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

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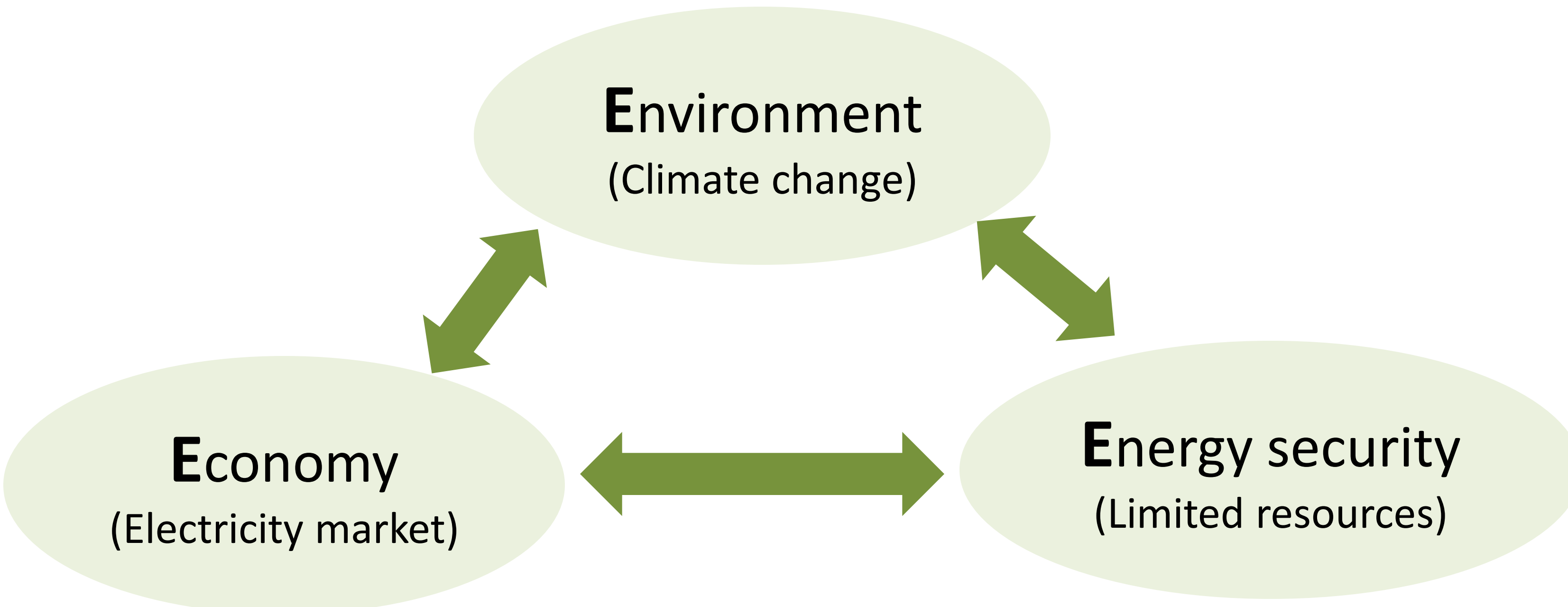
Outline

