Real-Time Studies for Smart Grid Operations

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Outline

- Power System Stabilizer Tuning
- Coherency Analysis
- Modal Analysis
- Tie-Line Bias Control

Clemson University RTPIS Lab's Rapid Prototyping Platform

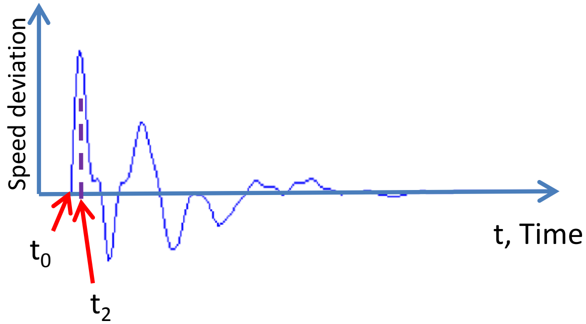
Situational Intelligence Laboratory

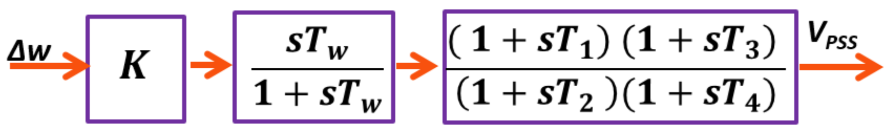
Real-Time Grid Simulation Laboratory

Power System Stabilizer (PSS)

PSS is one of the power system oscillation damping device. The function of PSS is to add an auxiliary signal to the generator's **AVR** in order to improve the damping of power system oscillations. PSSs are classified as,

- Linear Compensators
  e.g. - Lead-lag controller
- Non-Linear Compensators





K – gain
T_w – washout time constant
T_1, T_2, T_3 & T_4 – Phase compensation time constants

The objective function, J for simultaneous tuning of PSSs:

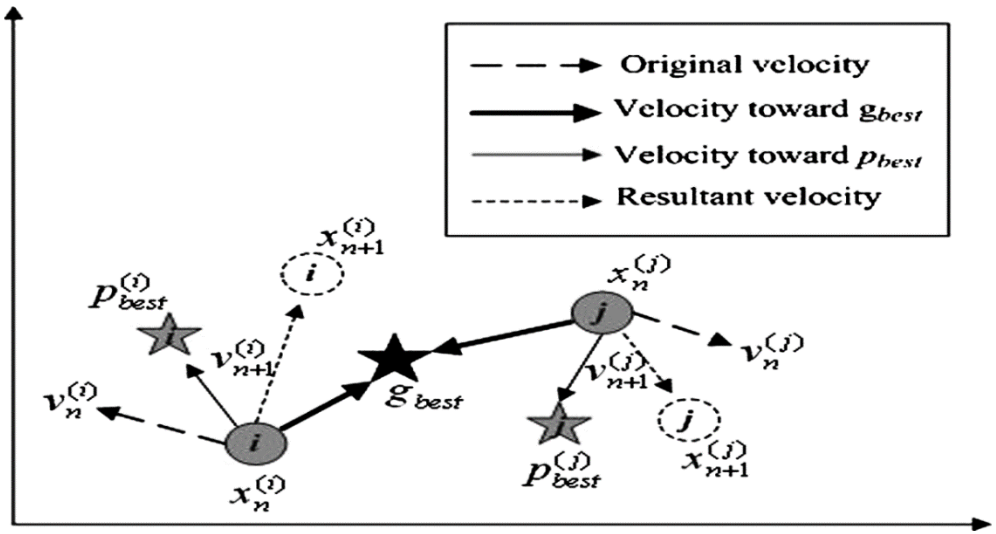
$$J = \sum_{j=1}^{N} \sum_{t=t_0}^{t_2} \frac{1}{2} . (|\Delta w(t)| + |\Delta w(t-1)|). \Delta t$$

t = time,
N = Number of generators,
t_0 & t_2= start & stop time for area calculation respectively

STATE-OF-THE-ART INDUSTRY POWER SYSTEM STABILIZERS NEED TO BE ADAPTIVE

PSO – Particle Swarm Optimization

Particle Swarm Optimization is a population based search algorithm. The particles change their positions within the search space based on their personal experience and knowledge of their neighbors.



$$v_{id}^{k+1} = v_{id}^{k} + c_1 R_1^k (pbest_{id}^k - x_{id}^k) + c_2 R_2^k (gbest_d^k - x_{id}^k)$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1}$$

where,
k – iteration number
v_i - velocity of particle i,
x_i - position of particle i,
c_1 & c_2 - constants regulating the reaching to the best location of particles,
R_1 & R_2 - random numbers in the interval [0,1].

