

An Approach to Control a Photovoltaic Generator to Damp Low Frequency Oscillations in an Emerging Distribution System

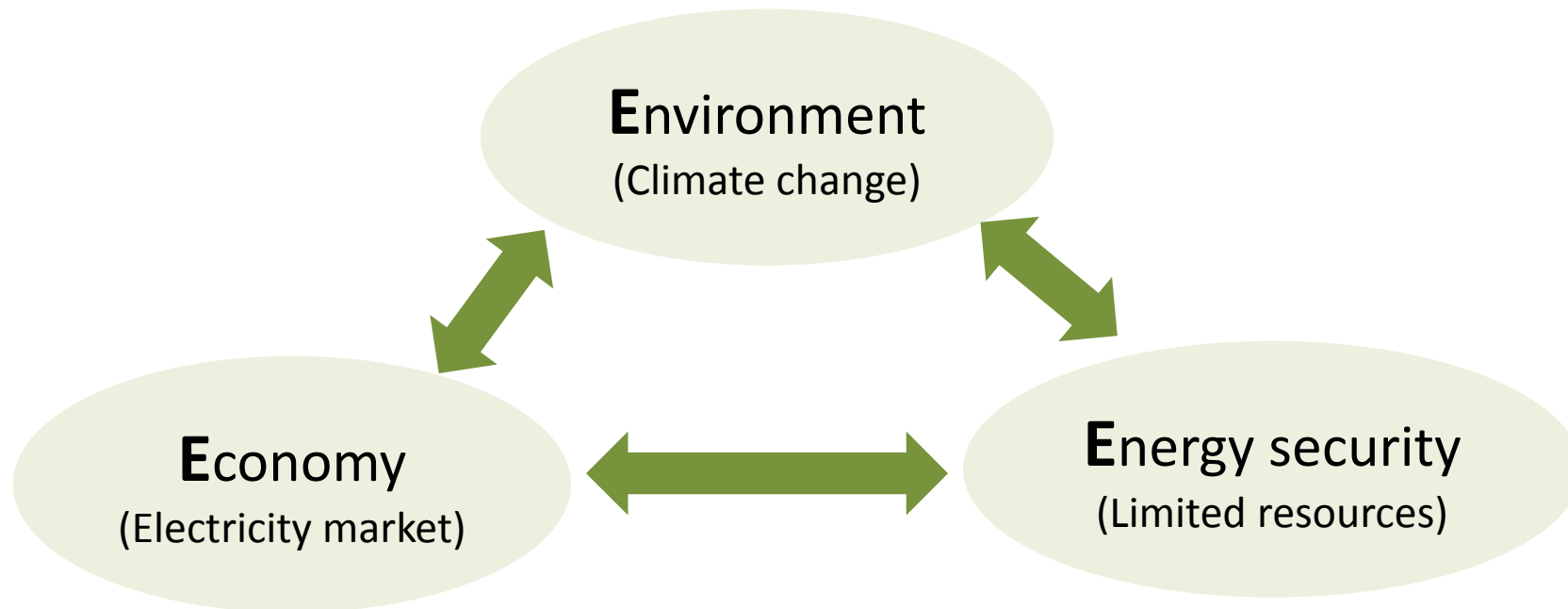
Sudarshan Dahal, Mithulananthan Nadarajah, Tapan Saha
School of Information Technology and Electrical Engineering
The University of Queensland, Australia

IEEE Power and Energy Society General Meeting
July 26, 2011

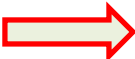
Outline

- Background & Objective
- System Modelling ,Stability Analysis & Control Design
- Results and Discussions
- Conclusions and Future works

