PMU Based Real-Time Oscillation Monitoring

G. Kumar Venayagamoorthy, PhD, FIET, FSAIEE
Duke Energy Distinguished Professor &
Director of the Real-Time Power and Intelligent Systems Laboratory
Holcombe of Department of Electrical & Computer Engineering
Clemson University

E-mail: gkumar@ieee.org
http://people.clemson.edu/~gvenaya
http://rtpis.org
http://brain2grid.org

Outline

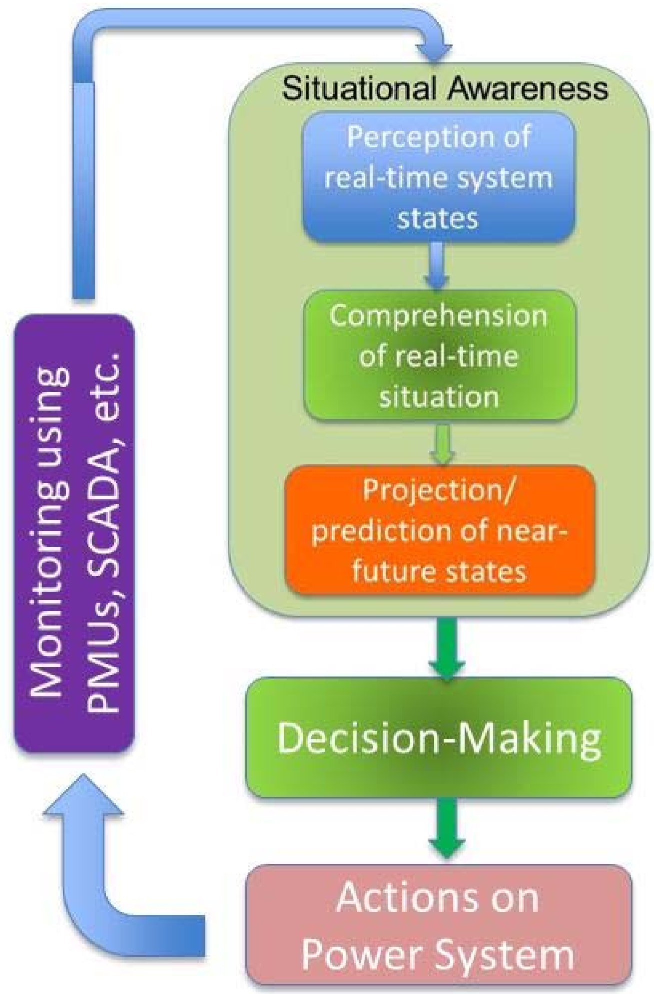
- Introduction
- Situational Intelligence
- RTPIS Lab Facility
- RT Monitoring
- Results

Situational Awareness (SA) in a Control Center

- When a disturbance happens, the operator is thinking:
  - **Received a new alert!**
    - **Is any limit in violation?**
      - **If so, how bad?**
  - **Problem location?**
    - **What is the cause?**
  - **Any possible immediate corrective or mitigative action?**
    - **What is the action?**
    - **Immediate implementation or can it wait?**
  - **Has the problem been addressed?**
    - **Any follow up action needed?**

- SA is aimed at looking into a complex system from many different perspectives in a holistic manner.

- Local regions are viewed microscopically and the entire system is viewed macroscopically.



PMU Placement

- Ideally - every bus of the grid but economically not practical
- Data requirements for multiple synchrophasor applications
- Guidelines:
  - HV substations
  - Large power plants
  - Major transmission corridors
  - Remedial action schemes based substations
  - Renewable generation plants

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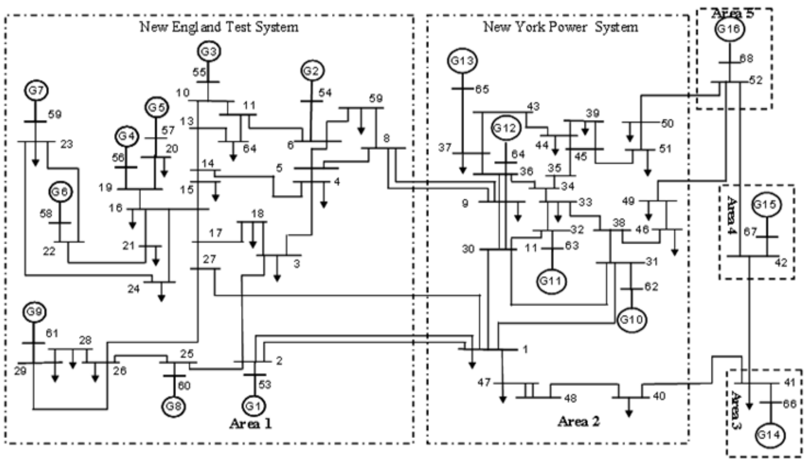
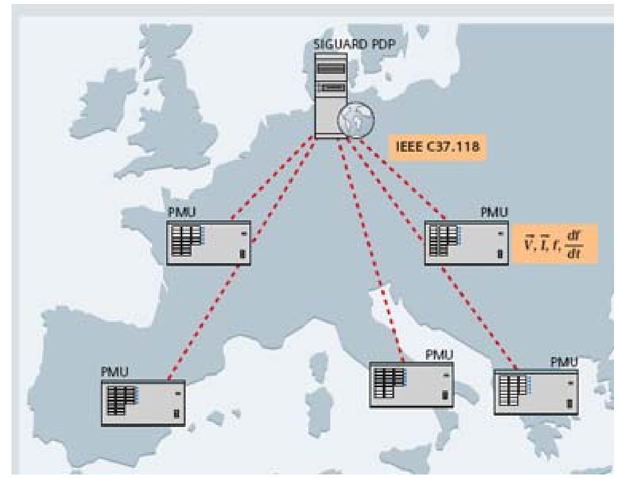
Online Oscillation Monitoring

- Due to the deregulation of the power market, the power systems have become more stressed.
- Large power exchanges over long transmission lines are major contributing factors for oscillatory instability phenomena in power systems.
- Grid integration of large amounts of renewable sources will affect the dynamics of the power system – leading to 'renewable stress'.
- Each power system has its own characteristic modes, and therefore online oscillation monitoring is critical for the security of bulk power system.