•Y.D.Valle, G.K.Venayagamoorthy, S.Mohagheghi, J.Hernandez, R.G.Harley "Particle Swarm Optimization: Basic Concepts, Variants and Applications in Power Systems," IEEE Transactions on Evolutionary Computation, Vol. 12, No. 2, April 2008

MVO – Mean-Variance Optimization

Mean-Variance Optimization is a population based stochastic optimization technique. It is based on the strategic transformation of mutated genes of an offspring based on the mean-variance of an *n*-best population (n individuals).

Offspring creation steps:

- Selection
- Mutation
- Crossover

For every *m* selected dimension

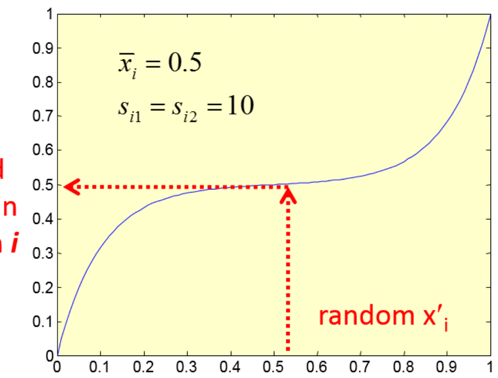
$$x_i' = rand(0,1)$$

Shape factor (controls exploration & exploitation)

$$s_i = -ln(v_i) \cdot f_s$$

f_s – scaling factor

Generated Offspring in dimension ***i***



Transformation/mapping function

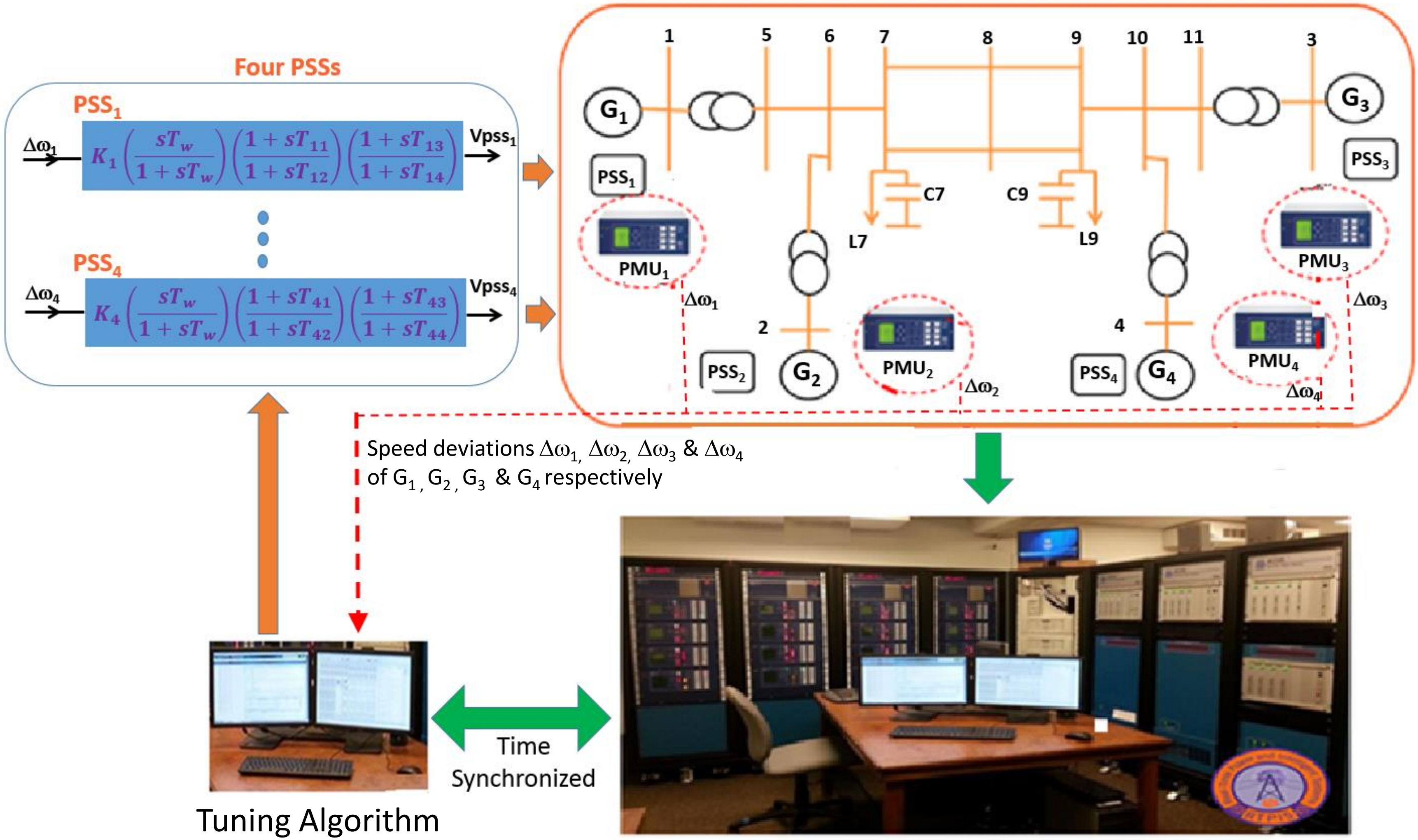
$$x_i = h_x + (1 - h_1 + h_0)x_i' - h_0$$

