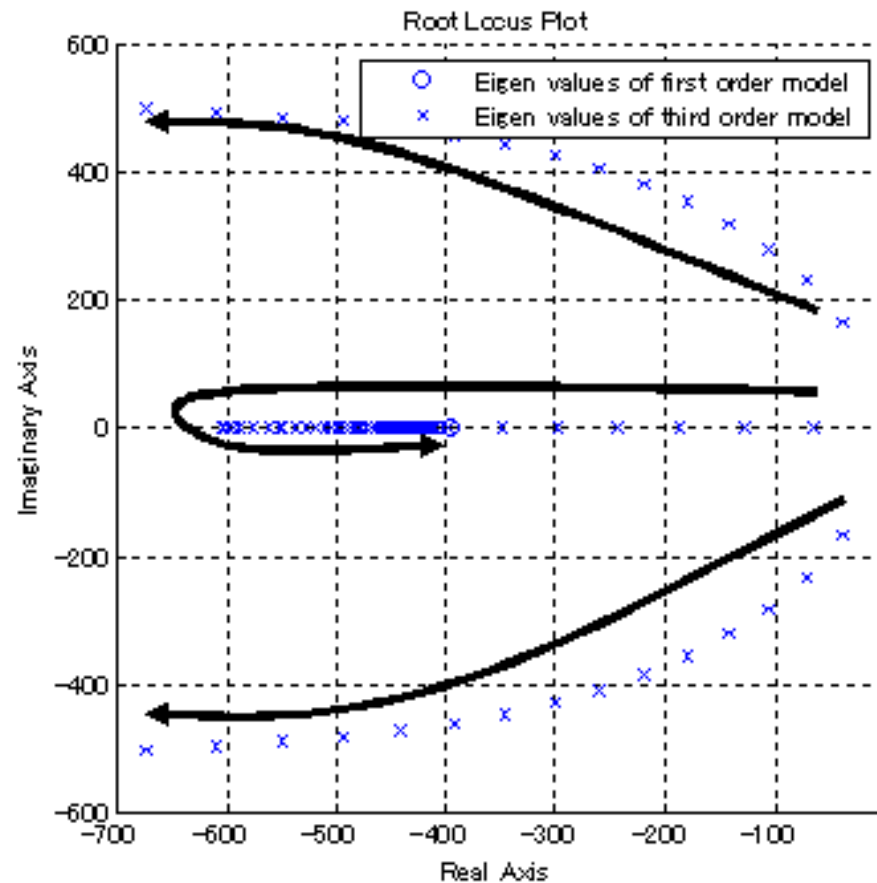
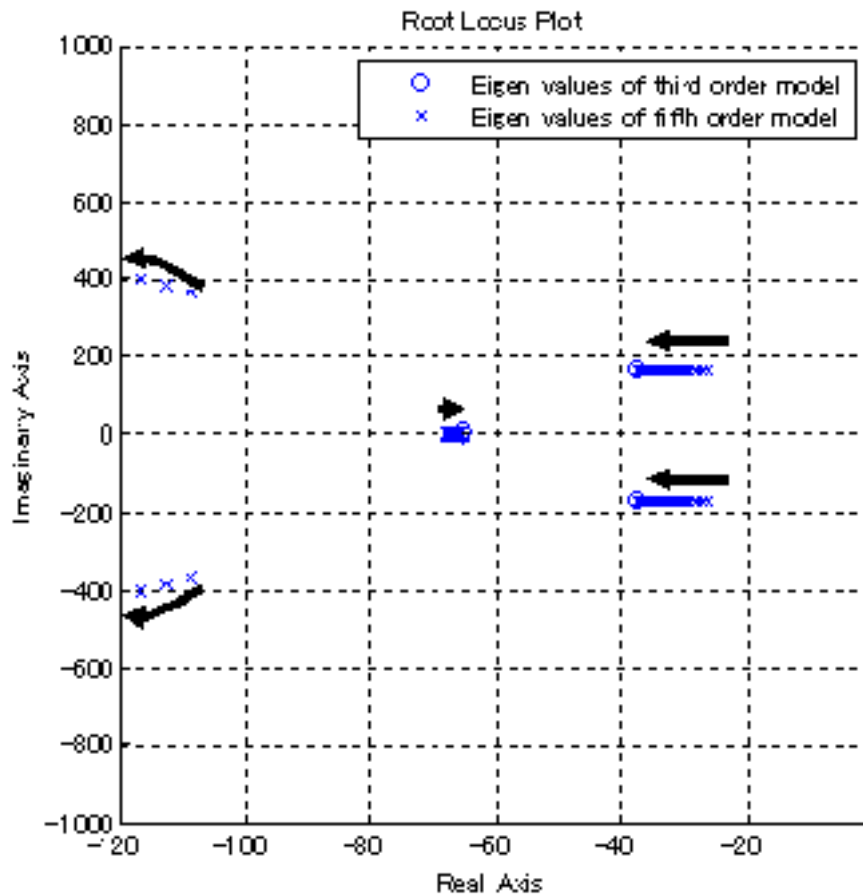
Application of SP



