Oscillations Monitoring and Tie-Line Bias Control with High Penetration of PV Systems Using PMUs

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Introduction

With the renewable energy regulation passed in many countries including Australia, Canada, China, Germany and United States, utility-scale photovoltaic (PV) plants ranging from 5 MW to more than 250 MW are in either operation or planned to be in the near-term.

If PV penetration become significant fractions of the connected generation, PV generators must take part in the operation of the power system.

A major challenge in integrating high PV penetration (>20%) rests in a grid's ability to handle the intrinsic variability of solar irradiance.

→ **ARPA-E FOA on NODES**

The power and frequency fluctuations in systems with large MW PV plants raise dynamic and transient stability concerns.

Introduction

With increasing distributed variable generation and emergence of smart markets, it is possible to have certain generation areas leverage interconnections to provide power interchange and regulate system frequency.

Emergence of smart market power purchase agreements (PPAs) in the near-future may cater for real-time variable scheduled interchange.

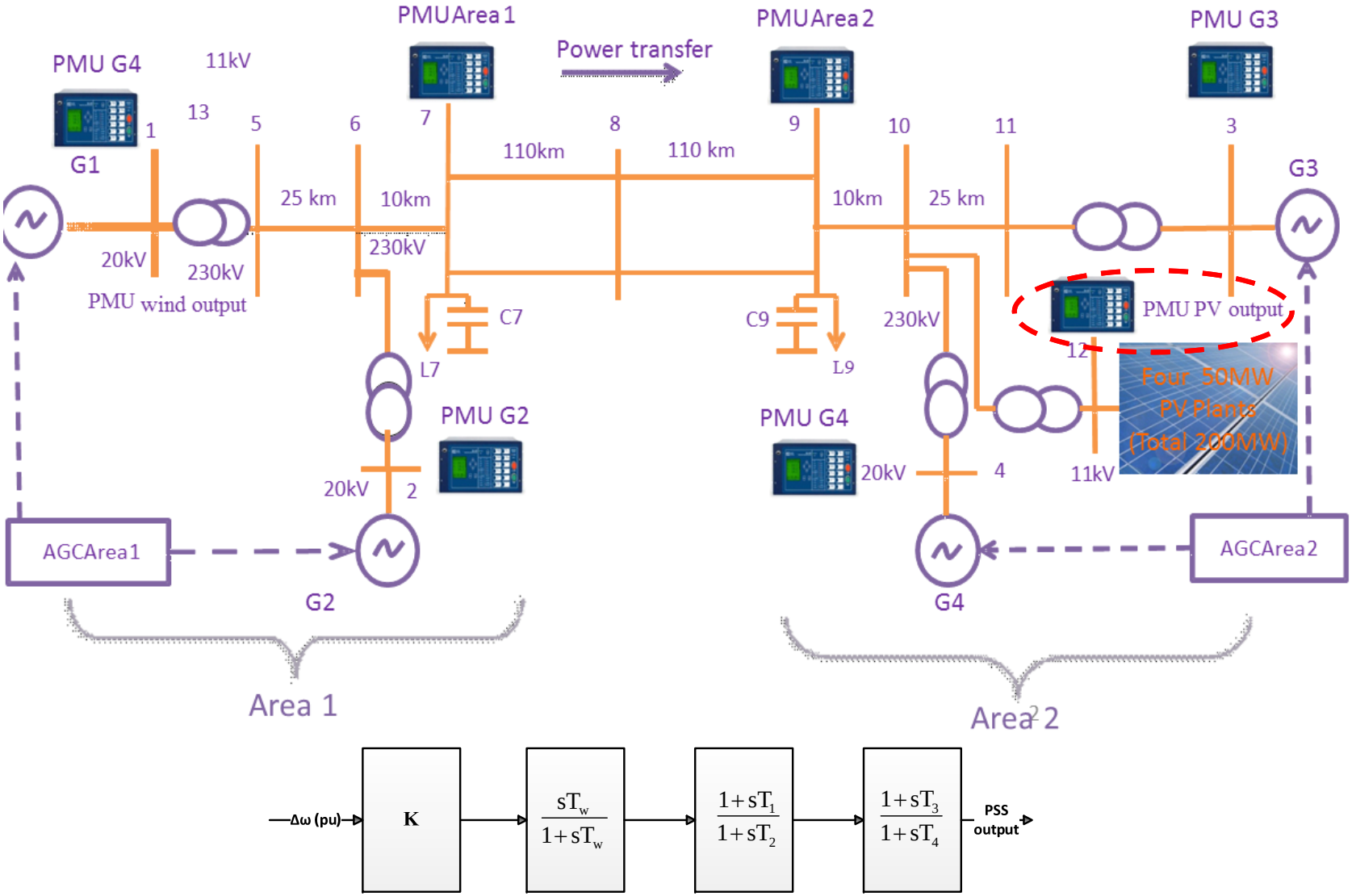
AGC with PMU technology will be able to provide tie-line bias control for such smart market PPAs.

In this paper, real-time ‘variable’ tie-line bias control with a utility-scale PV plant integrated into a two-area power system is investigated.