- 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

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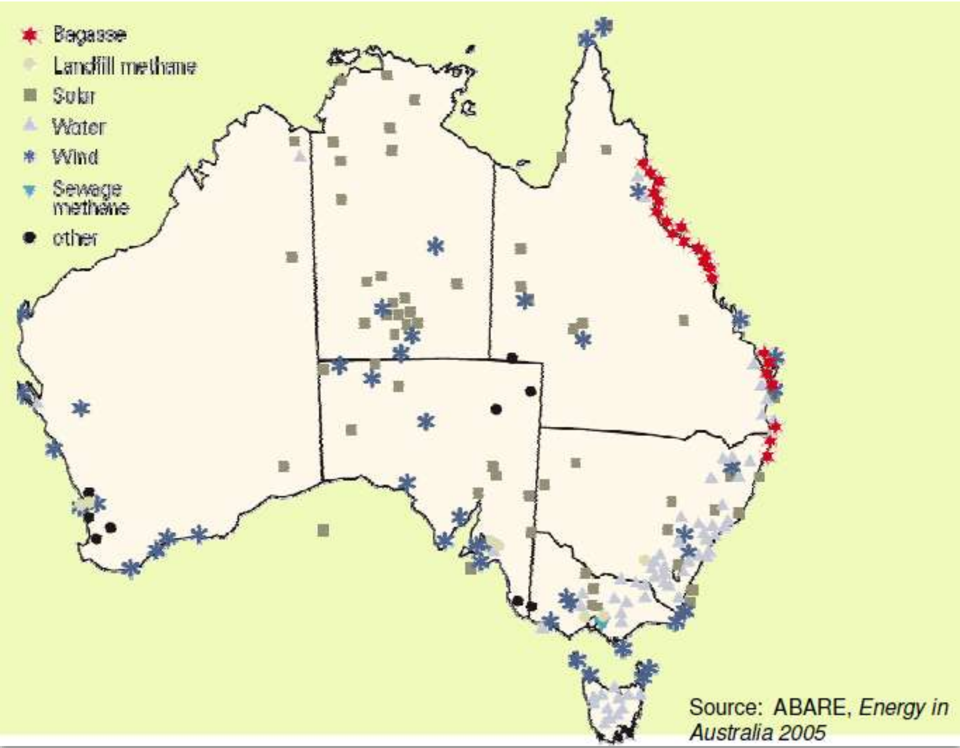
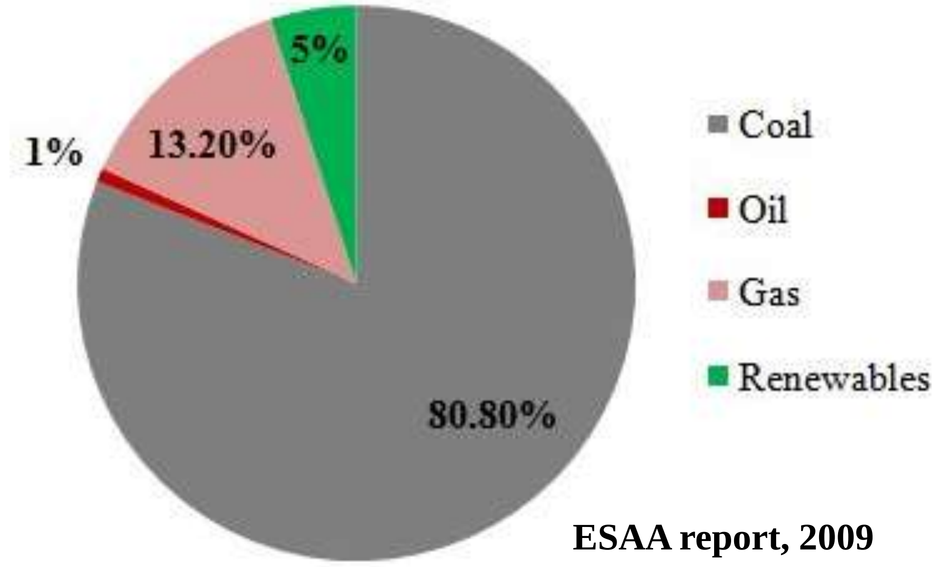
Renewable Energy in Australia



Source: ABARE, *Energy in Australia 2005*



ESAA report, 2009

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

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

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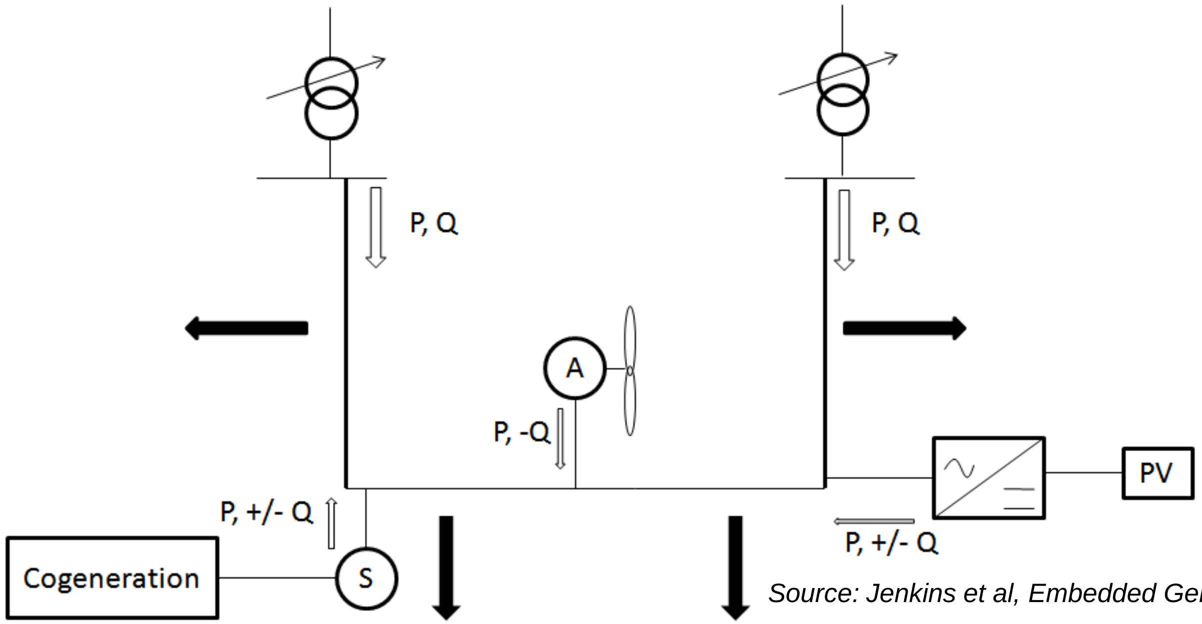
Future Distribution Systems