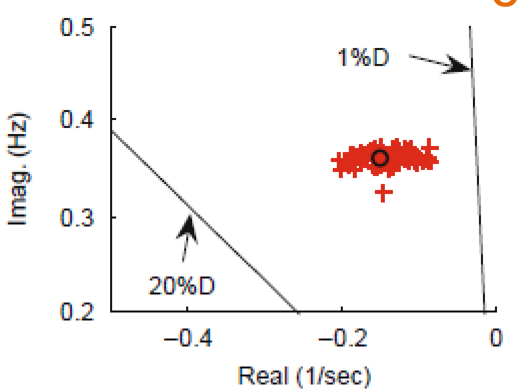
Online Oscillation Monitoring

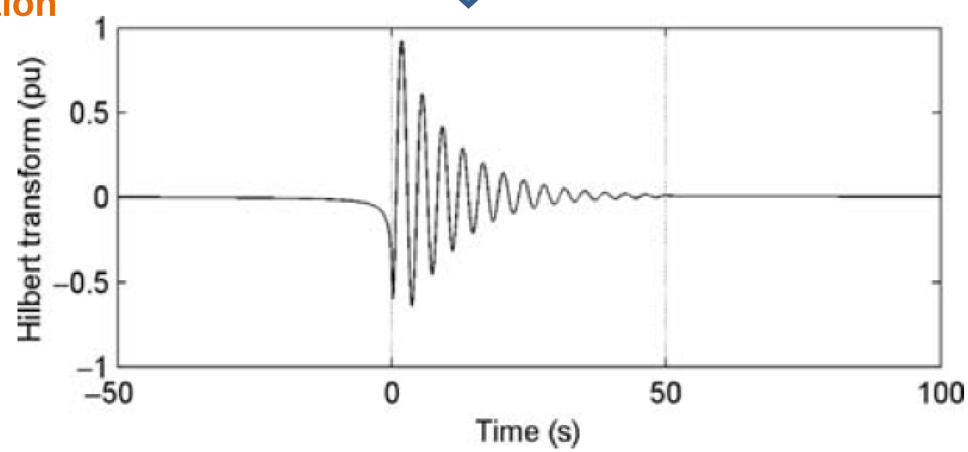




Continuous incoming data

Computation





Mode frequency and damping information in control center display

Results from monitoring algorithms

Oscillation Monitoring Methods

- Prony method
- Hankel total least squares method
- Matrix pencil method
- Eigensystem realization algorithm
- Kalman filter methods (extended, unscented)
- Wavelet analysis
- Hilbert-Huang transform

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Situational Intelligence

- Integrate historical and real-time data to implement near-future situational awareness

  Intelligence (near-future) =
  function(history, current status, some predictions)

- Predict security and stability limits
  - RT operating conditions
  - Oscillation monitoring
  - Dynamic models
  - Forecast load
  - Predict/forecast generation
  - Contingency analysis
- Advanced visualization
  - Integrate all applications
  - Topology updates and geographical influence (PI and GIS – Google earth tools)

Predictions is critical for Real-Time Monitoring

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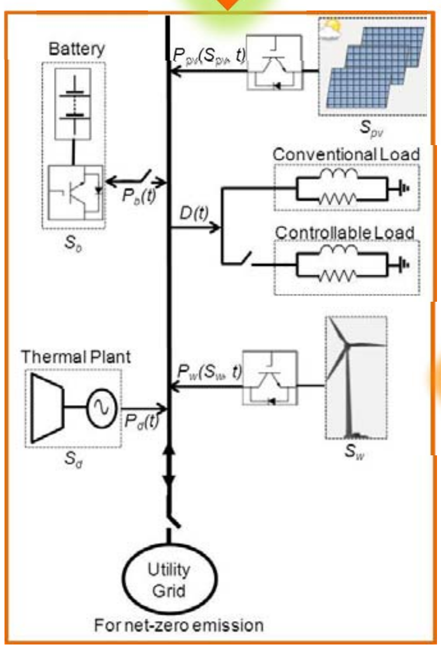
Situational Intelligence Laboratory

High-speed 1-10 Gbit/s fiber link

Dedicated fiber link

Micro-grid



High-speed 1-10 Gbit/s fiber link

High-speed 1-10 Gbit/s fiber link

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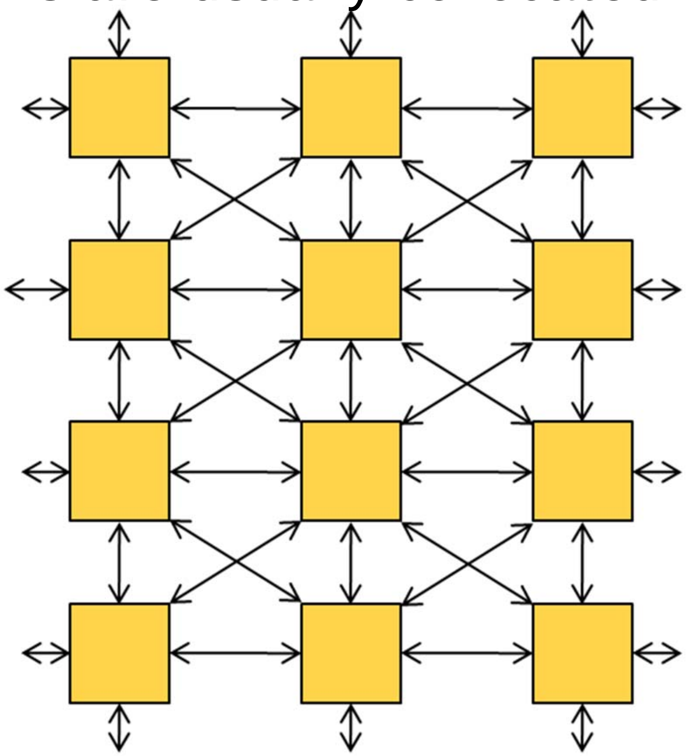
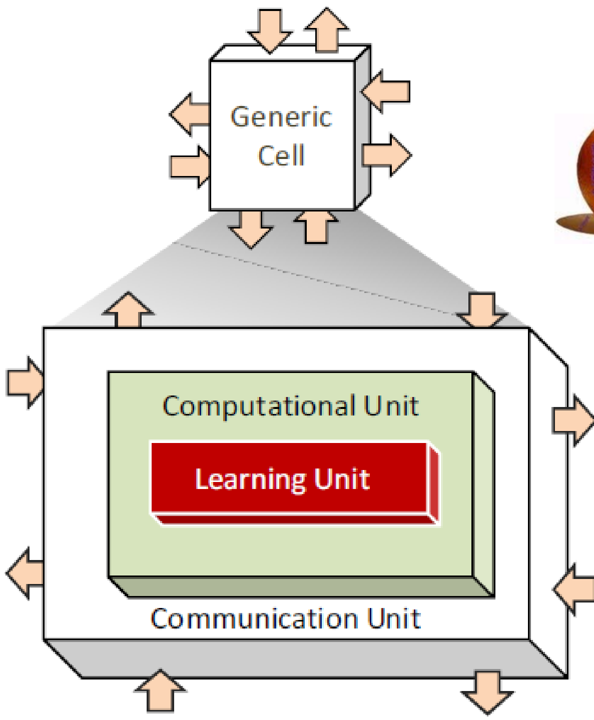
Cellular Computational Networks

- Cellular computational networks (CCNs) generally mean computational units connected to each other.
- Cells are usually collocated and trained synchronously.