$$h(\bar{x}_i, s_{i1}, s_{i2}, u_i) = \bar{x}_i(1 - e^{-u_i s_{i1}}) + (1 - \bar{x}_i)e^{(1-u_i)s_{i2}}$$

$$h_x = h(u_i = x_i') \qquad h_0 = h(u_i = 0) \qquad h_1 = h(u_i = 1)$$

•I. Erlich, G. K. Venayagamoorthy and N. Worawat, "A mean-variance optimization algorithm," in *WCCI 2010 IEEE World Congress on Computational Intelligence*, July 2010.

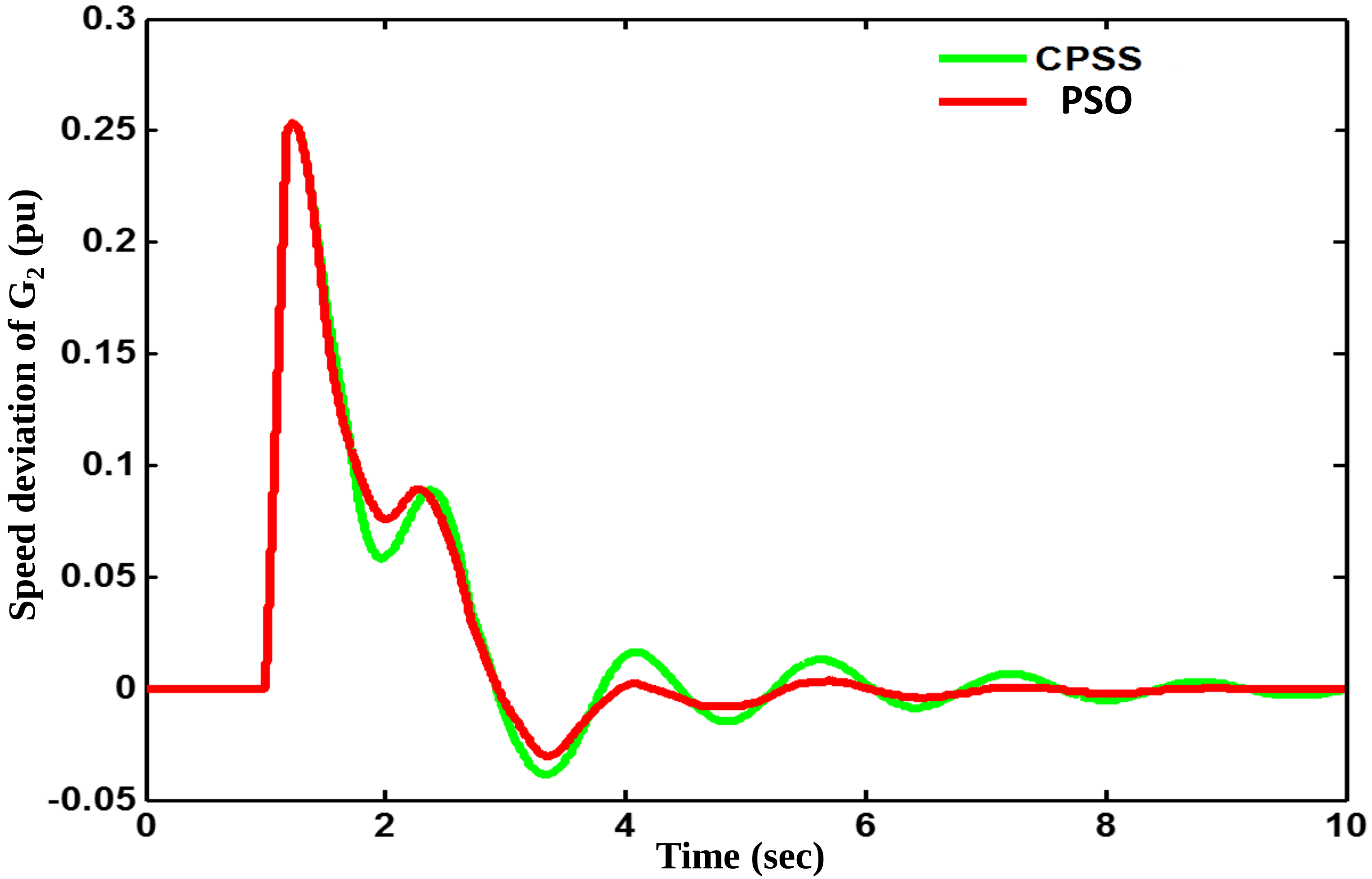
RTPIS Laboratory's PSS Tuning Experimental Setup



