On the Design and Placement of a Supplementary Damping Controller in an Embedded VSC-MTDC Network

Omar Kotb*, Mehrdad Ghandhari*, Robert Eriksson, Javier Renedo***, Luis Rouco***,**

*__Department of Electric Power and Energy Systems, KTH, Stockholm, Sweden__
Svenska Kraftnät (Swedish National Grid), Sundbyberg, Sweden
Institute for Research in Technology, Comillas Pontifical University, Madrid, Spain

Presented by:

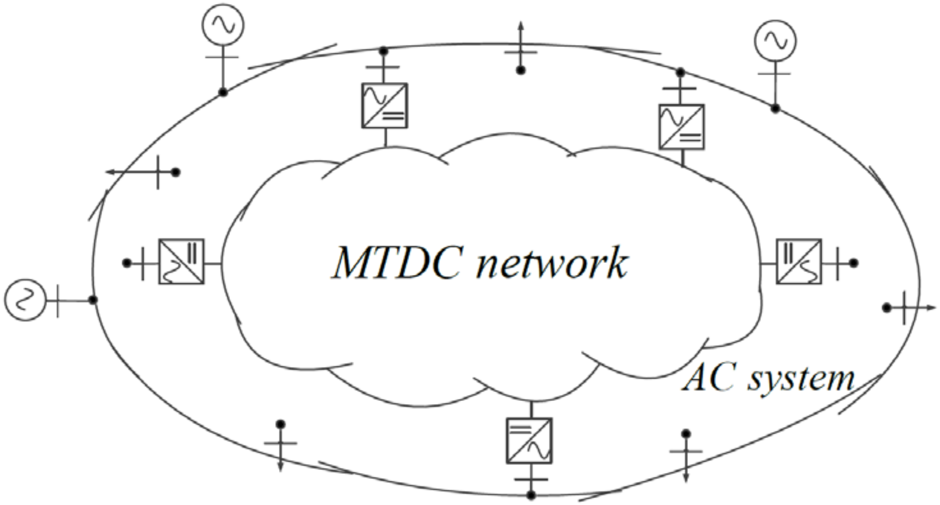
Omar Kotb

Elkraft 2017
Chalmers University of Technology
Gothenburg, Sweden
2017-05-18

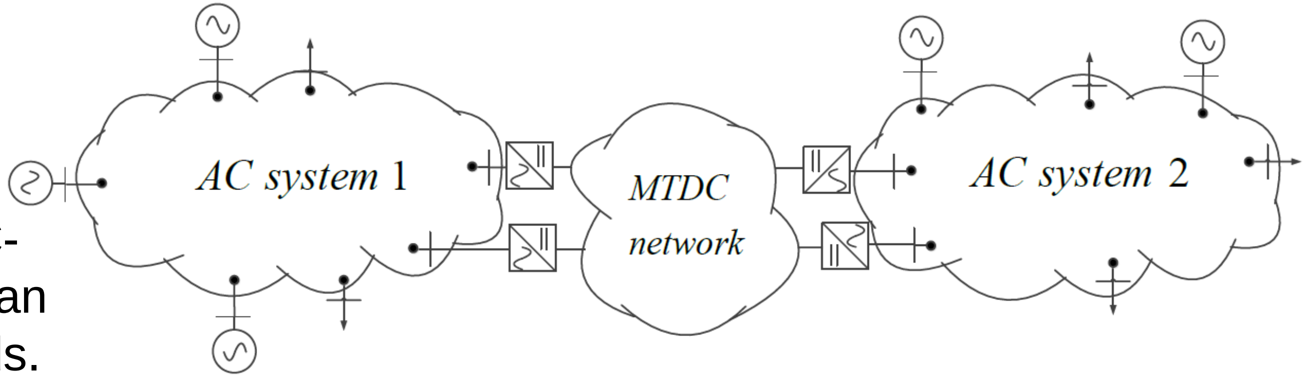
Presentation Outline

- Introduction
- Motivation
- Power System Model
- Controller Design
- Conclusions

Introduction: Embedded VSC-MTDC Network



Embedded VSC-MTDC: located within one synchronous AC grid.