Luitel B, Venayagamoorthy GK, “Decentralized Asynchronous Learning in Cellular Neural Networks”, *IEEE Transactions on Neural Networks*, November 2012, vol. 23. no. 11, pp. 1755-1766,

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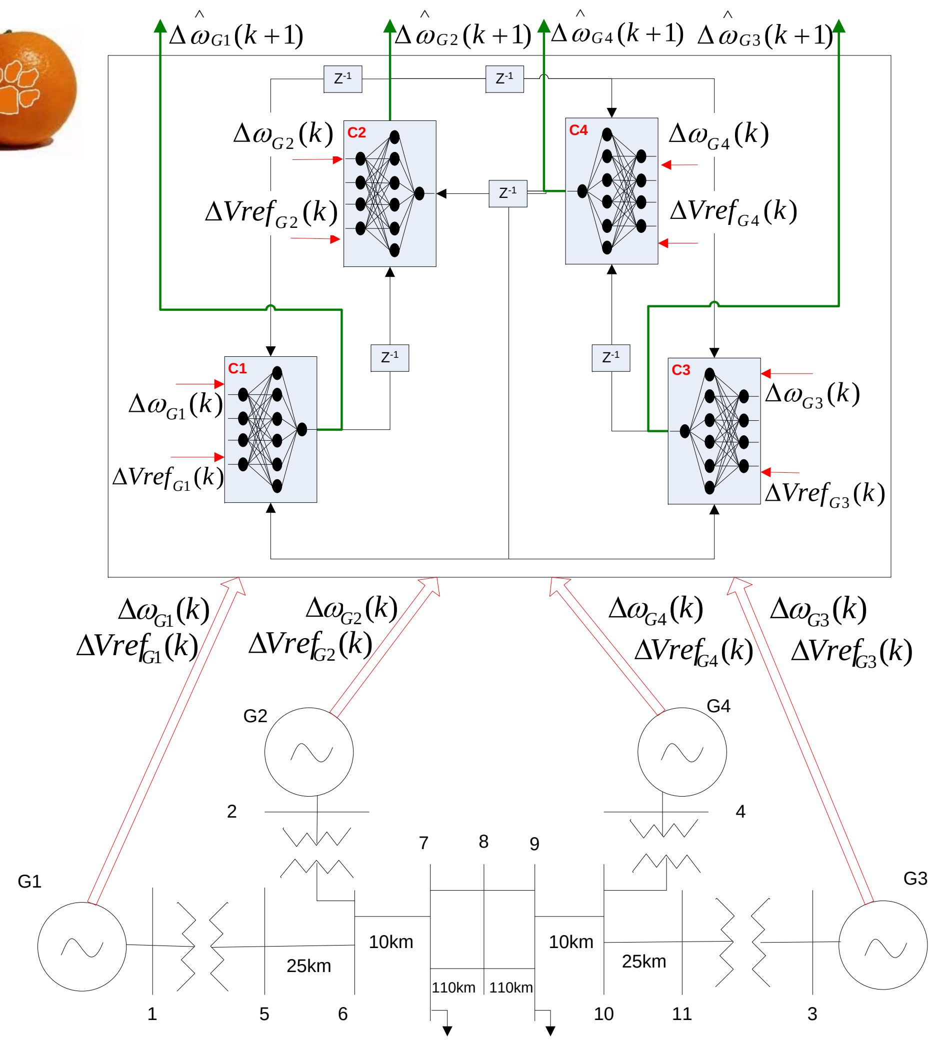
Online Monitoring Systems Using CCN

- Each cell represents one generator of a multi-machine power system - Each cell predicts speed. deviation of one generator
- The cells are connected to each other in the same way as the components in the physical system.
- Nearest neighbors topology is used (*n=2*) to reduce complexity.