Tuning Algorithm (MATLAB Platform)

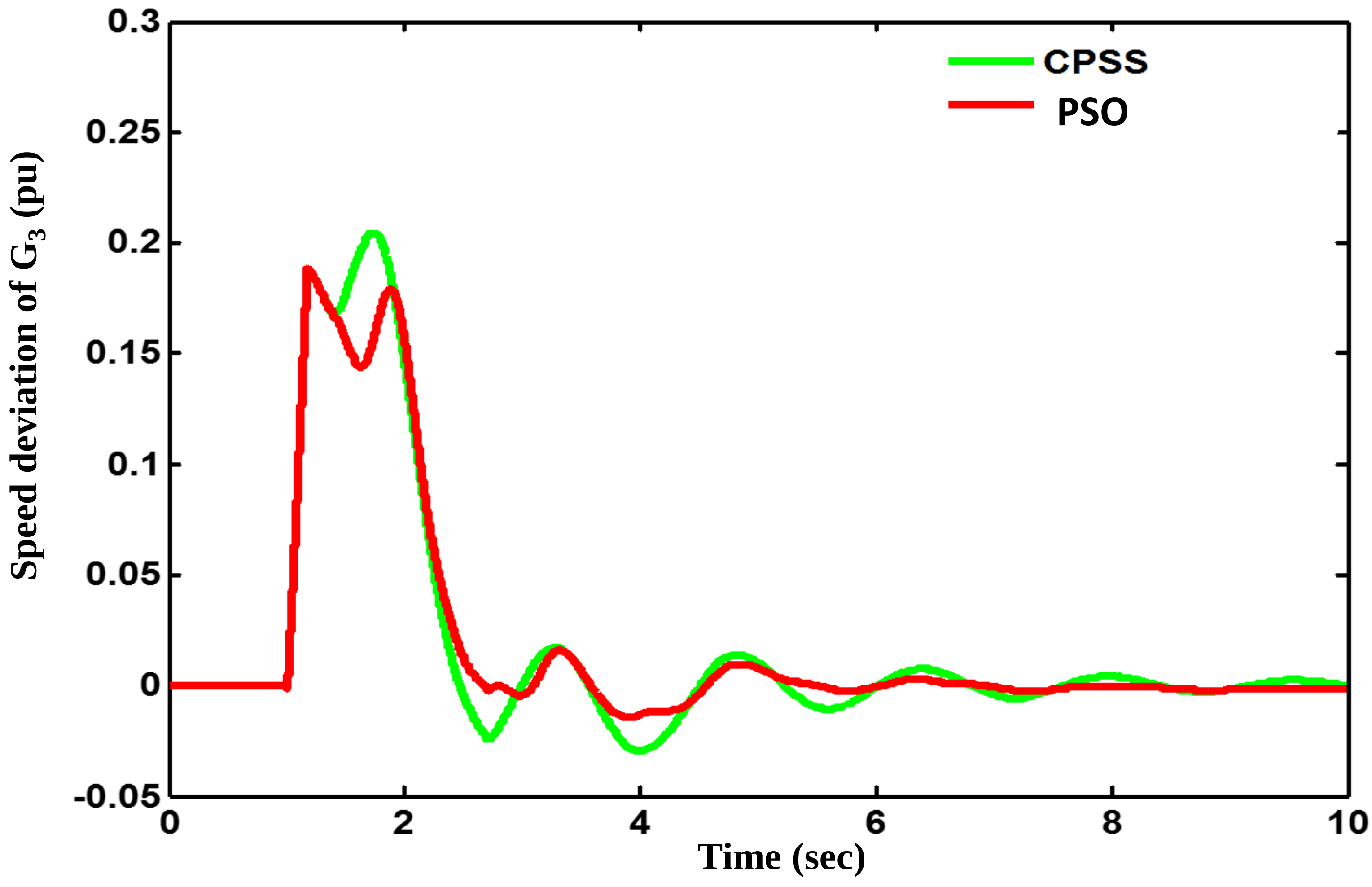
Real-Time Digital Simulation & PMUs

PSO Results – Generator 2