Source: Jenkins et al, Embedded Generations, IET,2000

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

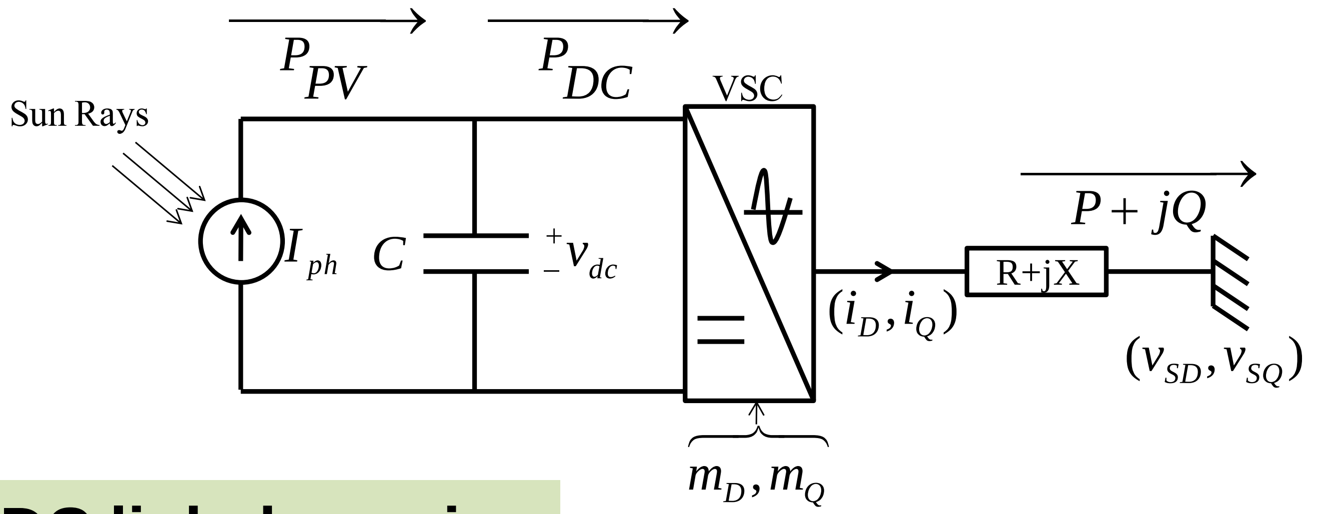
- Impact of PV generator on critical mode
- Controller design