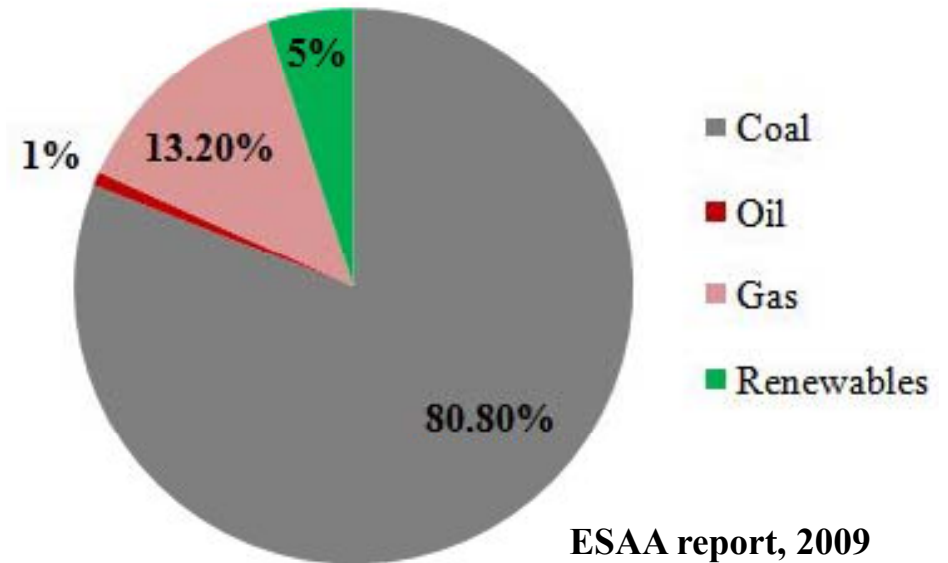
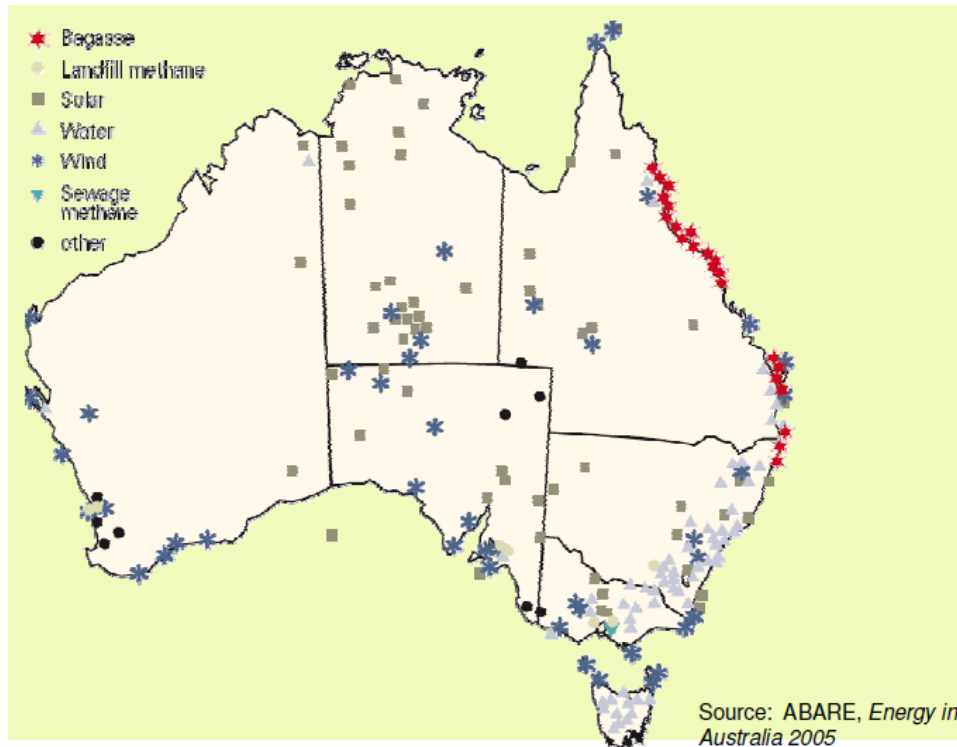
Present Trend



Focus areas

1. Market deregulation
2. Energy efficiency and conservation
-  3. Renewable energy and distributed generation
4. Reduced oil consumption, PHEVs