Responses approach to lower order models as $\varepsilon \rightarrow 0$

Root Locus as $\varepsilon \rightarrow 0$

➤ Plot of eigenvalues as ε approaches zero

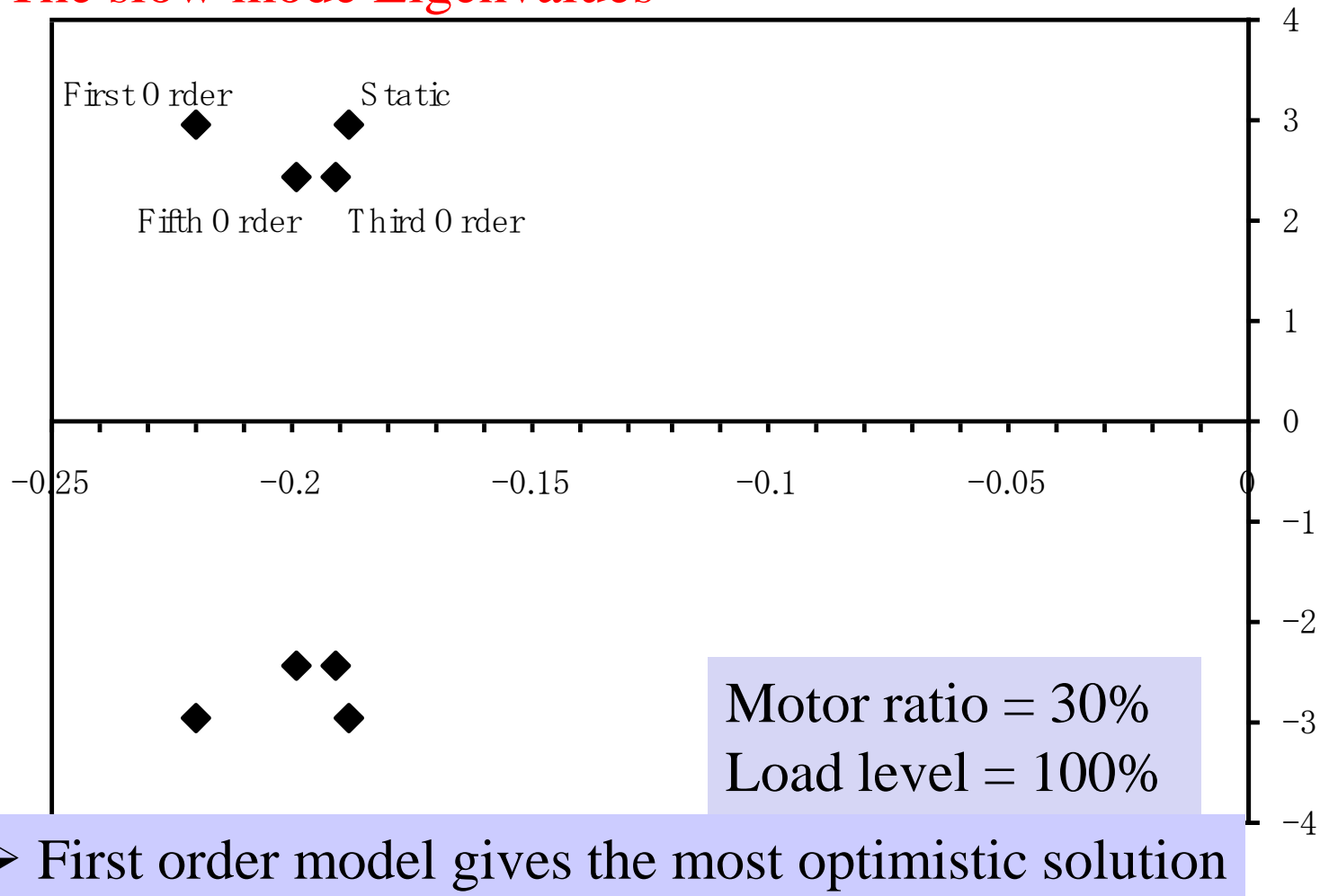


Fifth Order to Third Order

Third order to First Order

Comparison of eigenvalues

The slow mode Eigenvalues



- First order model gives the most optimistic solution
- 3rd and 5th order models have similar stability margins