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

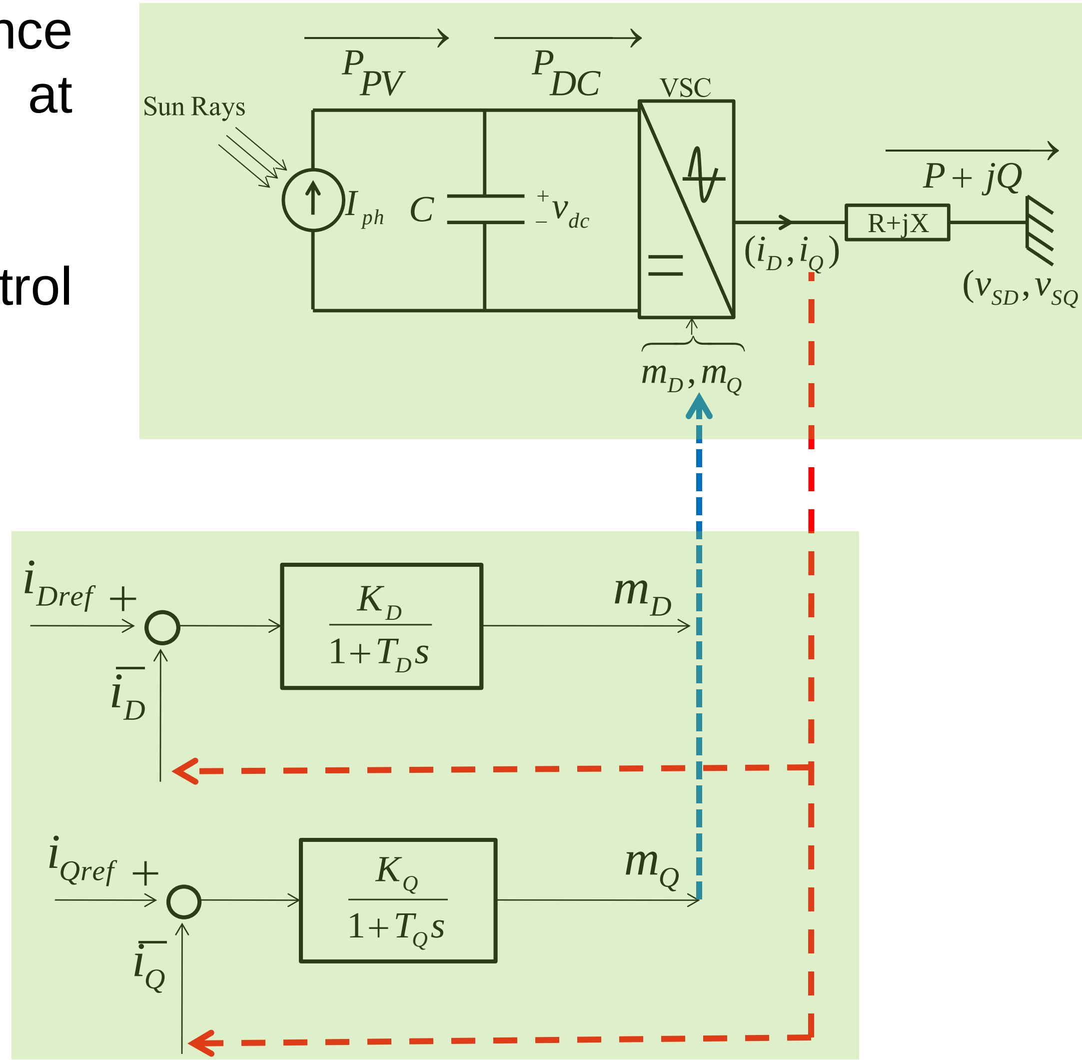
$$\frac{C}{2}\frac{dv_{dc}^2}{dt} = P_{pv} - P_{dc}$$