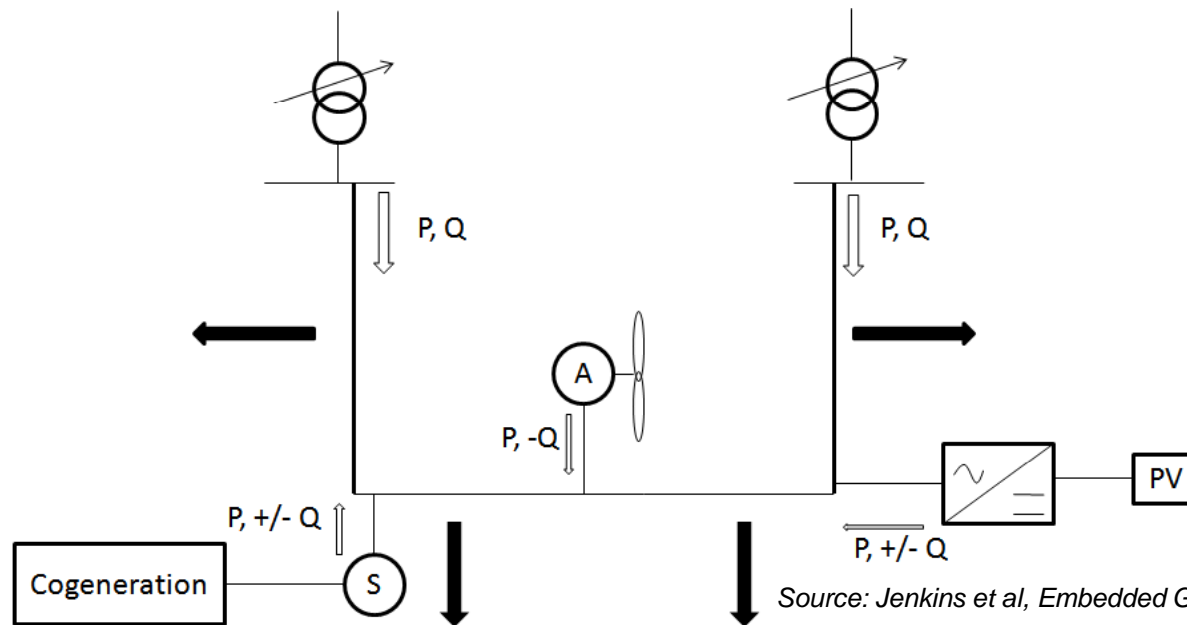
Renewable Energy in Australia



- Resources scattered over the country (Bagasse, hydro, wind, solar, geothermal)

- MRET Policy → 20% by 2020
- Tax rebate, feed in tariff

Future Distribution Systems



Characteristics	Challenges
Different Generation Technologies	Stability , Control
Bidirectional Power Flow	Stability, Protection
Intermittency	Dispatch, Regulation, Quality

Research Problem

- **Proximity and negative interactions** among DG units in emerging distribution networks result in low frequency oscillations.
- Conventional controllers such as **SVC, STATCOM** are **not very common** in distribution systems.
- Conventional controllers are not very attractive for distribution networks due to their **cost and complexity**.
- **Control of DG units** may be applied for enhanced network stability and control.

Objectives

Assessment of small signal stability

- appropriate models of DG units, network & Load
- Existence of low damped oscillatory modes

PV Control for small-signal stability

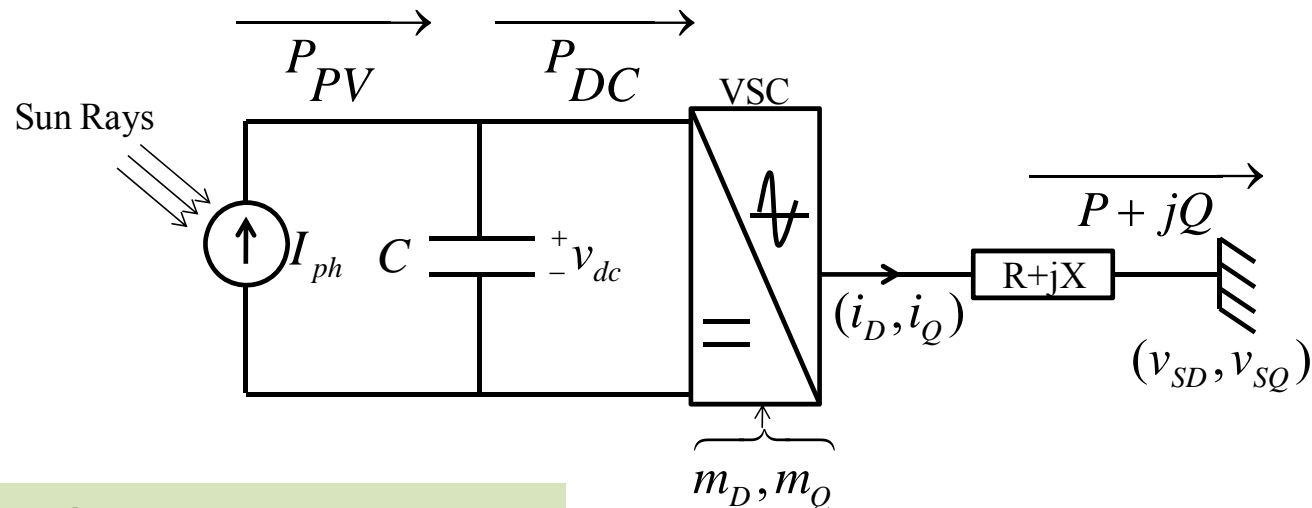
- Impact of PV generator on critical mode
- Controller design

System Modelling, Stability Analysis & Control Design

Generator Modelling

Generator	Stator Flux Dynamics	Rotor Flux Dynamics	Rotor Inertia Dynamics	Exciter/ Governor	Converter/ Inverter
Synchronous Generator	✓	✓	✓	✓	X
Squirrel Cage Induction Generator	✓	✓	✓	X	X
Doubly Fed Induction Generator	✓	✓	✓	X	✓
Photovoltaic Generator	X	X	X	X	✓