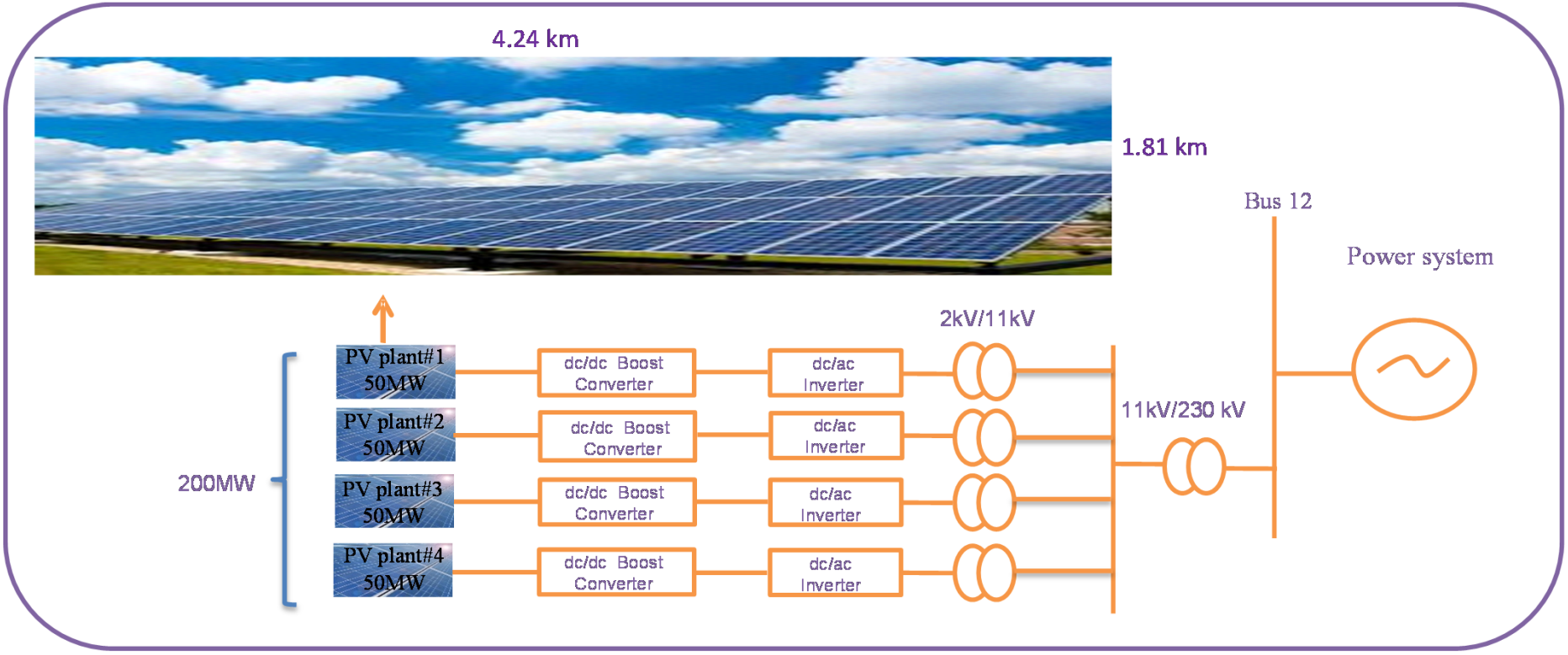
The tie-line bias control is implemented using an AGC receiving system measurements from PMUs including the PV power output in the adjacent area.

Furthermore, oscillations due to cloud cover and disturbances are investigated.