Output Power

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

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

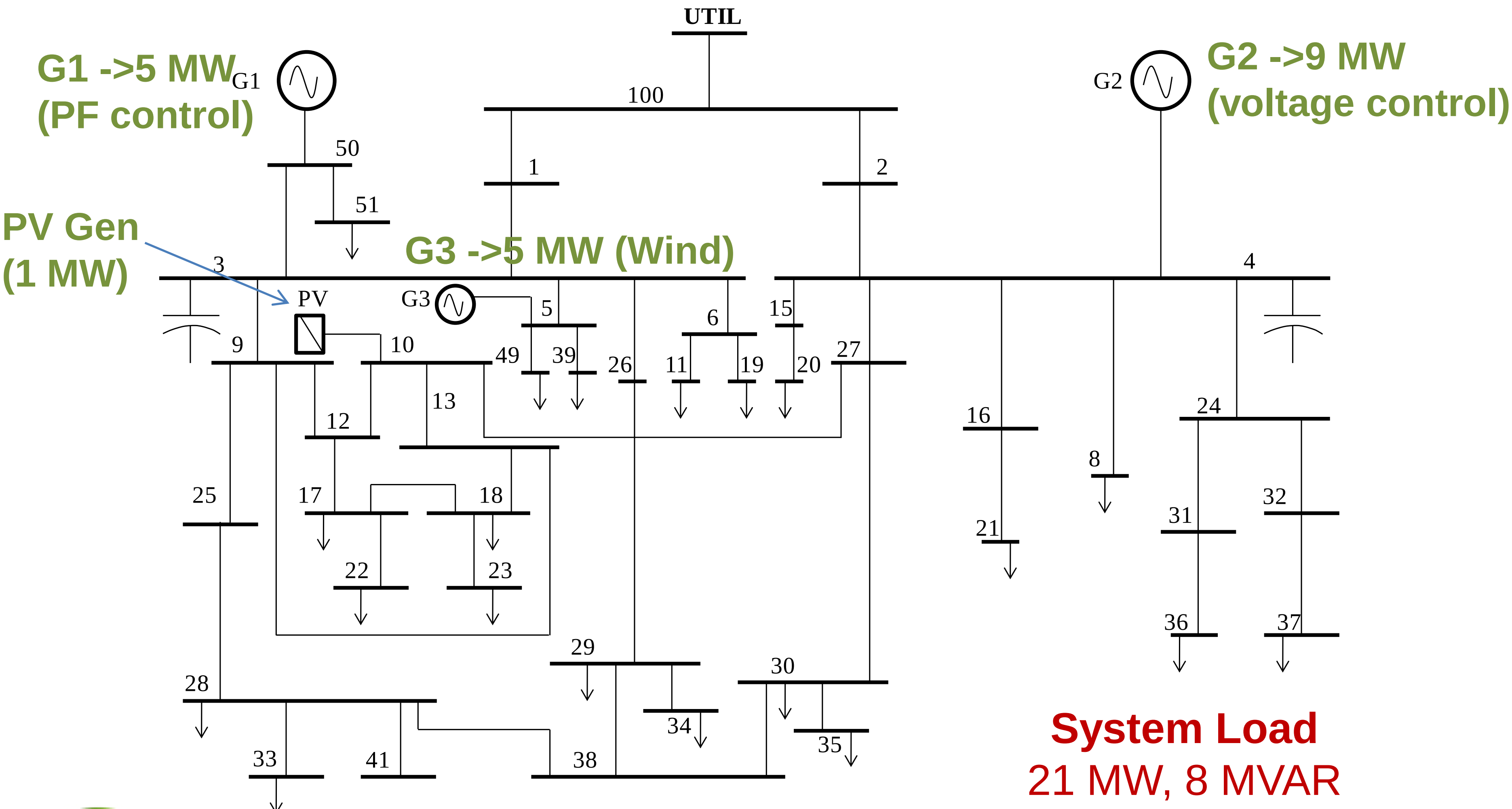
- ➢ used for setting desired angle of an oscillatory mode