PV System Model



DC link dynamics

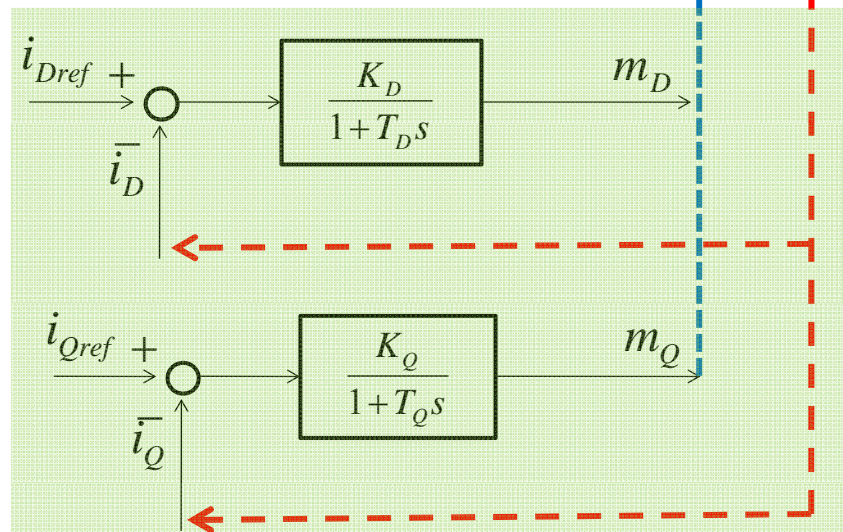
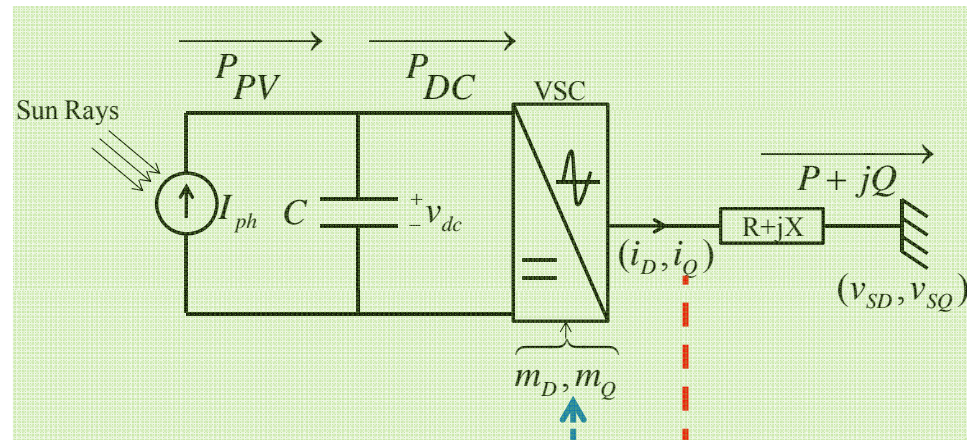
$$\frac{C}{2} \frac{dv_{dc}^2}{dt} = P_{pv} - P_{dc}$$

Output Power

$$\begin{cases} P = \frac{3}{2} (v_{SD} i_D + v_{SQ} i_Q) \\ Q = \frac{3}{2} (v_{SQ} i_D - v_{SD} i_Q) \end{cases}$$

PV Control

- i_{Dref} and i_{Qref} are reference value of output currents at desired power factor.
- m_D and m_Q are control parameters of VSC.



Modal Analysis

DAEs of power systems

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

$$0 = g(x, y)$$

Participation factor

- relates the states and the modes
- an element of product of right and left eigenvector