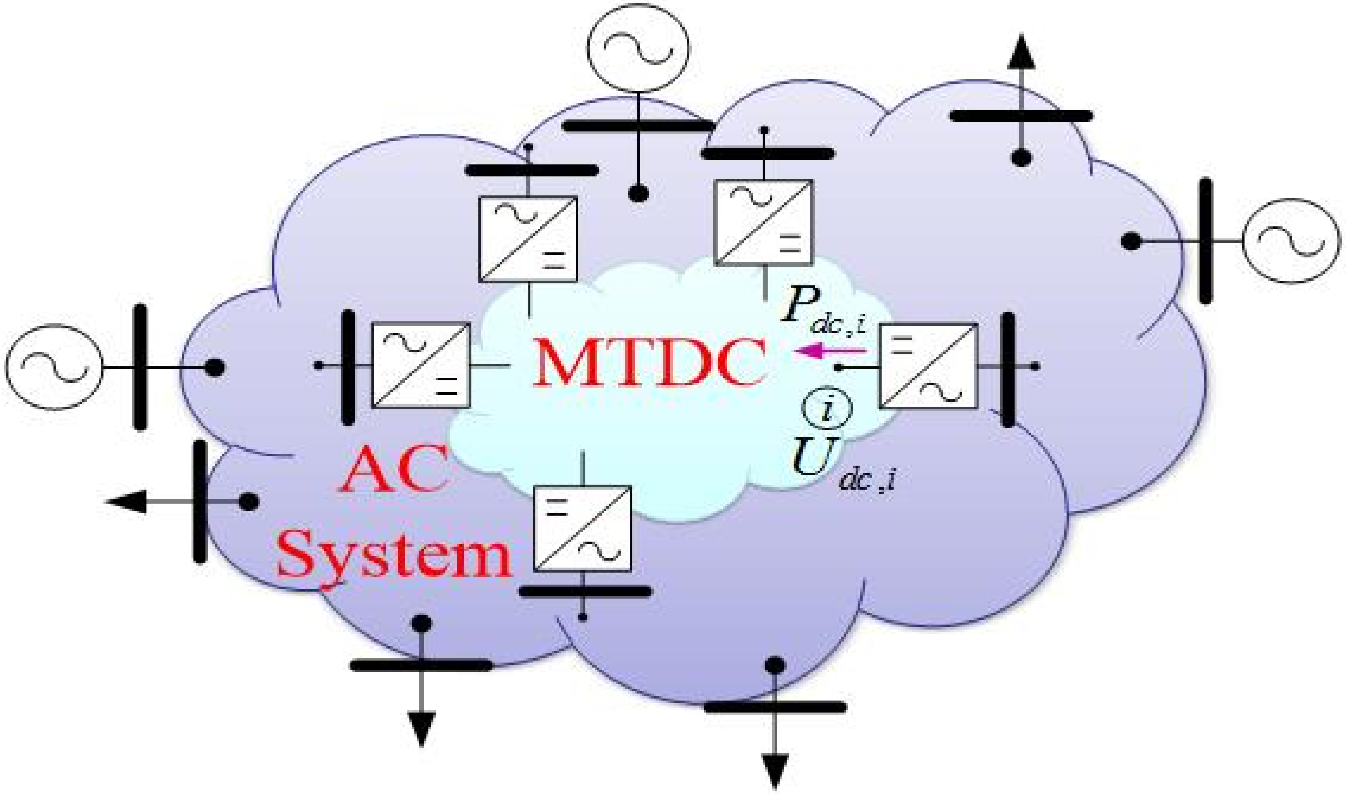


Segmented AC system: VSC-MTDC connecting more than one asynchronous AC grids.