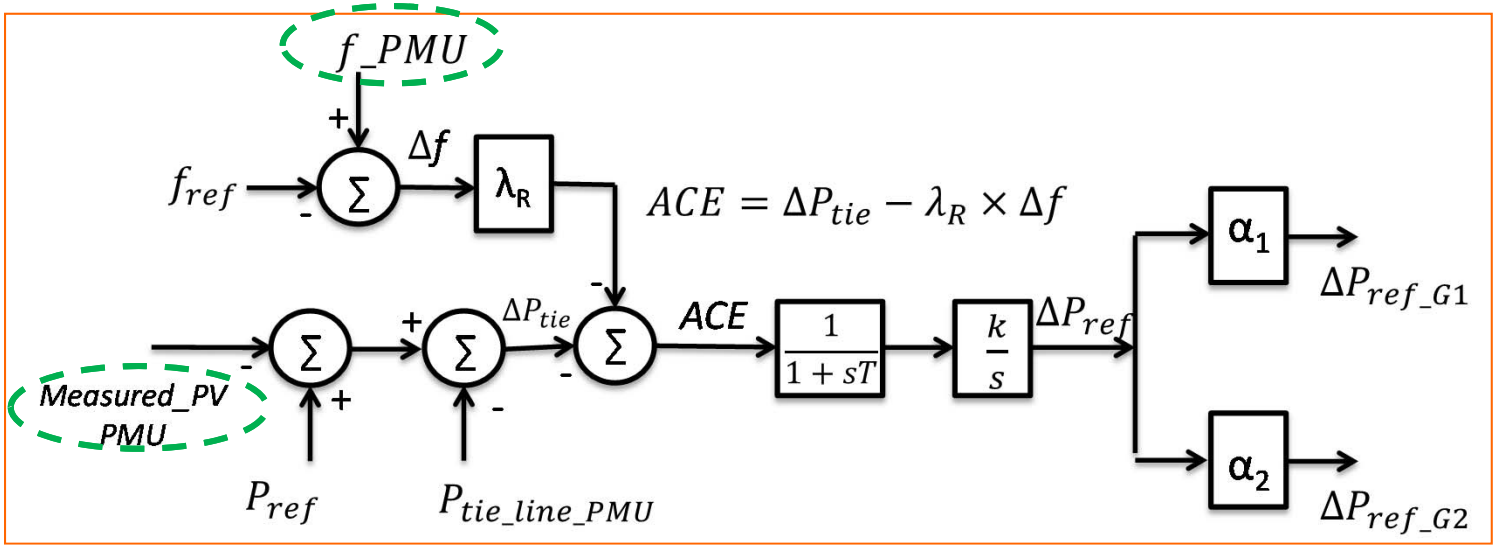
Power System with PV Plants

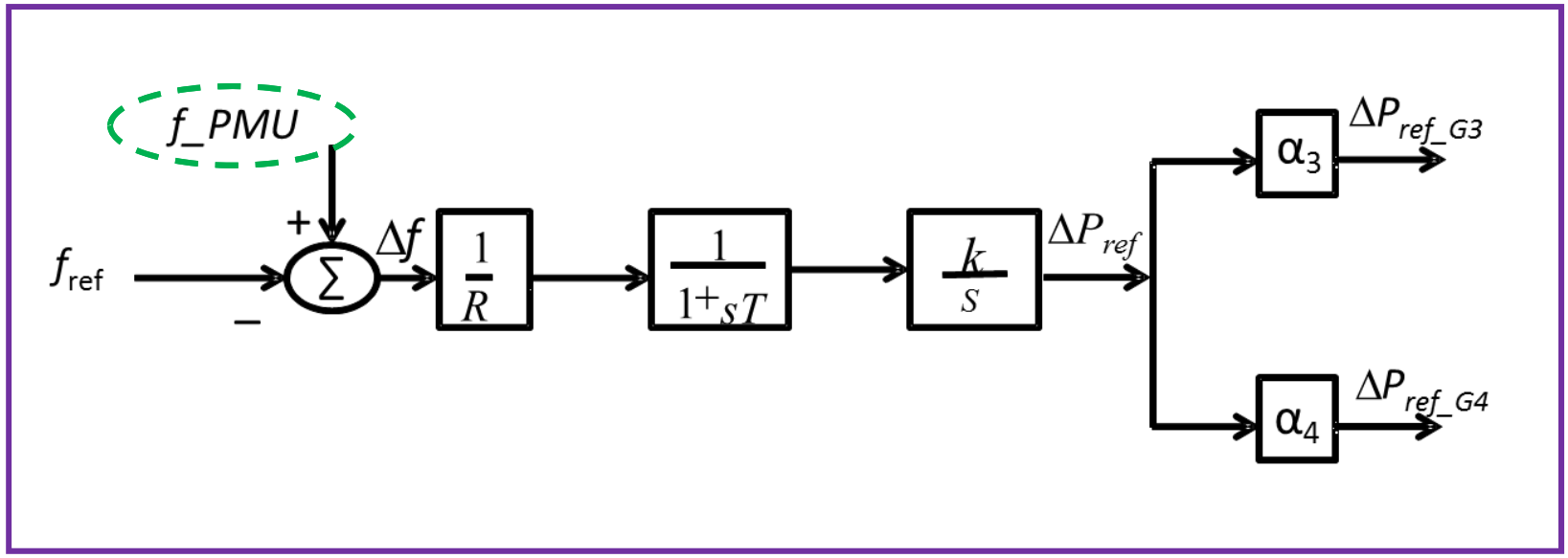


Large PV Plant



Areas 1 and 2 AGCs



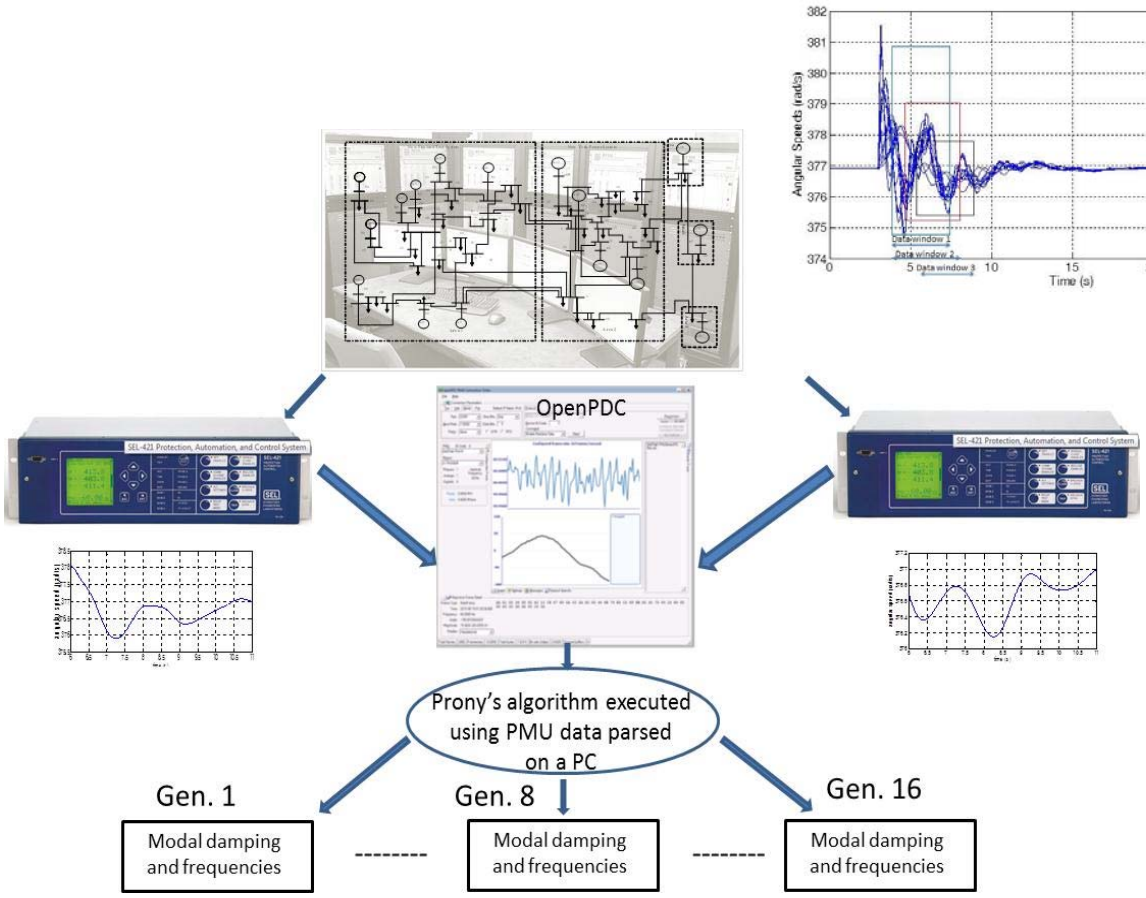


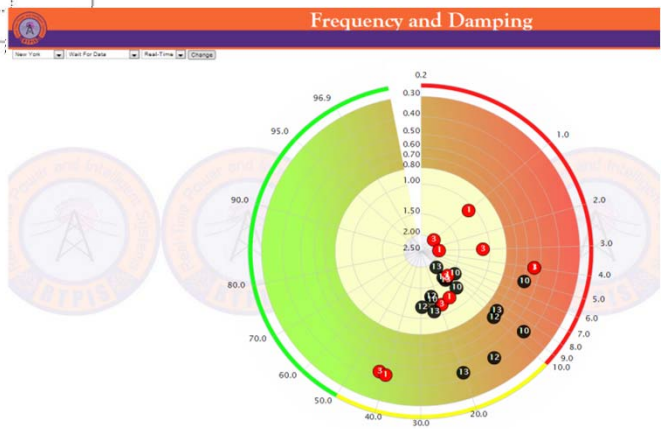
Rapid Prototyping Laboratory

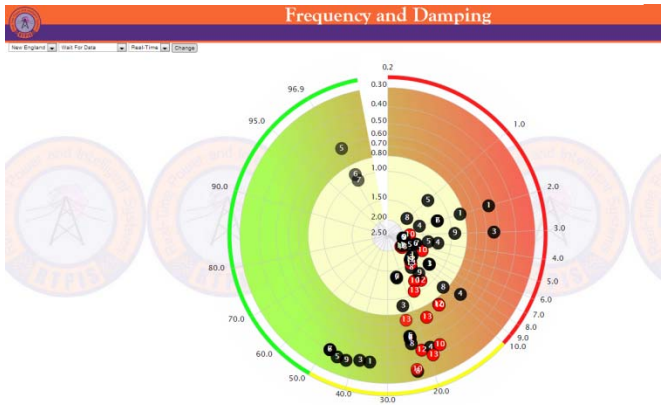