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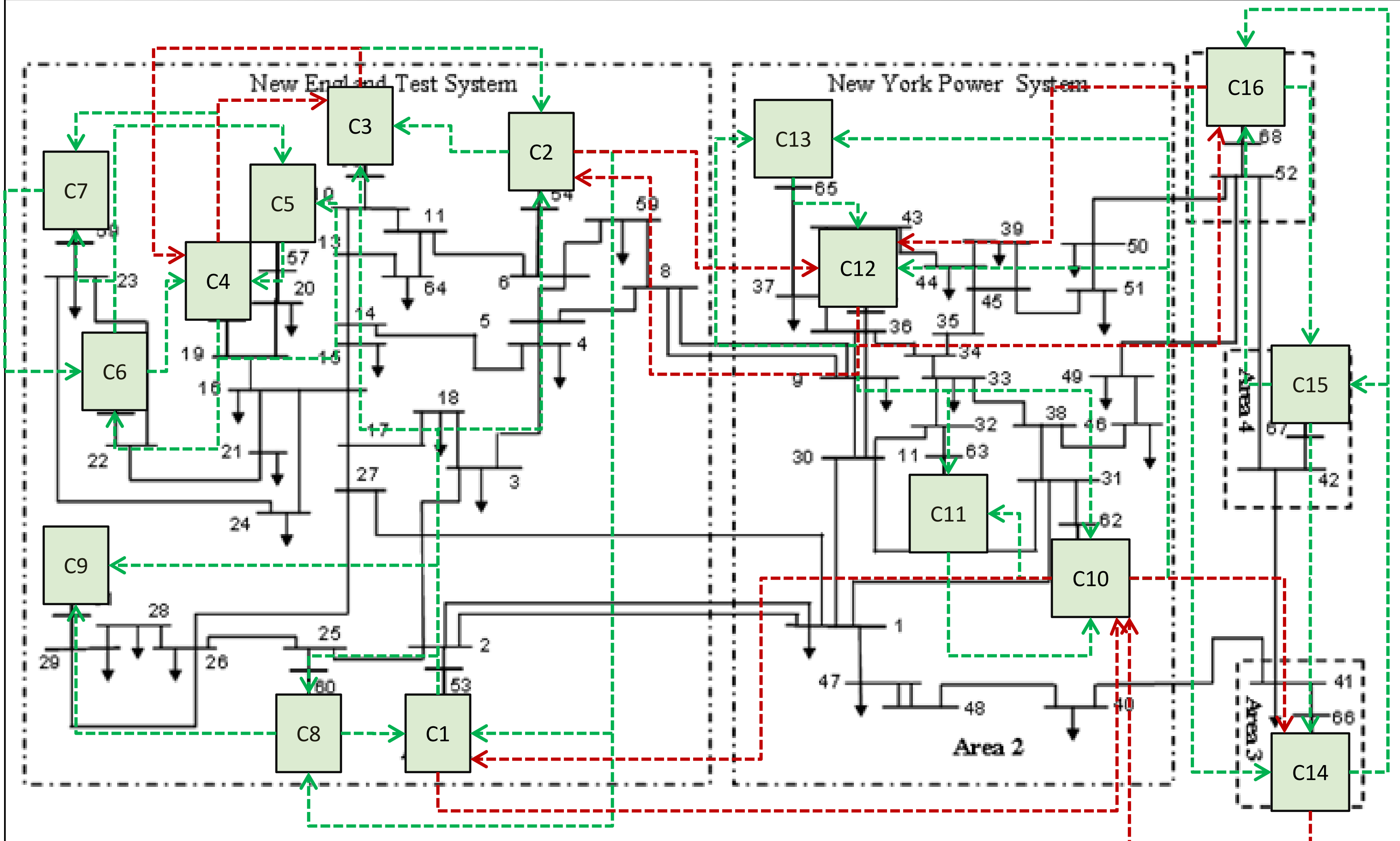
Scalable Online CCN based Monitoring Systems



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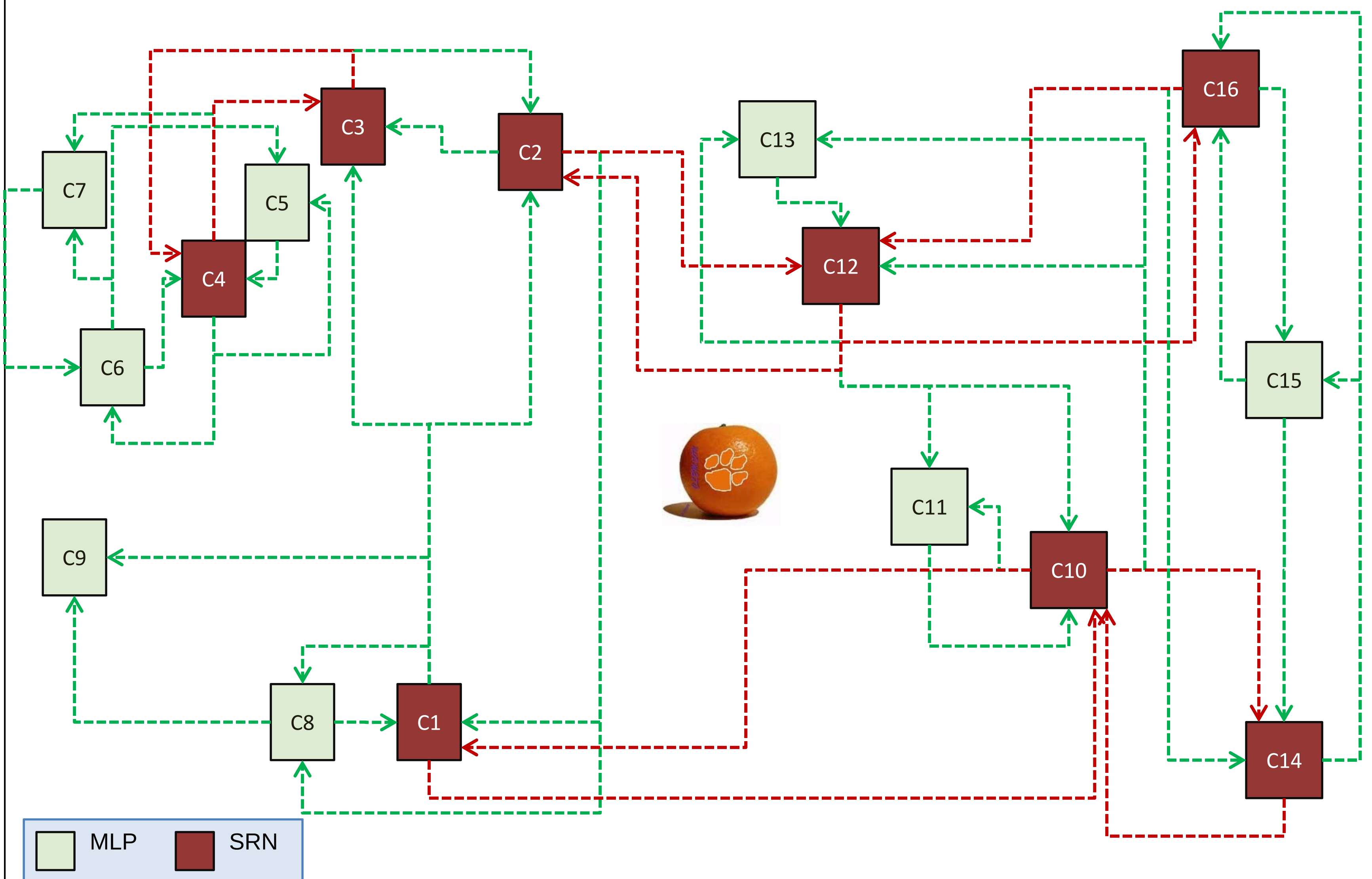
Scalable Online Monitoring Systems