Gain Selection

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

Results & Discussion

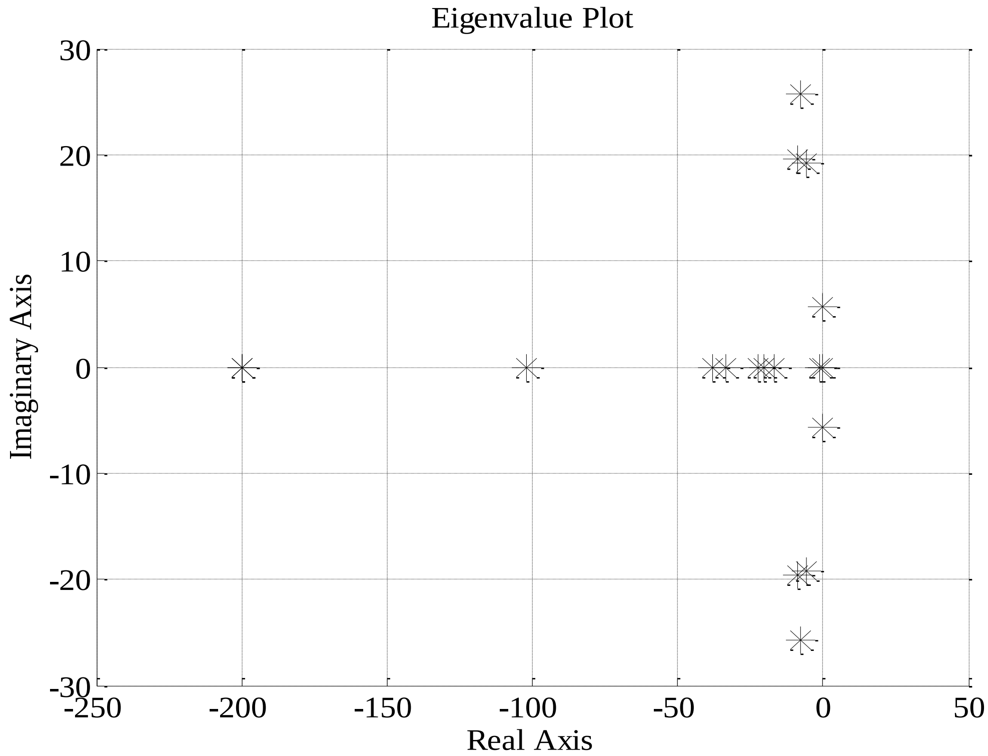
Case Distribution System



System Load

21 MW, 8 MVAR

System Eigenvalues



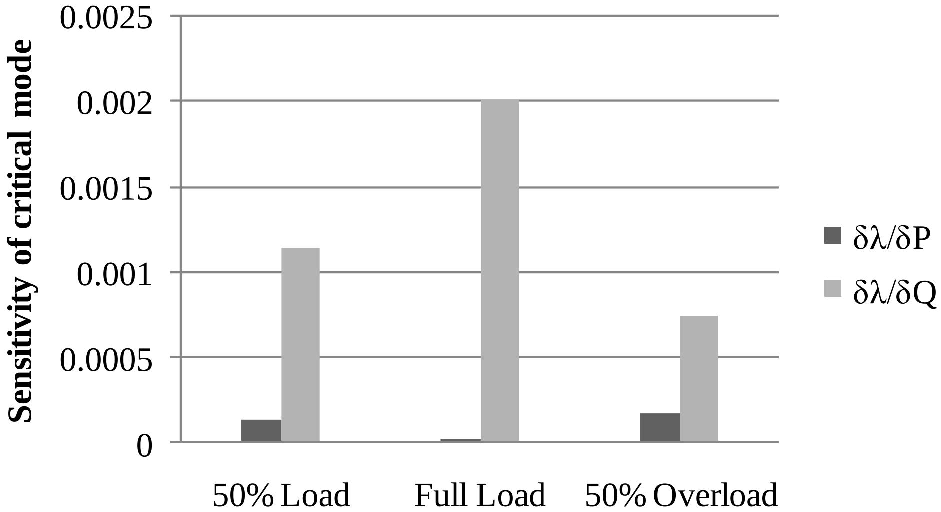
- Eigenvalues in left half of Imaginary axis→ stable system
- Four oscillatory Modes