Situational Intelligence Laboratory

Real-Time Grid Simulation Laboratory

Online Modal Analysis of Synchronous Generators







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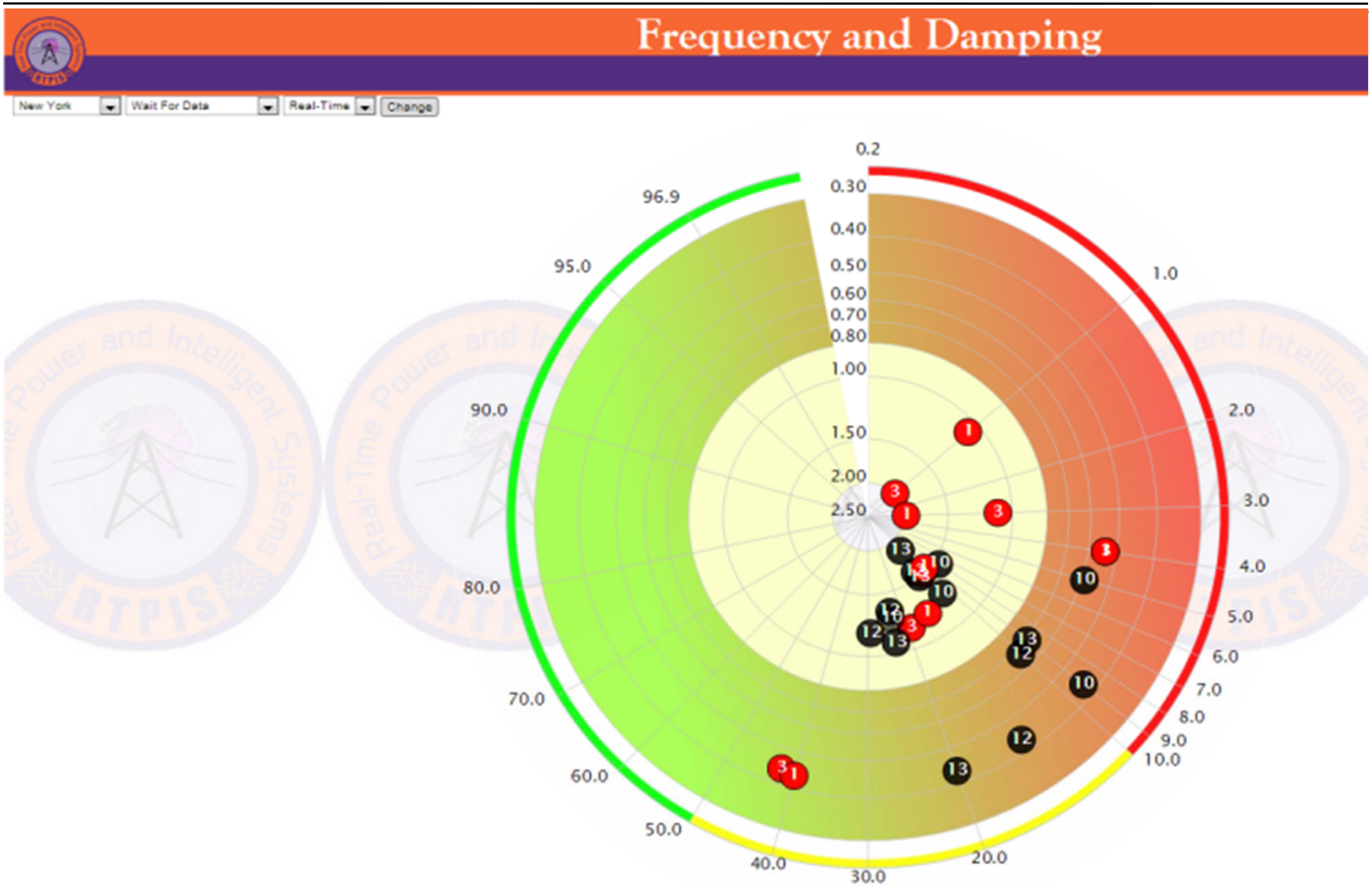
Online Modal Analysis of Synchronous Generators