Introduction: Embedded VSC-MTDC Network

AC/DC Power System Model:

- One slack bus
- VSC represented by average model
- Master-slave DC voltage control



Introduction: Embedded VSC-MTDC Network

MTDC Control Imperatives in AC/DC Power System

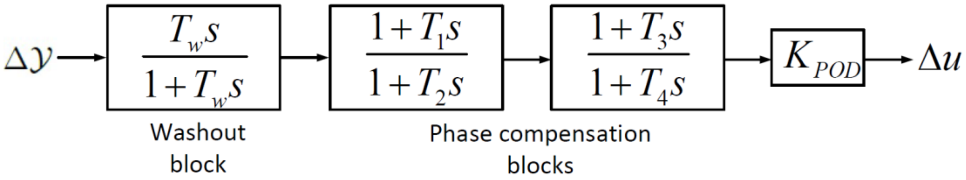
- **Primary control**: active&reactive power, DC voltage, AC voltage
- **Supplementary control**: Power Oscillation Damping (POD), frequency support
- **Control coordination**: PSS, other FACTS POD

Motivation

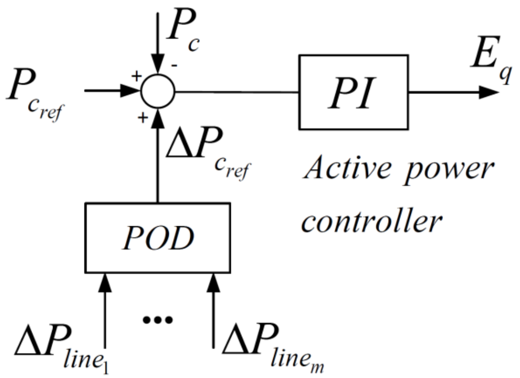
- Supplementary (POD) control not sufficiently investigated as compared to primary control in VSC-MTDC
- Multiple damping controllers: adverse control interactions
- Control coordination problem through nonlinear optimization:
  - Complex objective functions
  - Time-consuming solutions
- Strategic placement of supplementary controller(s)

Motivation

❑ MLQG-MISO control allows damping of targeted modes of interest, other modes are not affected



SISO control structure



MISO control structure

<u>Assumptions:</u>

- Negligible time delays
- PMUs readily available

Power System Model

- Nonlinear DAE system model:

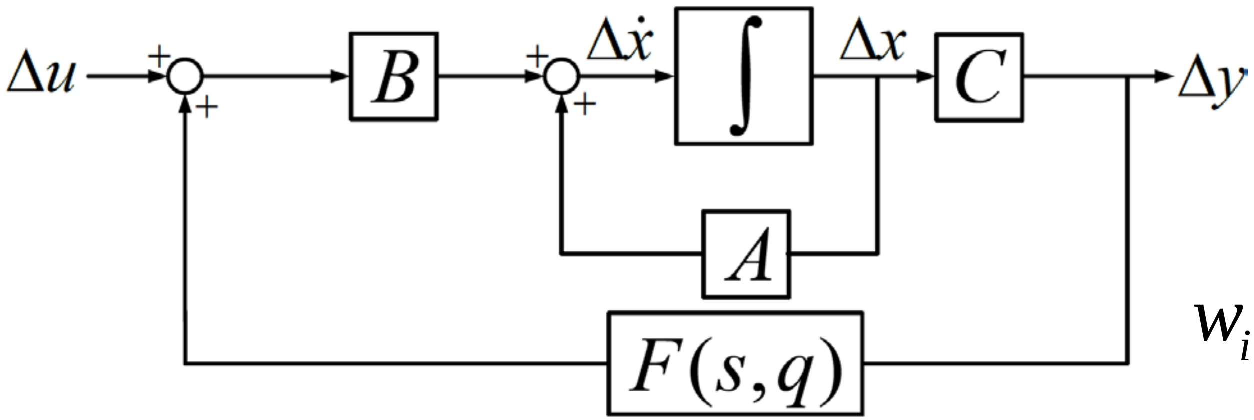
$$\dot{x} = f(x, y, u)$$
$$0 = g(x, y, u)$$

- Linearized system model:

$$\Delta\dot{x} = f_x \Delta x + f_y \Delta y + f_u \Delta u$$
$$0 = g_x \Delta x + g_y \Delta y + g_u \Delta u$$

Linearization conducted around the equilibrium point of the DAE system.