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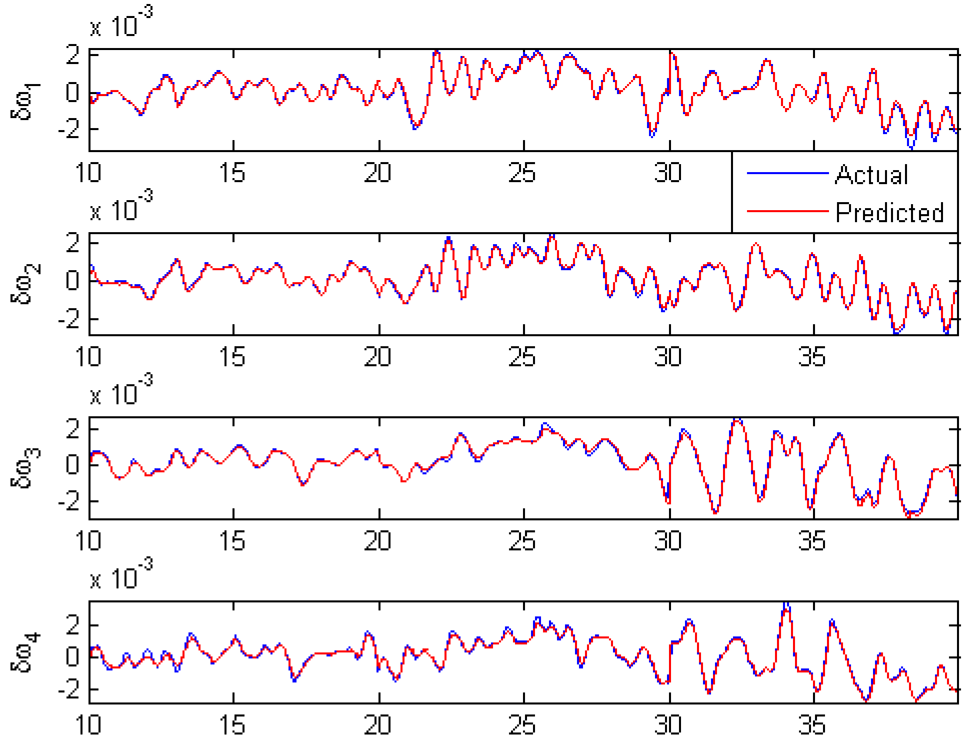
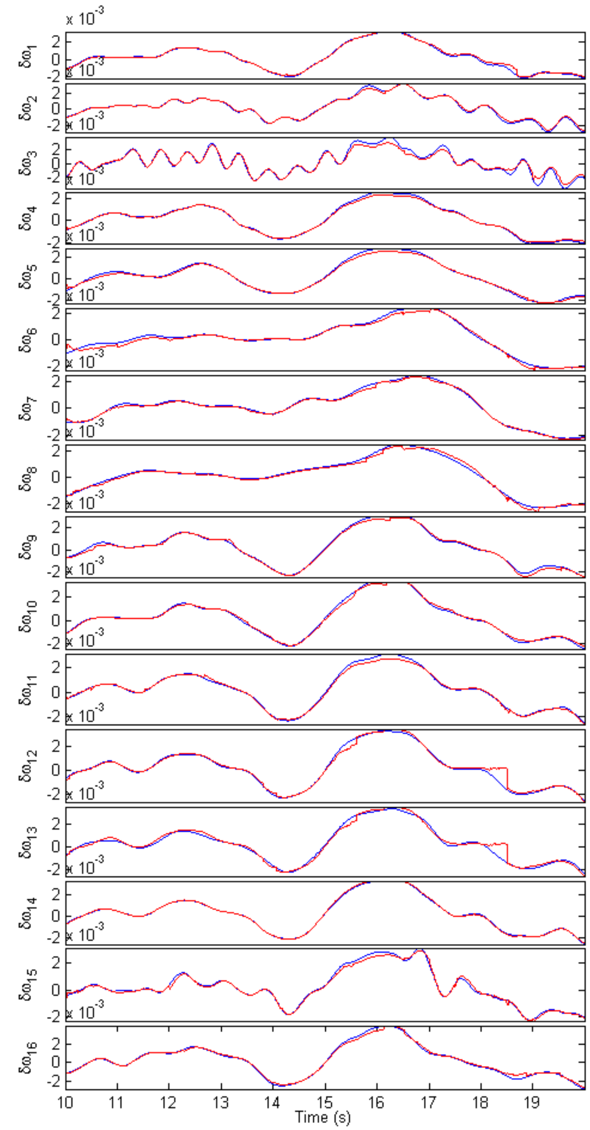
Oscillation Predictions





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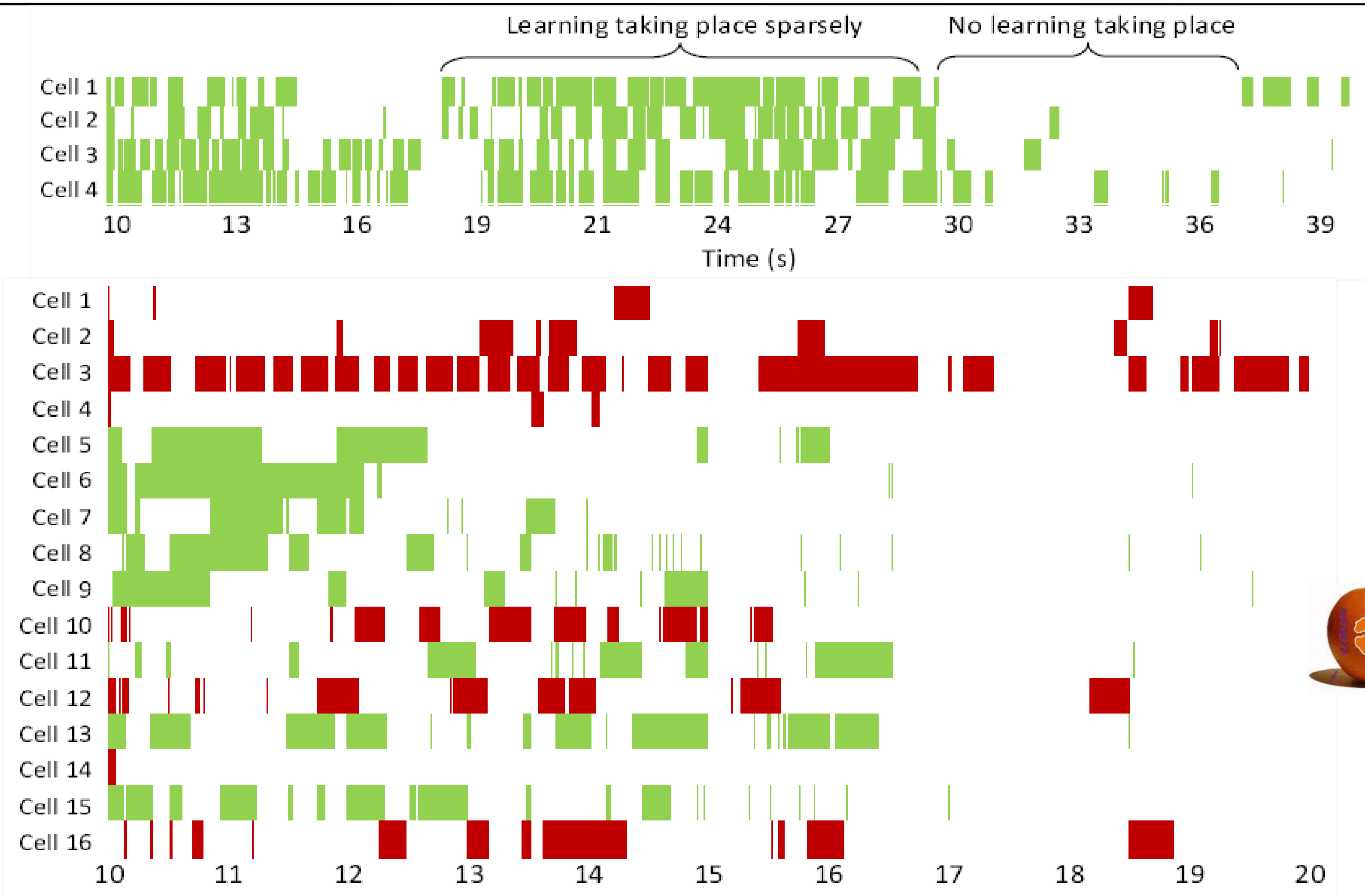
Asynchronous Learning in CCNs