Real-time Laboratory Experimental Setup

Weather system

Temperature *T(t)*

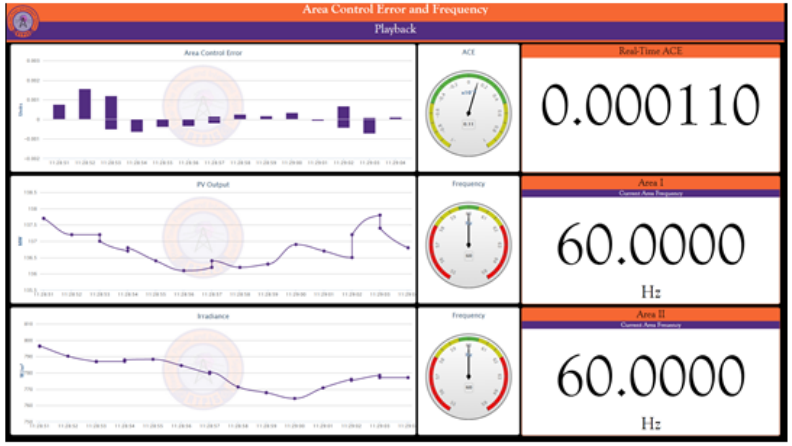
Solar Irradiance *I(t)*

Two-Area four machine power system in fig.1

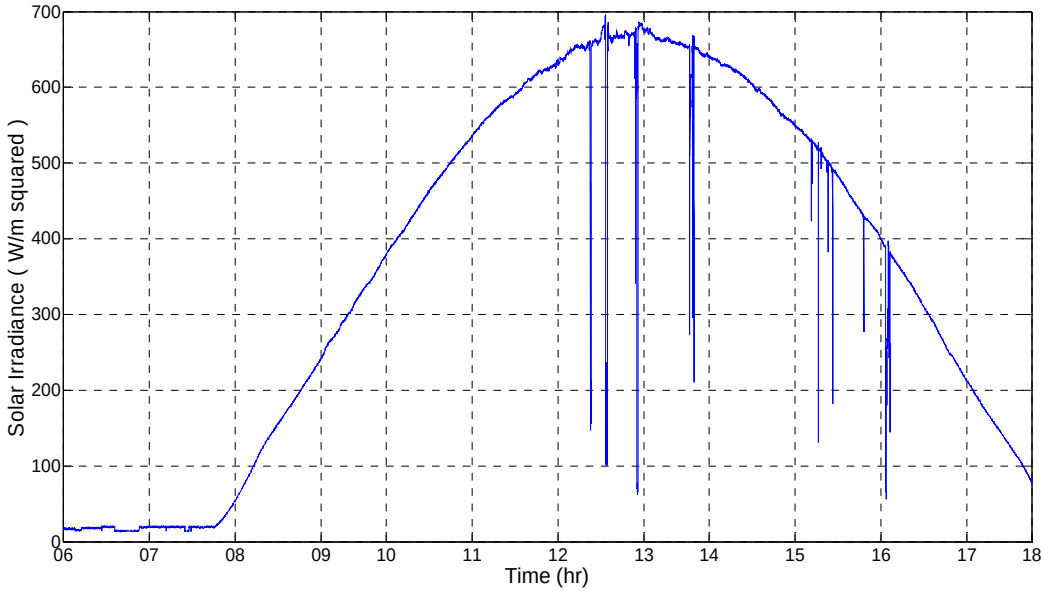
RTDS Racks

PMUs

ACE and Area frequency Visualization



Solar Irradiance at Clemson



Solar irradiance on October 21, 2014 between 06h00 and 18h00.

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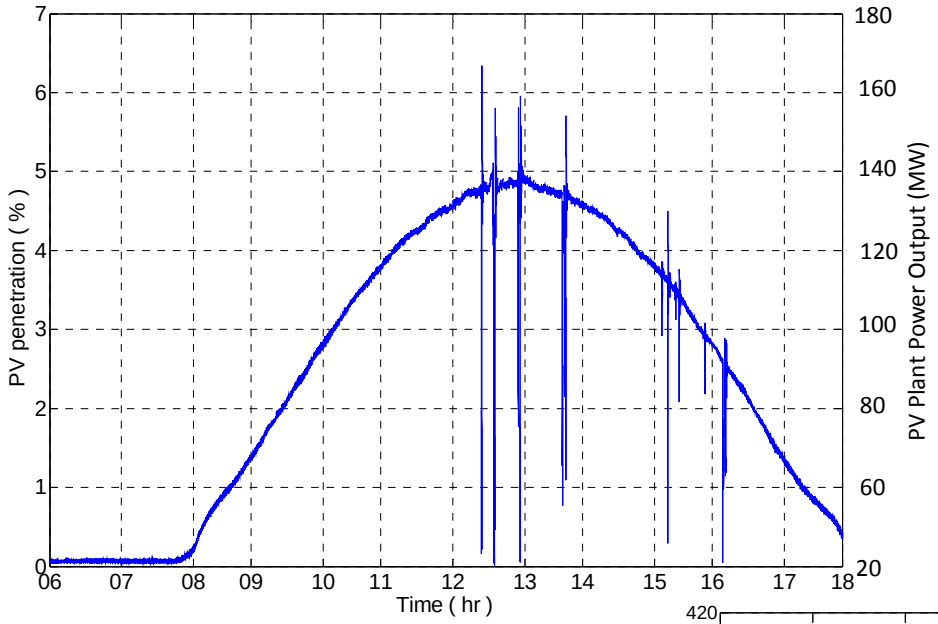
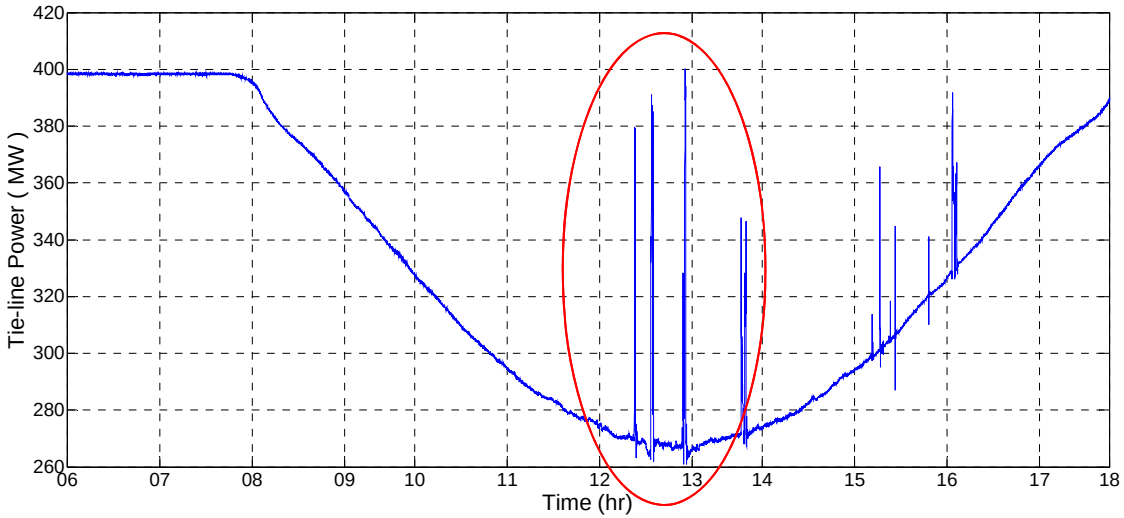
PV Power and Tie-Line Power Flow