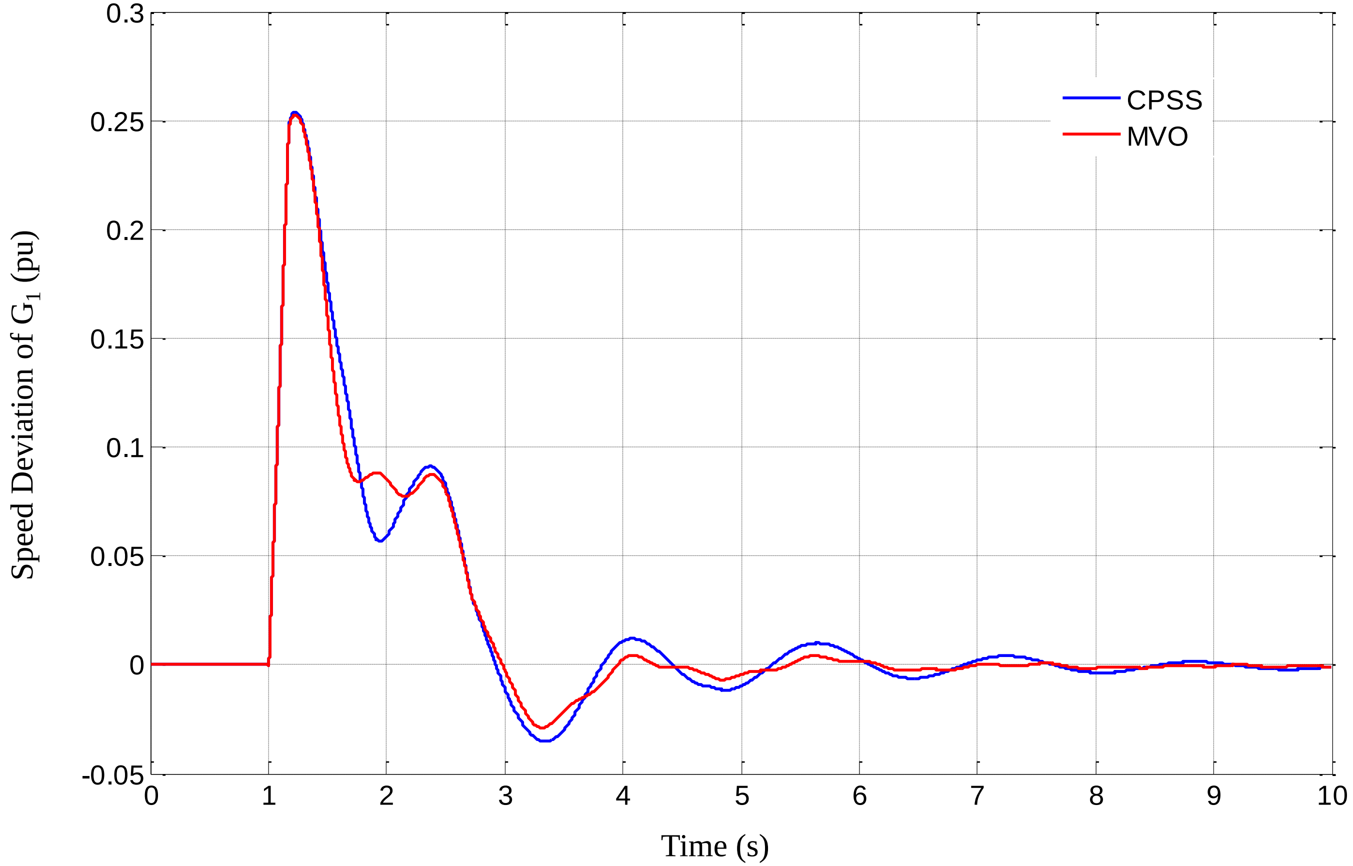
Speed deviation of G_2 for a three phase short circuit at Bus 8, duration 10 cycles