Power System Model



w_i **:** Mode’s left eigenvector

v_i **:** Mode’s right eigenvector

Eigenvalue sensitivity to controller parameter (*q*):

$$\frac{\partial \lambda_i}{\partial q} = R_i \frac{\partial F(s,q)}{\partial q}\Big|_{s=\lambda_i} = w_i^T B \frac{1}{\left(1 - F(\lambda_i, q)\right)^2} C v_i$$

Power System Model

- Linearized state-space system model:

$$\dot{x} = Ax + Bu + \Gamma w$$

$$y = Cx + \upsilon$$

w: Process noise

υ: measurement noise

- Modal variables:

$$z(t) = Mx(t)$$

MLQG Control Design

- Cost function:

$$J_k = \lim_{T \to \infty} E\left\{ \int_0^T \left(x^T \left(M^T Q_m M \right) x + u^T R u \right) dt \right\}$$

Q_m : Weighting matrix for modal variables

R : Weighting matrix for controller output

M : Mapping matrix

Feedback control law given by: $u(t) = -K\hat{x}(\mathrm{t})$

K : MLQG controller gain

MLQG Control Design

$\hat{x}(\mathrm{t})$ obtained using Kalman filter: $\dot{\hat{x}}(\mathrm{t}) = A\hat{x} + Bu + L\left(y - C\hat{x}\right) + L\upsilon$

L : Constant estimation error feedback matrix, obtained by the solution of Algebraic Ricccati Equation (ARE):

$$\dot{\hat{x}}(\mathrm{t}) = A\hat{x} + Bu + L\left(y - C\hat{x}\right) + L\upsilon$$

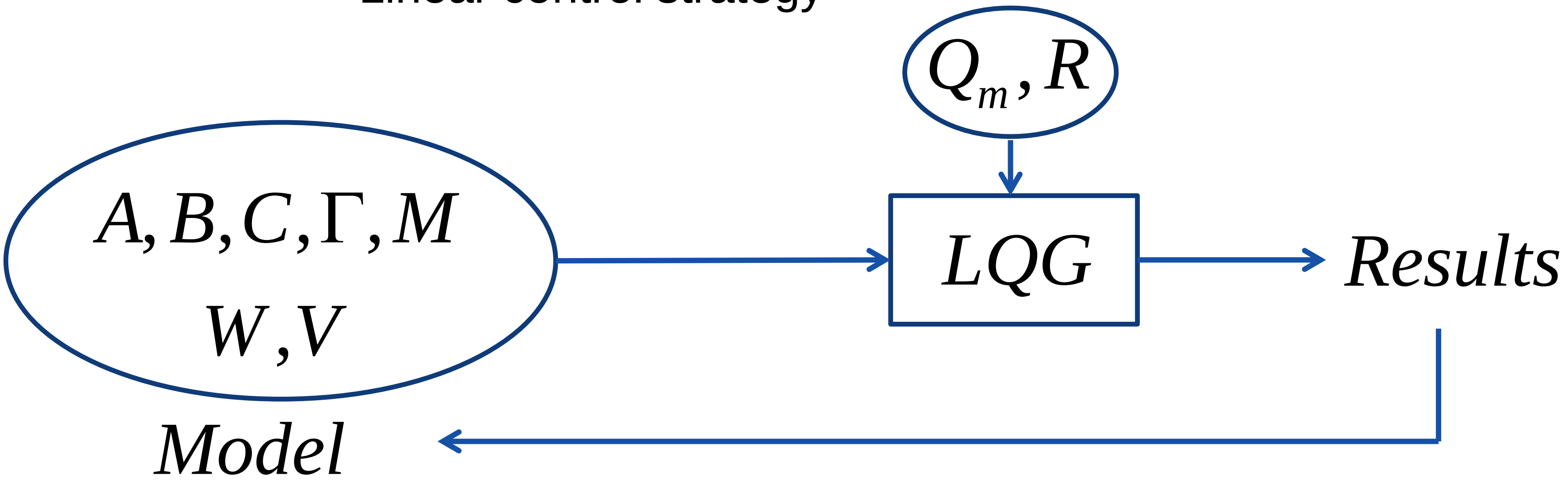
ARE solution is according to cost function for Kalman filter:

$$J_L = \lim_{T \to \infty} E\left\{ \int_0^T \left(x^T W x + u^T V u \right) dt \right\}$$

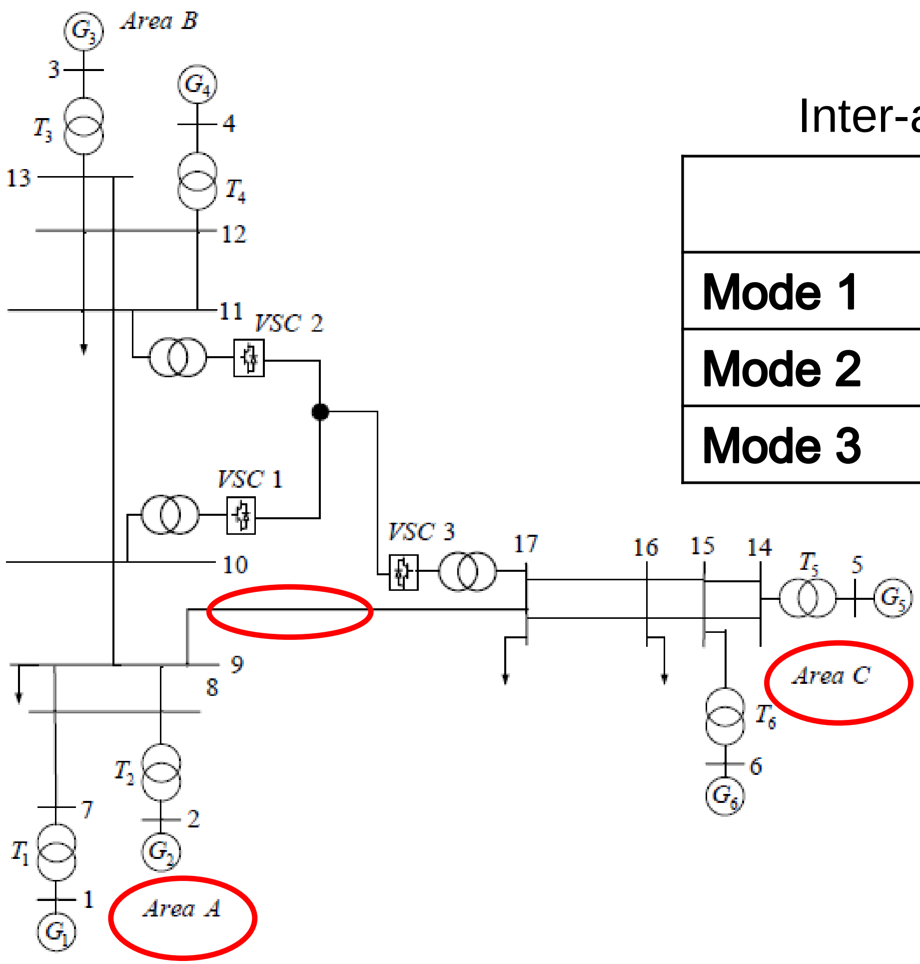
MLQG Control Design

MLQG POD supplementary controller design merits:

- Enhanced robustness
- Targeted damping of specific oscillatory modes (weighting matrices)
- Linear control strategy



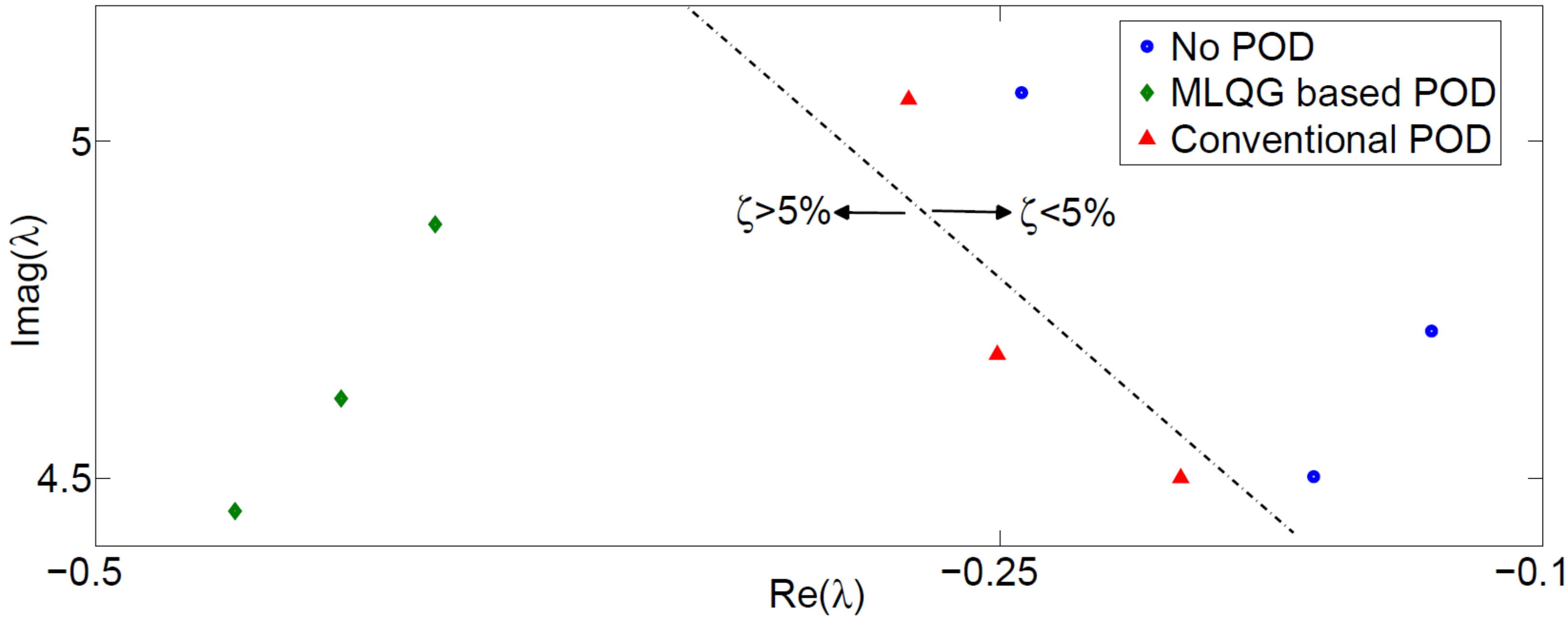
Results



Inter-area modes' observabilities (normalized).