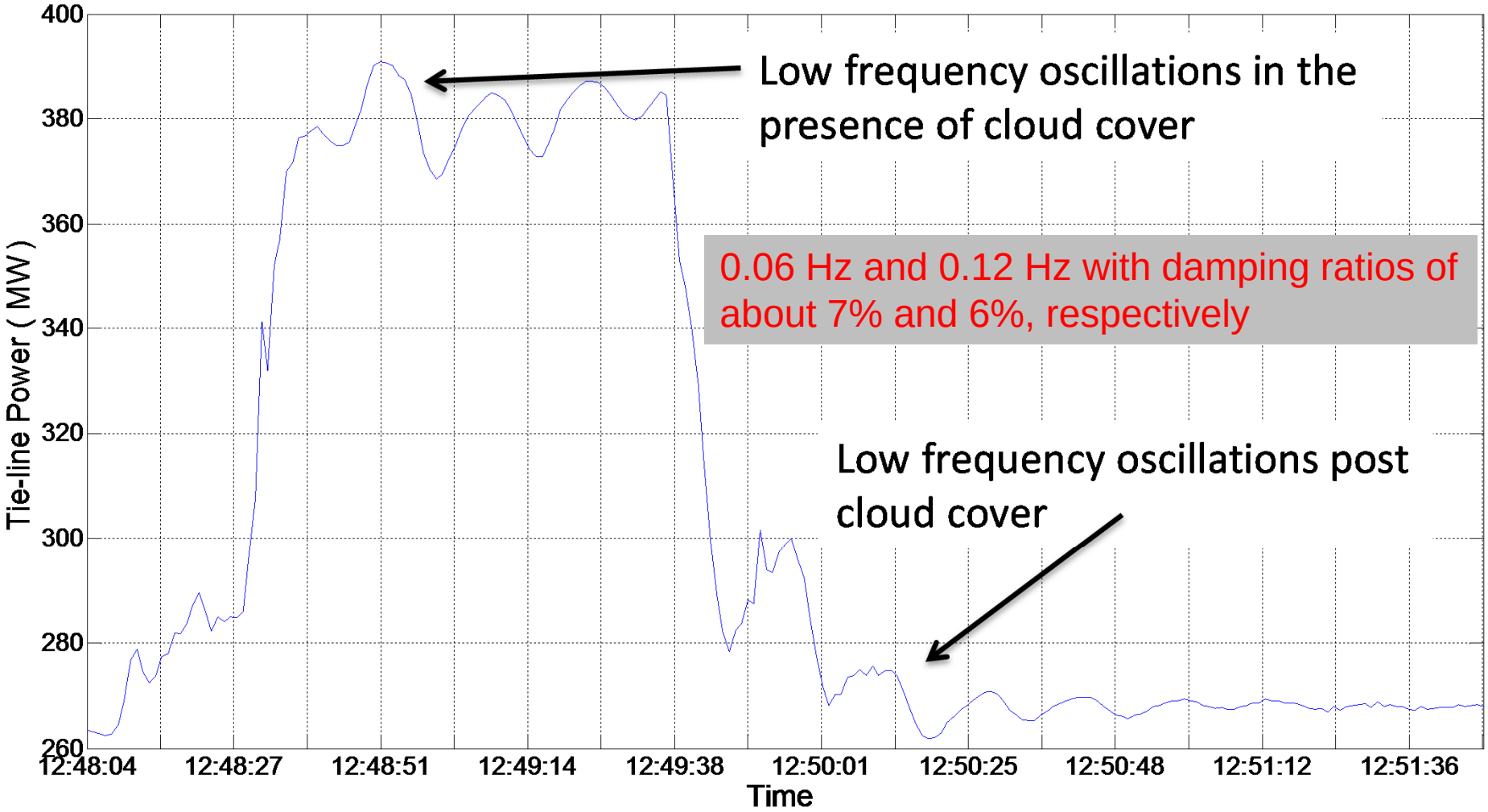
Tie-line power flow with the PV plant operation on October 21, 2014 between 06h00 and 18h00.