Eigenvalue sensitivity

- shows impact of system parameters (K) on eigenvalue

Control Design

Controllability and Observability

- used for controller placement and control signal selection

Residue Compensation

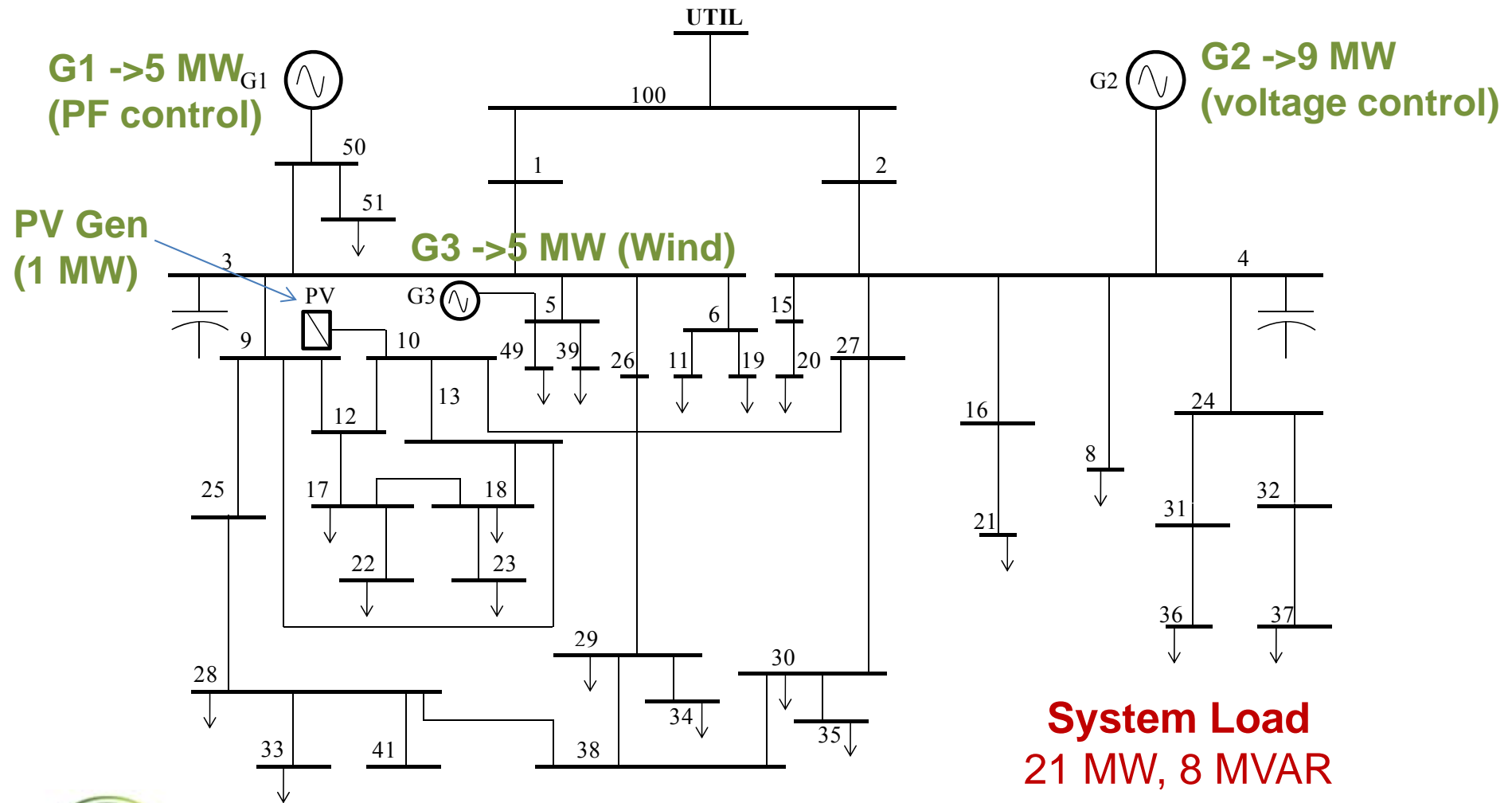
- used for setting desired angle of an oscillatory mode

Gain Selection

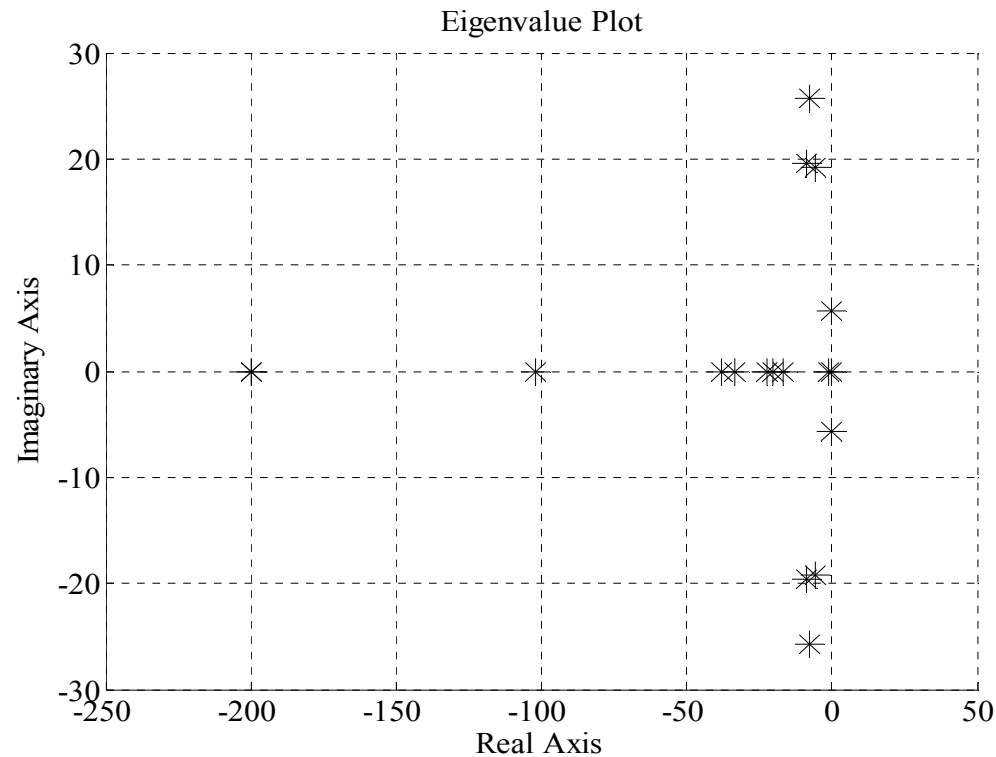
- used for achieving desired damping ratio of an oscillatory mode.