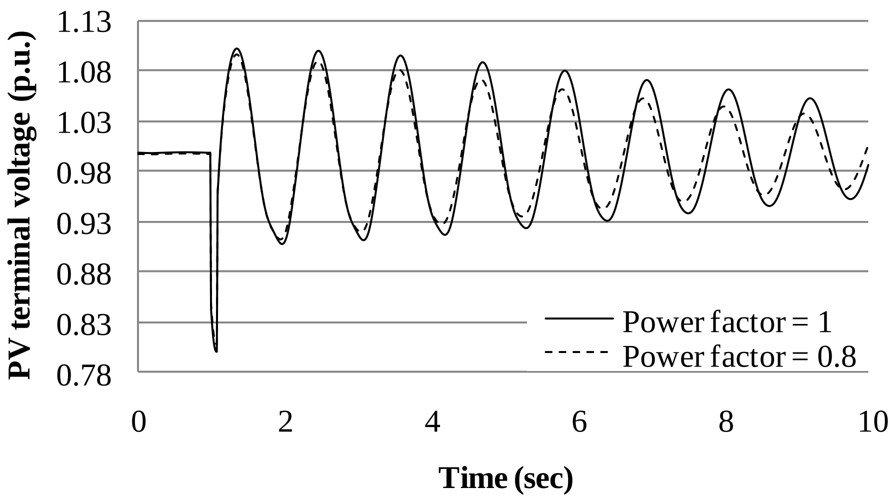
Oscillatory Modes

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



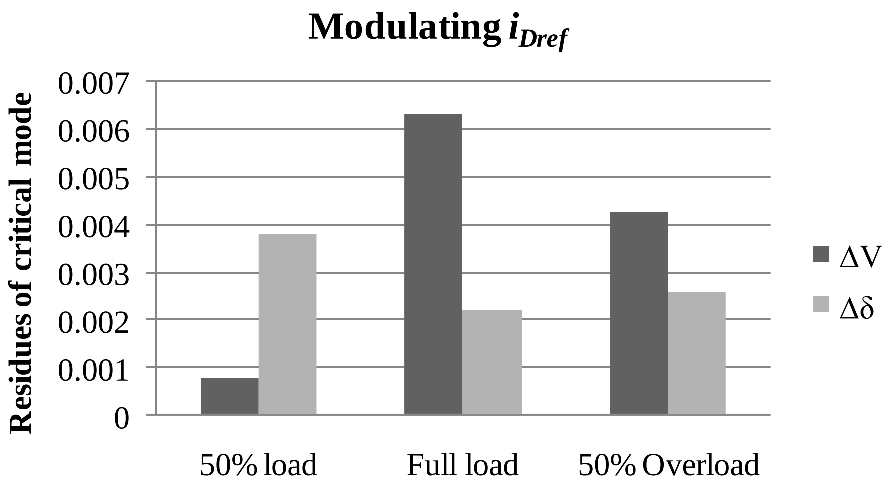


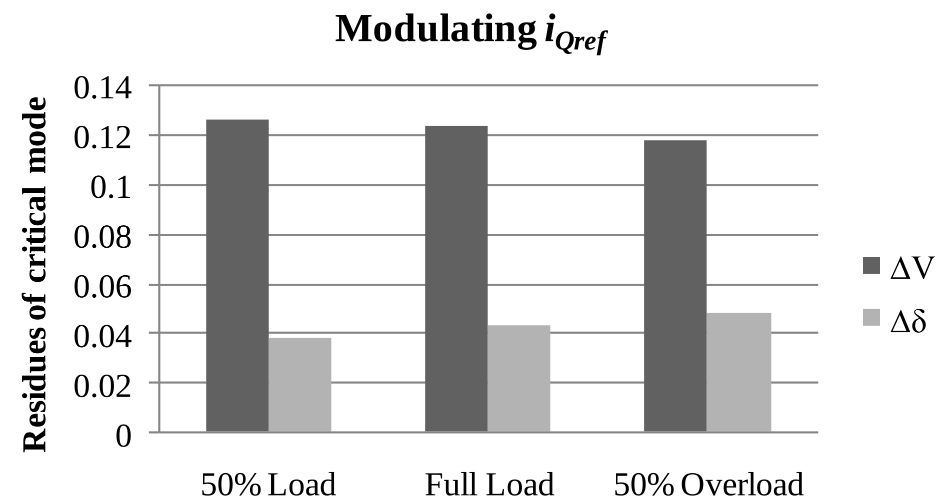
- Critical mode sensitivity
  → Higher for reactive power