130 MW drop

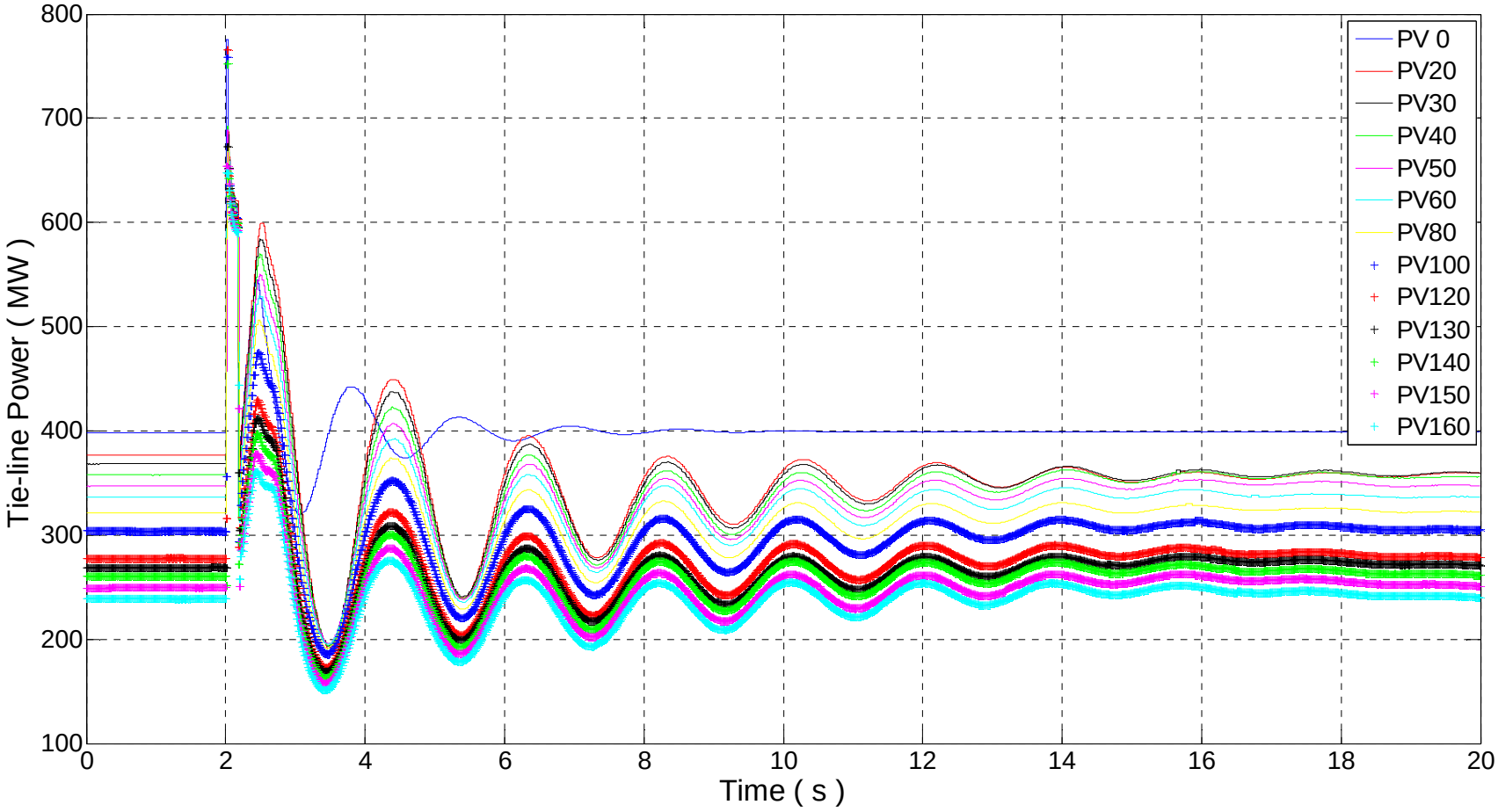
Tie-line power flow lines between buses with the PV plant operation on October 21, 2014 between 06h00 and 18h00.



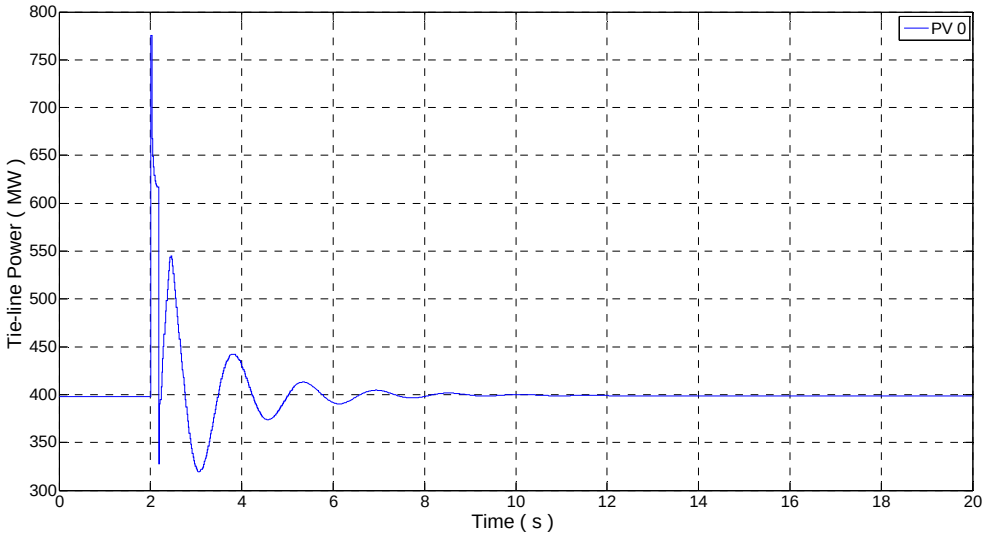
Low frequency oscillations during and after cloud cover



Tie-line power flow oscillations (10 cycle three phase short circuit disturbance)



Tie-line power flow oscillations

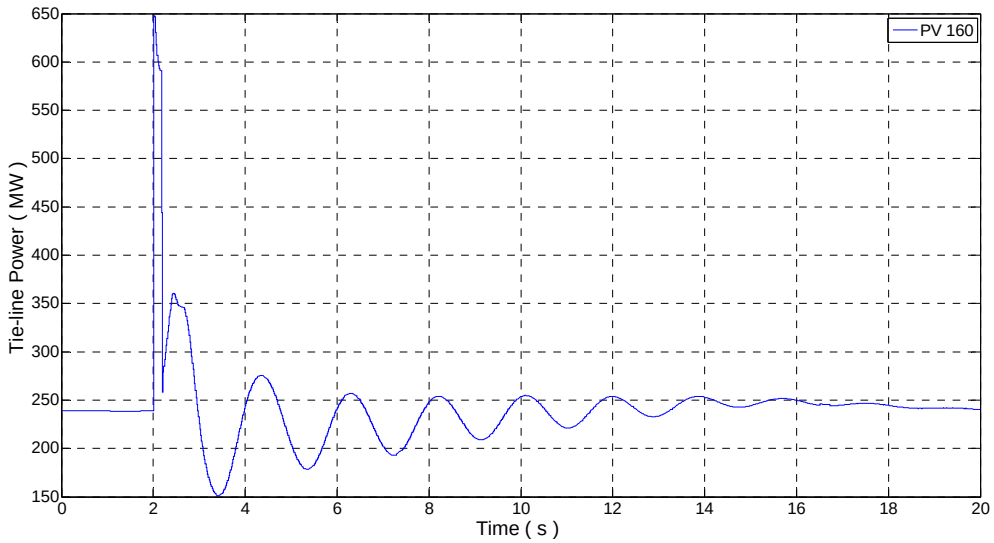


with no PV power injection.