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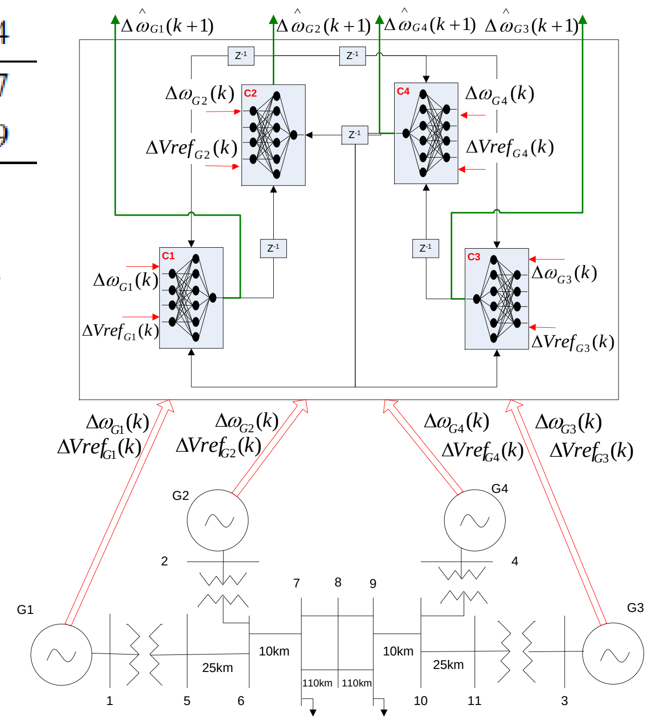
Frequency Modes from CCN Predictions

		Actual		Predicted		Error %	
		ω_N	ζ	$\hat{\omega_N}$	$\hat{\zeta}$	$E\omega_N$	$E\zeta$
G1	Mode 1	0.6023	0.1489	0.6035	0.1476	0.1992	0.13
	Mode 2	1.2075	0.1623	1.2026	0.1521	0.4058	1.02
G2	Mode 1	0.6023	0.1504	0.6039	0.1622	0.2657	1.18
	Mode 2	1.2482	0.1424	1.2298	0.1363	1.4741	0.61
G3	Mode 1	0.6036	0.1491	0.6059	0.1486	0.381	0.05
	Mode 2	1.251	0.1483	1.2311	0.1517	1.5907	0.34
G4	Mode 1	0.6036	0.1481	0.6051	0.1474	0.2485	0.07
	Mode 2	1.2196	0.1463	1.233	0.1802	1.0987	3.39

Natural frequencies and damping ratios obtained with Prony analysis on the actual generator outputs and predicted CCN outputs