Results & Discussion

Case Distribution System



System Eigenvalues



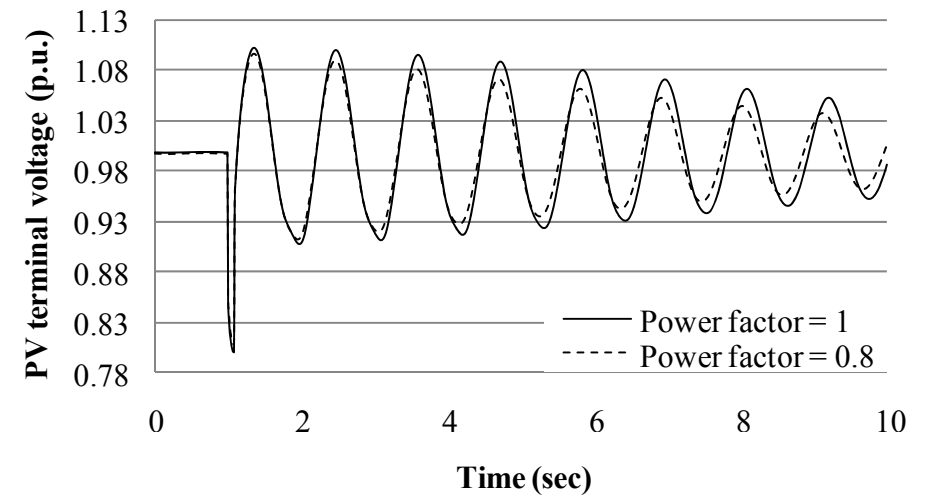
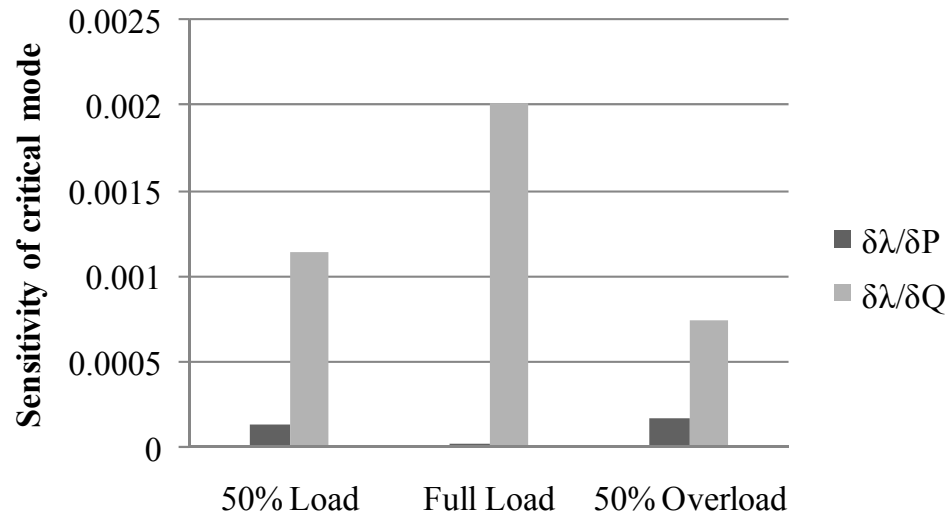
- Eigenvalues in left half of Imaginary axis \rightarrow stable system
- Four oscillatory Modes

Oscillatory Modes

Modes	Damping Ratio	Frequency (Hz)	Dominant Generator
1	0.28	4.2	G2 (Synchronous Gen)
2	0.28	3.2	G1 (Synchronous Gen)
3	0.41	3.4	G3 (Induction Gen)
4	0.02	0.9	G2 (Synchronous Gen)

- Critical mode dominated by excitation and rotor angle of G2
- PV control is proposed instead of G2, because
 - G2 (as a DG unit) may not always have a PSS.
 - PV converters can serve as decentralized damping controller

PV Impact on System Stability



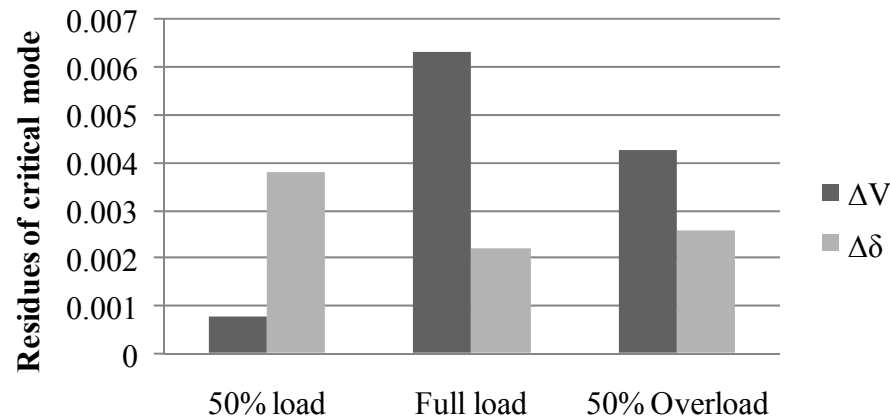
- Critical mode sensitivity
→ Higher for reactive power