20 MW to 160 MW, damping decreases from 8.72% to 6.01% for the 0.52 Hz mode

with 160 MW of PV power injection (5.5% penetration)

6.54% to 20.98% for the 1Hz mode



Frequency Modes and Corresponding Damping

PV Penetration (MW)	Frequency (Hz)		Damping (%)	
20	0.52	1.04	8.72	6.54
30	0.52	1.04	8.43	7.46
40	0.52	1.04	8.20	8.03
50	0.52	1.04	7.74	8.38
60	0.52	1.02	7.49	8.89
80	0.52	1.03	7.23	10.32
100	0.52	1.02	6.96	9.52
120	0.52	0.98	6.60	12.43
130	0.52	1.02	6.55	15.04
140	0.52	0.98	6.40	13.79
150	0.52	1.00	5.67	21.52
160	0.52	0.95	6.01	20.98

Summary

Real-time ‘variable’ tie-line bias control on a two-area power system with a 200 MW utility-scale PV plant was studied in this paper.

The tie-line bias control is implemented using an automatic generation controller

- PMUs
- PV power.

Variable tie-line bias control to enable smart markets and maximize utilization of PV power integration

- new/modified modes of oscillations
- cloud covers and large disturbances.

A wider spectrum of oscillation modes

- power system stabilizing controllers such as PSSs on synchronous generators
- power oscillation damping controllers that exploit the capability of FACTS devices to enhance system damping.

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NSF Industry/University Cooperative Research Center

Clemson University and Georgia Institute of Technology

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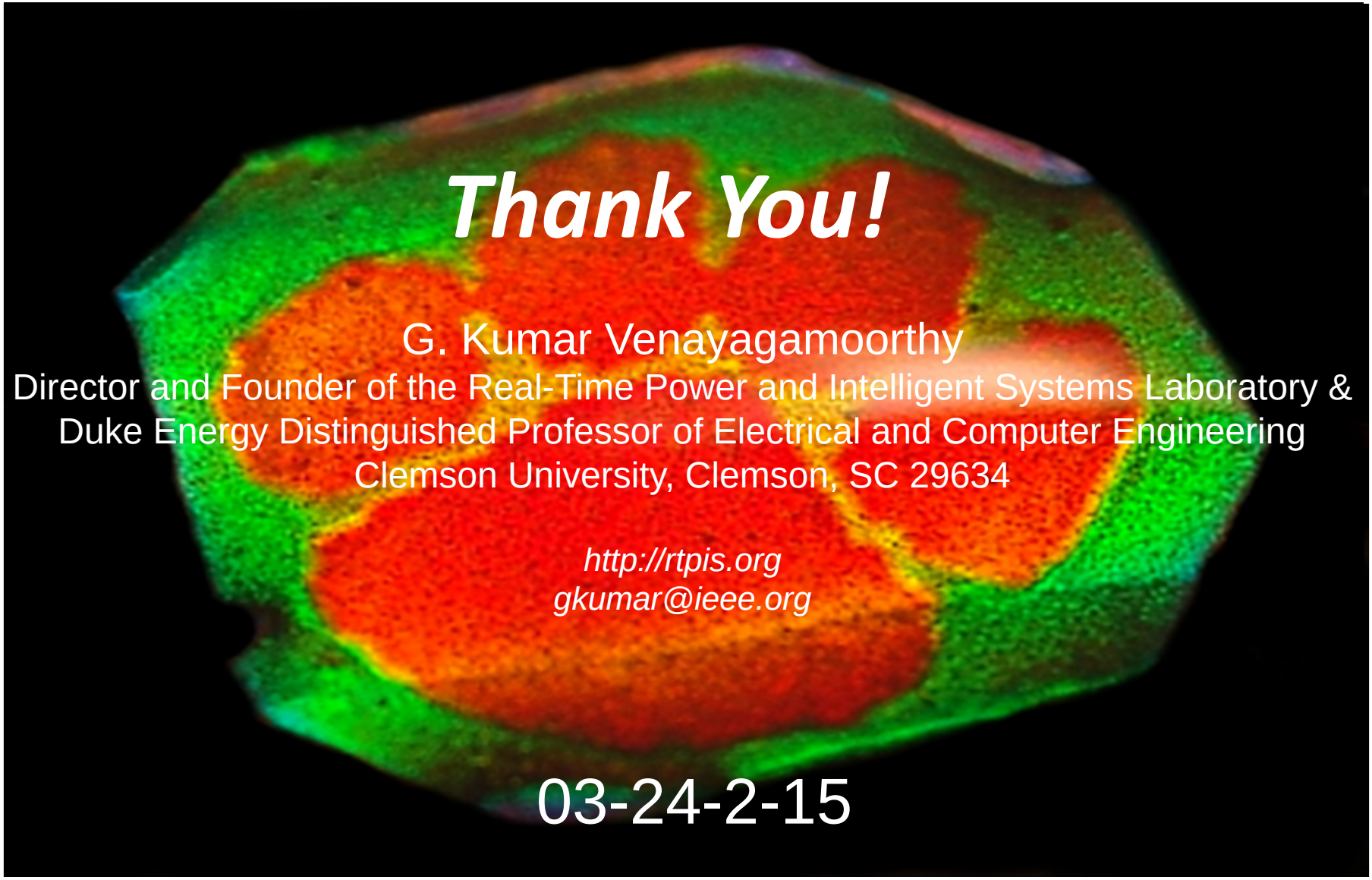

Thank You!

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