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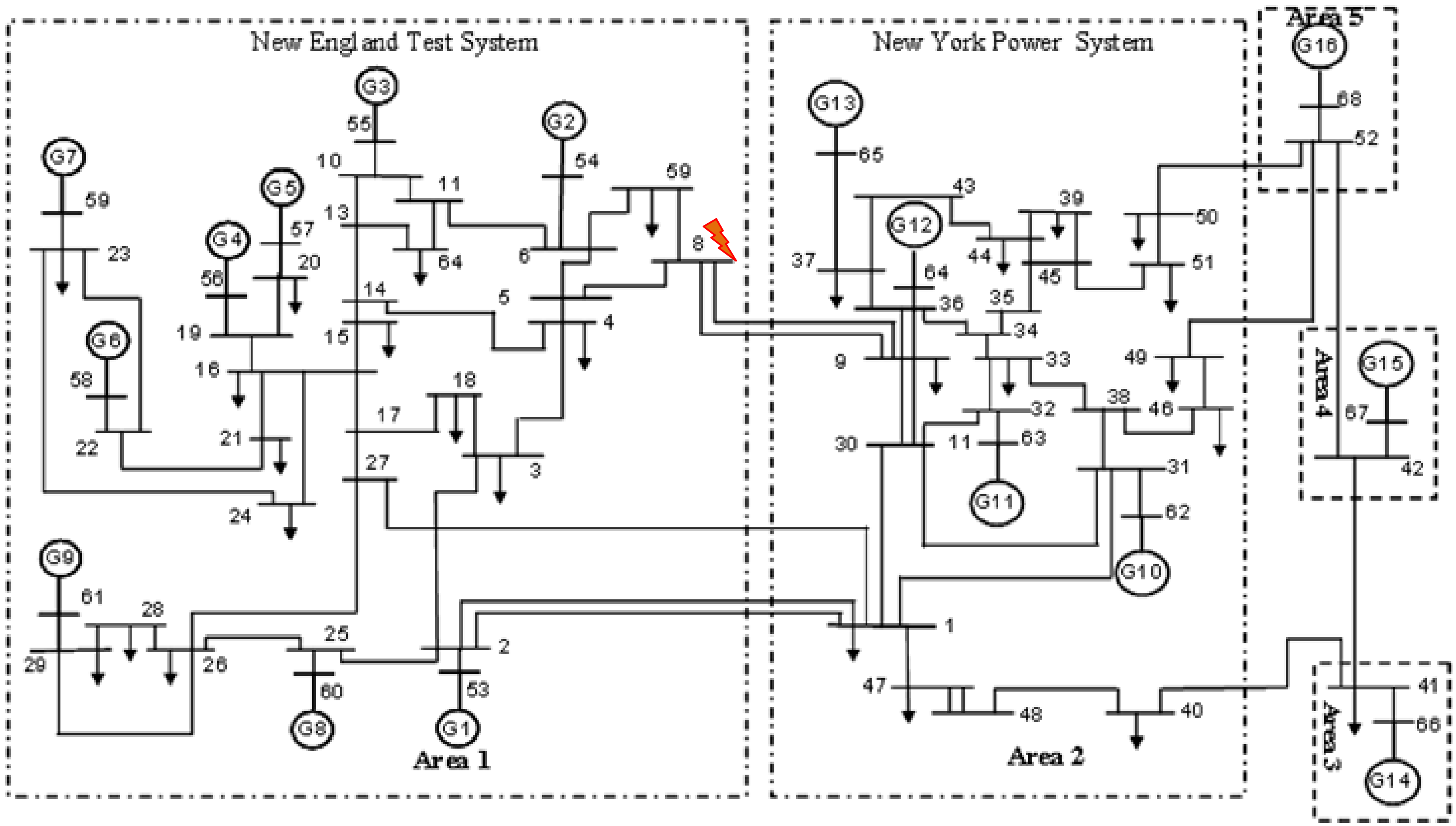
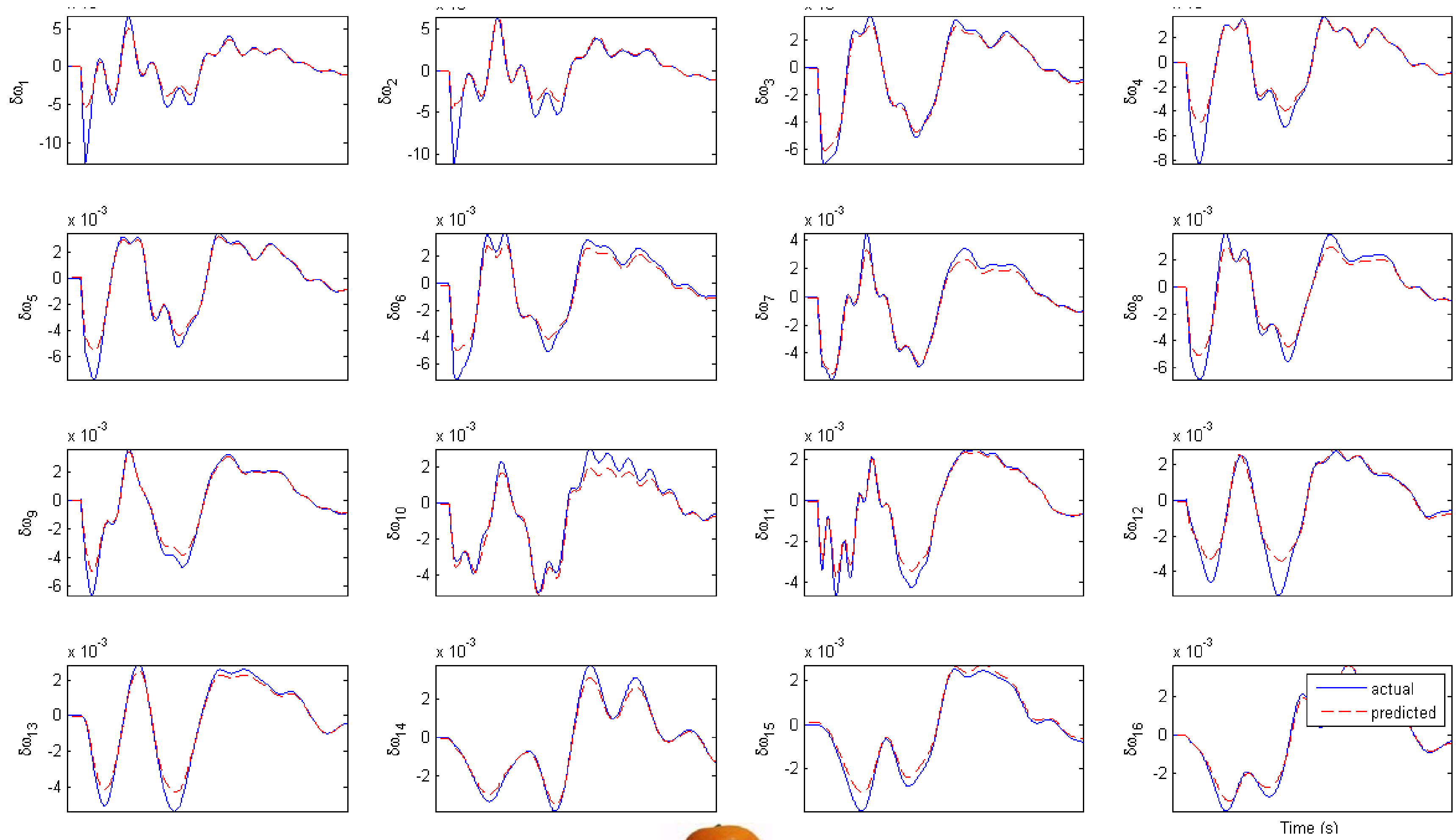
Online CCN based Monitoring Systems



Online CCN based Monitoring Systems



Online CCN based Monitoring Systems

G3			
0.1728	1	**0.1409**	**1**
0.2594	0.0549	**0.2625**	**0.0677**
0.2594	0.0549	**0.2625**	**0.0677**
0.6659	-0.0071	**0.5862**	**1**
0.6659	-0.0071	**0.6675**	**-0.0169**
0.8357	1	**0.6675**	**-0.0169**
1.0866	0.0382	**1.1102**	**0.0497**
1.0866	0.0382	**1.1102**	**0.0497**
1.5552	0.0614	**1.5753**	**0.0455**
1.5552	0.0614	**1.5753**	**0.0455**