- Time domain response
→ Slightly better for nonunity PF

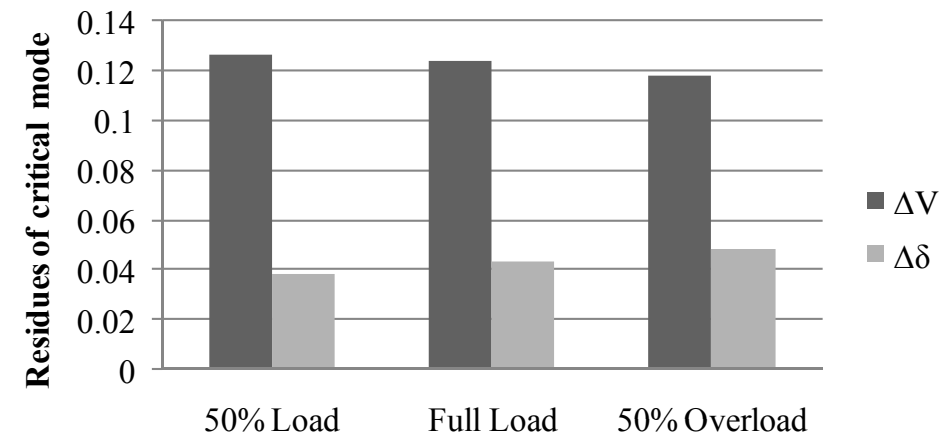
Reactive power support from PV is beneficial for damping