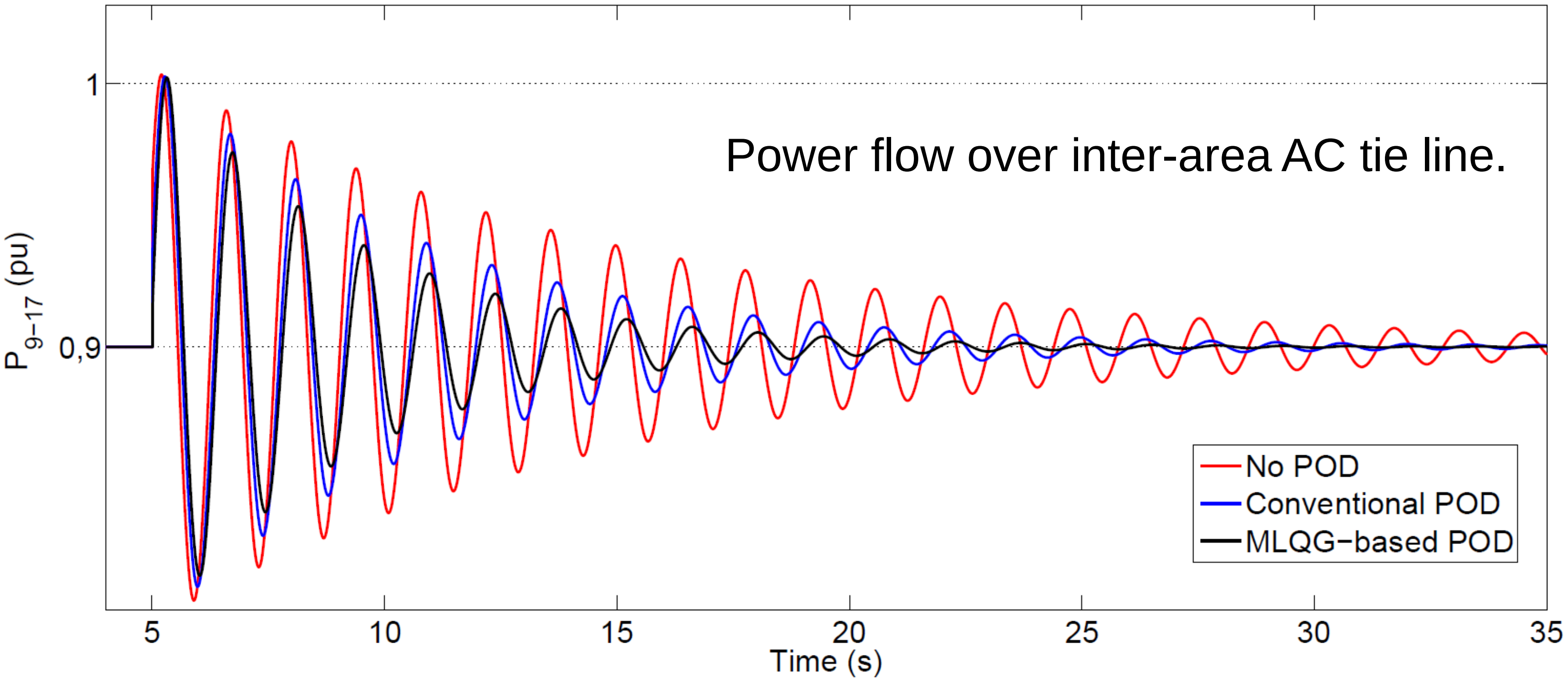
	$P_{12\text{-}13}$	$P_{5\text{-}14}$	$P_{11\text{-}12}$
Mode 1	1	0.4027	0.6974
Mode 2	0.3282	1	0.3402
Mode 3	0.6813	0.3661	1

Results



Inter-area modes' locations in complex plane.

Results



Disturbance: 10% load increase for 100 ms.

Conclusions & Future Work

- ❑ Research theme: AC/DC power system stability enhancement & control through MTDC supplementary controls

- ❑ Strategic positioning of a single damping controller within an embedded VSC-MTDC network

- ❑ Investigation of supplementary (POD) control in case of droop control used for DC voltage regulation.

Thank you! Questions?