G4			
0.1258	1	**0.1166**	**1**
0.2671	0.0497	**0.2729**	**0.045**
0.2671	0.0497	**0.2729**	**0.045**
0.6606	0.0124	**0.642**	**0.0191**
0.6606	0.0124	**0.642**	**0.0191**
1.0977	0.0395	**1.102**	**0.0334**
1.0977	0.0395	**1.102**	**0.0334**

G12			
0.1626	-0.0588	0.1466	-0.3717
0.1626	-0.0588	0.1466	-0.3717
0.3911	0.161	0.3676	0.1189
0.3911	0.161	0.3676	0.1189
0.8112	0.6316	0.7301	0.0779
0.8112	0.6316	0.7301	0.0779
1.093	-0.04	1.1251	-0.0185
1.093	-0.04	1.1251	-0.0185
1.2984	-0.0368	1.4635	0.0008
1.2984	-0.0368	1.4635	0.0008

G6			
0.1159	1	**0.1072**	**1**
0.2678	0.0564	**0.2646**	**0.0748**
0.2678	0.0564	**0.2646**	**0.0748**
0.6478	0.0152	**0.6518**	**-0.0026**
0.6478	0.0152	**0.6518**	**-0.0026**
1.1176	0.0507	**1.1395**	**0.0495**
1.1176	0.0507	**1.1395**	**0.0495**
1.6009	0.0682	**1.4669**	**1**
1.6009	0.0682	**1.527**	**0.0462**
1.6891	0.2584	**1.527**	**0.0462**

G15			
0.0891	-0.4184	0.0973	-0.4306
0.0891	-0.4184	0.0973	-0.4306
0.4567	0.0318	0.4538	0.0203
0.4567	0.0318	0.4538	0.0203
0.7859	0.0801	0.8494	0.0384
0.7859	0.0801	0.8494	0.0384
0.8993	0.025	0.9144	0.1537
0.8993	0.025	0.9144	0.1537
1.2611	-0.0831	1.3902	0.0315
1.2611	-0.0831	1.3902	0.0315

Upcoming Conference

Power Systems Conference 2013

Advanced Metering, Protection, Control,
Communication, and Distributed Resources

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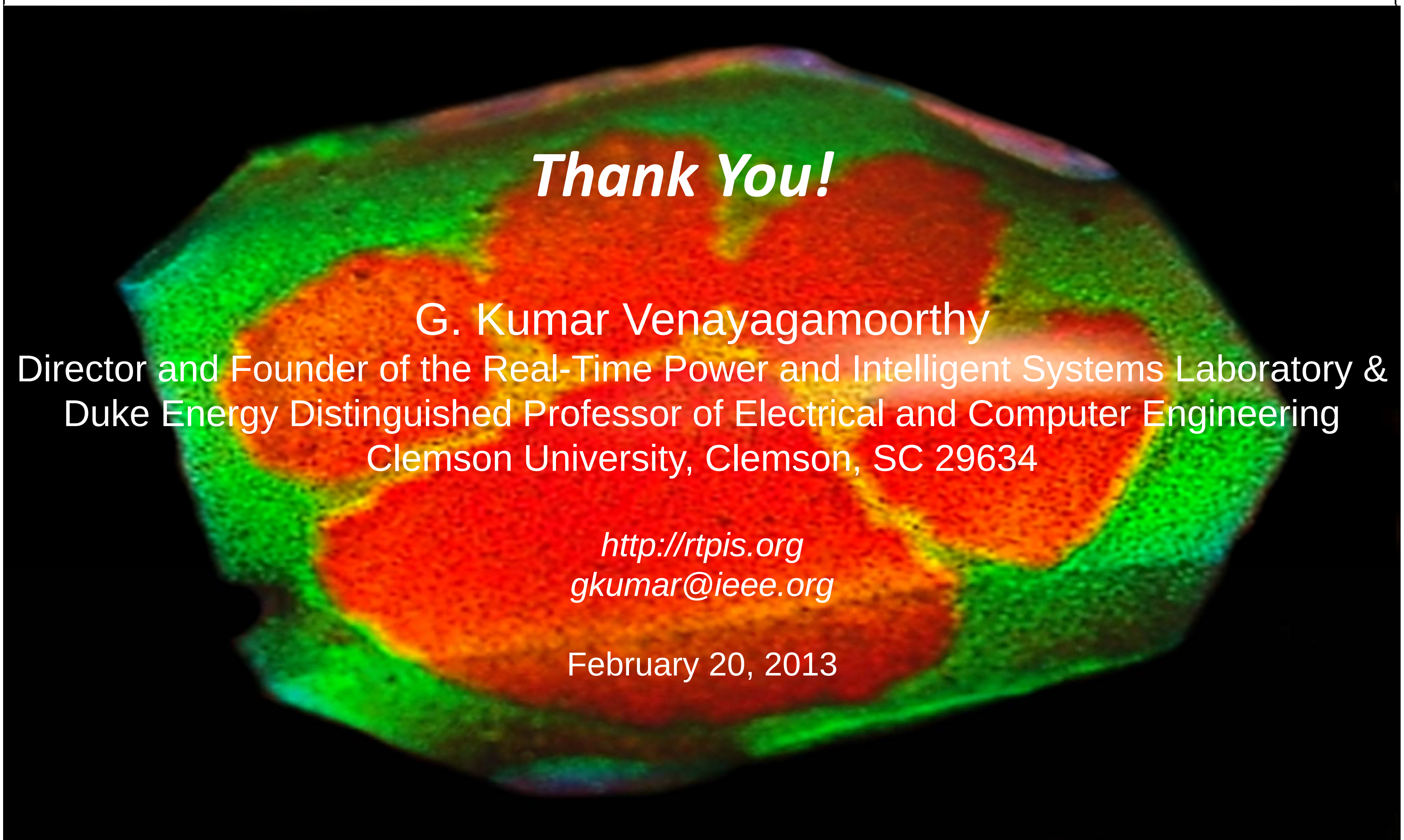
This is the twelfth annual conference dedicated to power system issues associated with Advanced Metering, Protection and Control, Communication and Distributed Resources. This year's conference will be expanding on Advanced Metering, Protection, Control and Communication. The program includes a number of tutorials by power industry's leading companies in Protection, Control, Communications, Automation and Metering. All tutorials are available to all registered attendees at no additional cost. Advanced registration is required to attend tutorials, panel discussions and technical paper sessions.

Preferred topics include, but not limited to, the following:



Thank You!

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