PV Control: Signal Selection

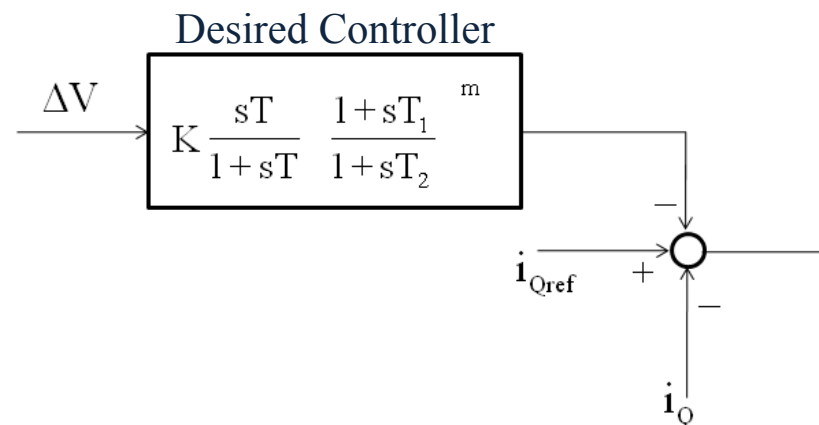
Modulating i_{Dref}



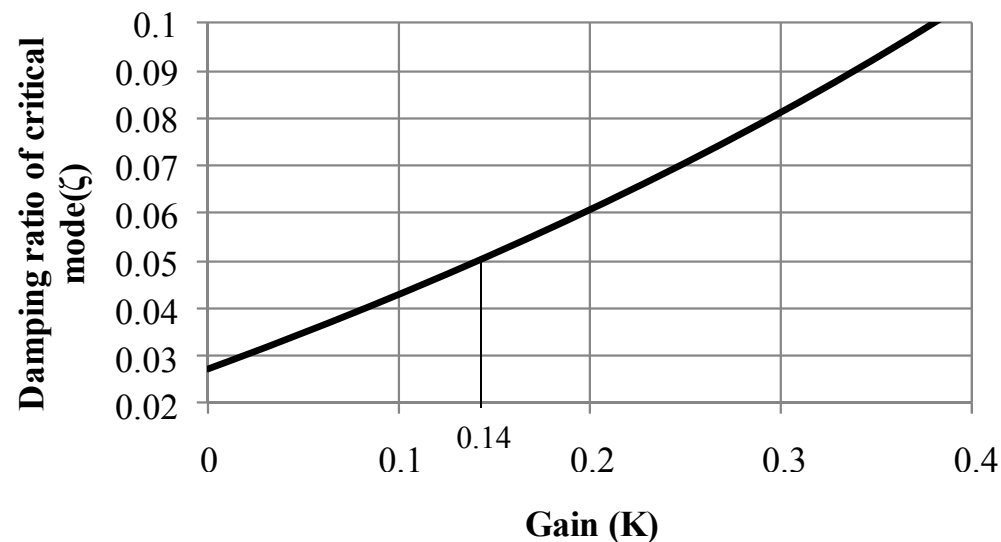
Modulating i_{Qref}



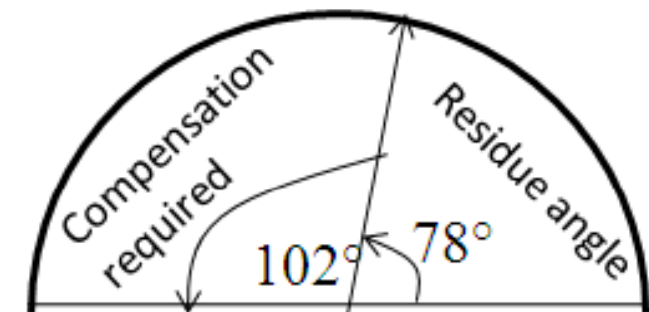
- Terminal voltage is better feedback signal (most of the loading conditions).
- i_{Qref} is selected as modulating signal



PV Control: Gain and Compensation

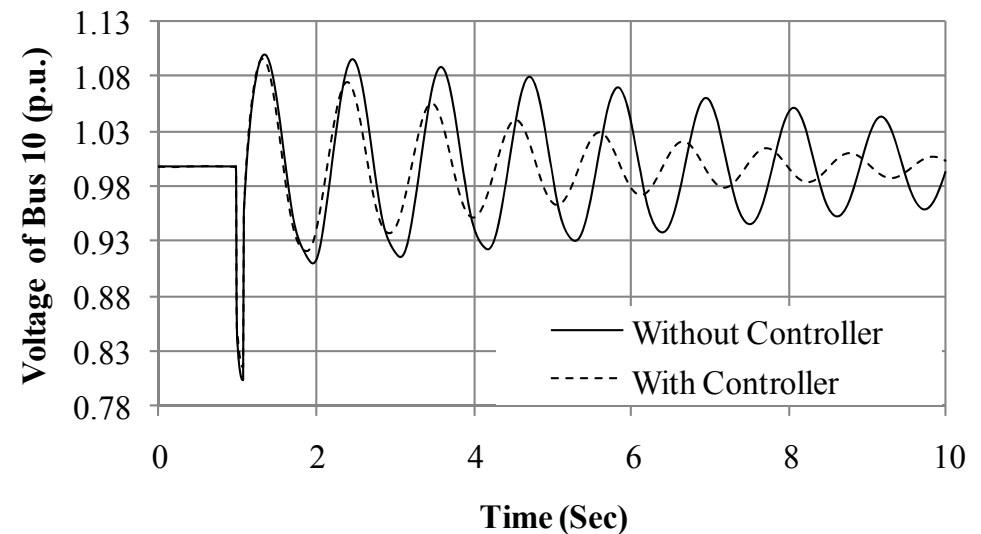
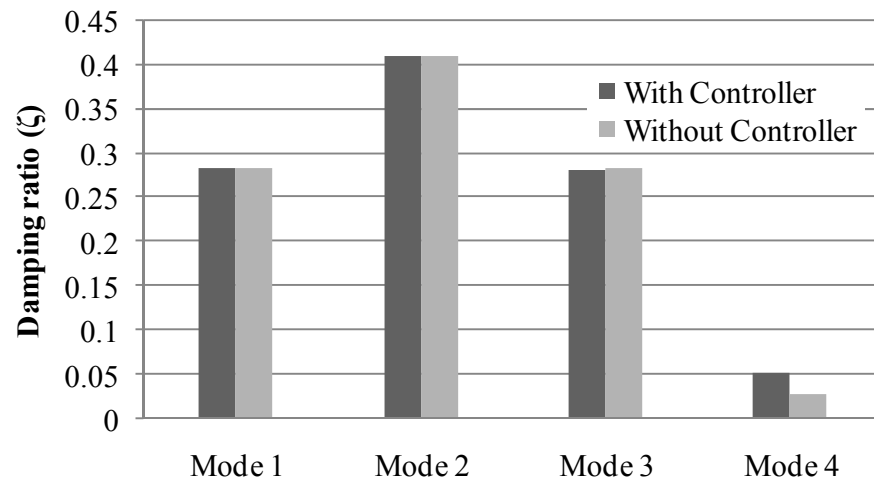


Gain (K) was selected 0.14 for damping ratio 0.05.



Phase compensation required is 102° .

PV Control: Controller Performance



- Critical mode damping improved
(Other modes remain unaffected)

- Improves time domain response of bus voltage.

Controller is successfully implemented for damping improvement.

Conclusions

- Reactive power support from PV can be beneficial to the damping of low frequency oscillation.
 - Higher sensitivity with reactive power
 - Better time domain response at non unity power factor.
- A controller for PV can be designed for small signal stability.
 - PV output currents can be modulated for better stability.
 - Local signals (voltage or angle) can be used for controller tuning.
- A desired damping characteristics can be achieved by selecting an appropriate value of controller gain.
- The controller affects only the critical mode while the other modes are unaffected.

Thank You Very Much!!

Comments/Questions are welcome