- Time domain response
  → Slightly better for nonunity PF

Reactive power support from PV is beneficial for damping

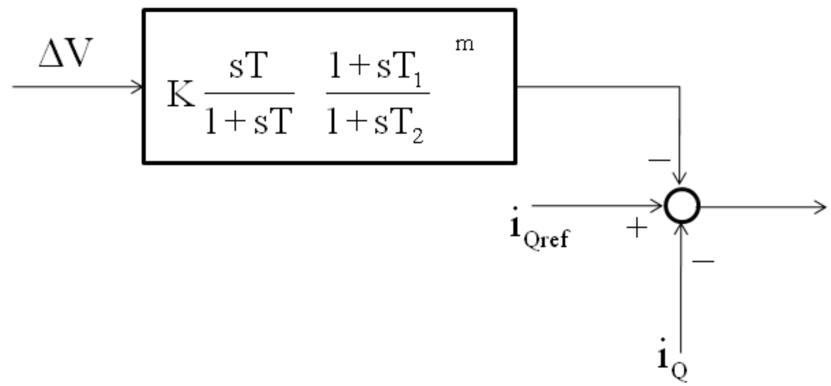
PV Control: Signal Selection



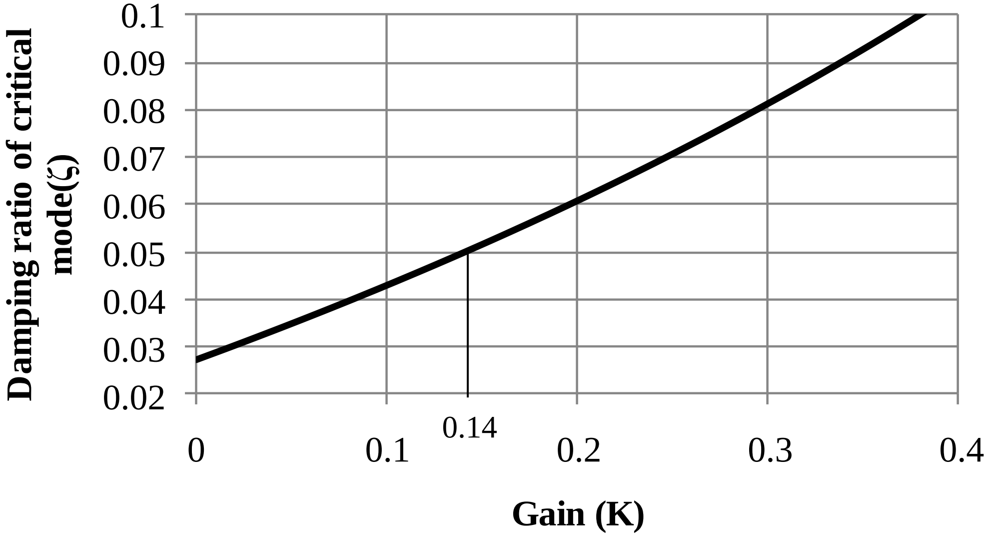


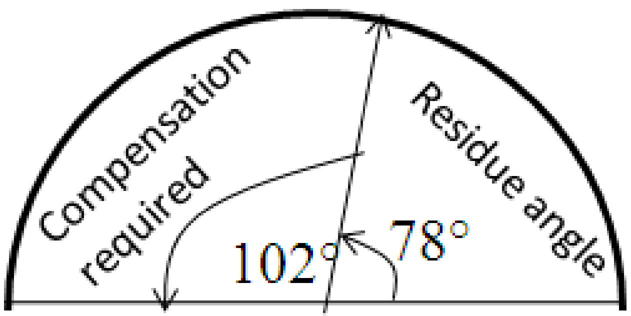
- Terminal voltage is better feedback signal (most of the loading conditions).
- i_{Qref} is selected as modulating signal

Desired Controller



PV Control: Gain and Compensation

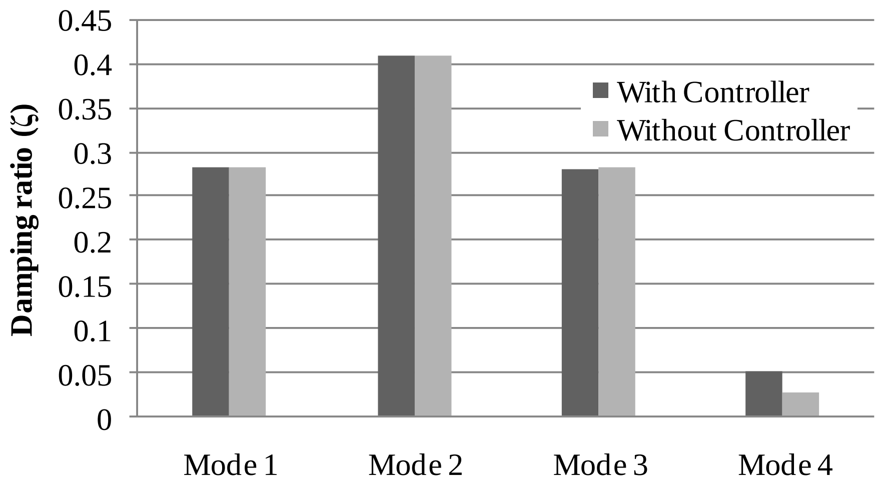


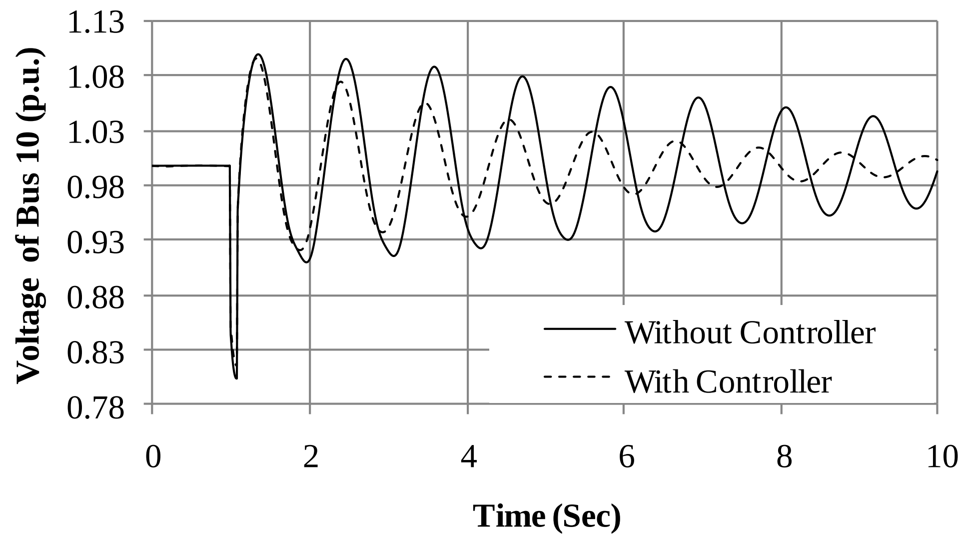


Gain (K) was selected 0.14 for damping ratio 0.05.

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