PSO Results – Generator 3



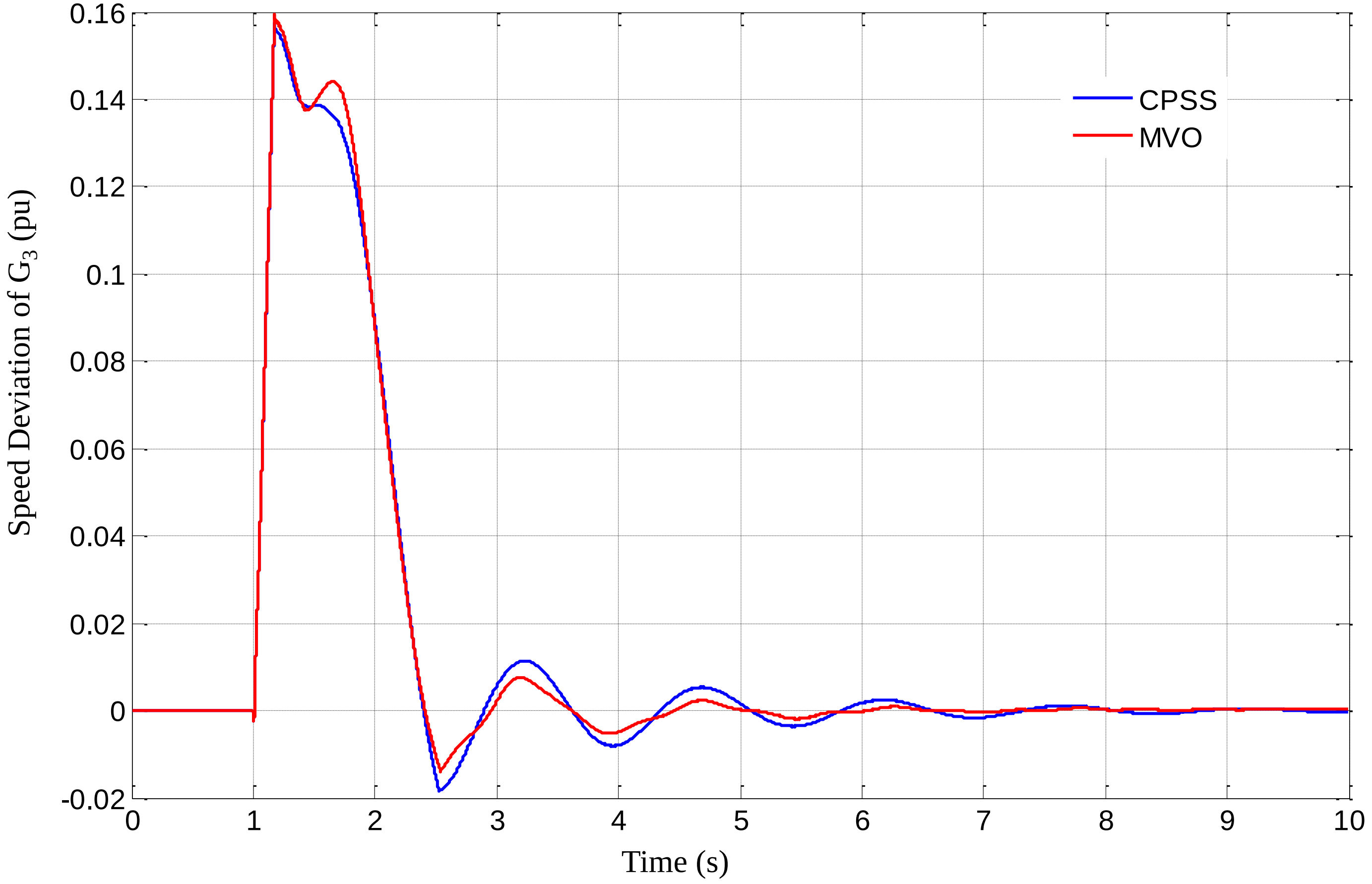
Speed deviation of G_3 for a three phase short circuit at Bus 8, duration 10 cycles

MVO Results – Generator 1



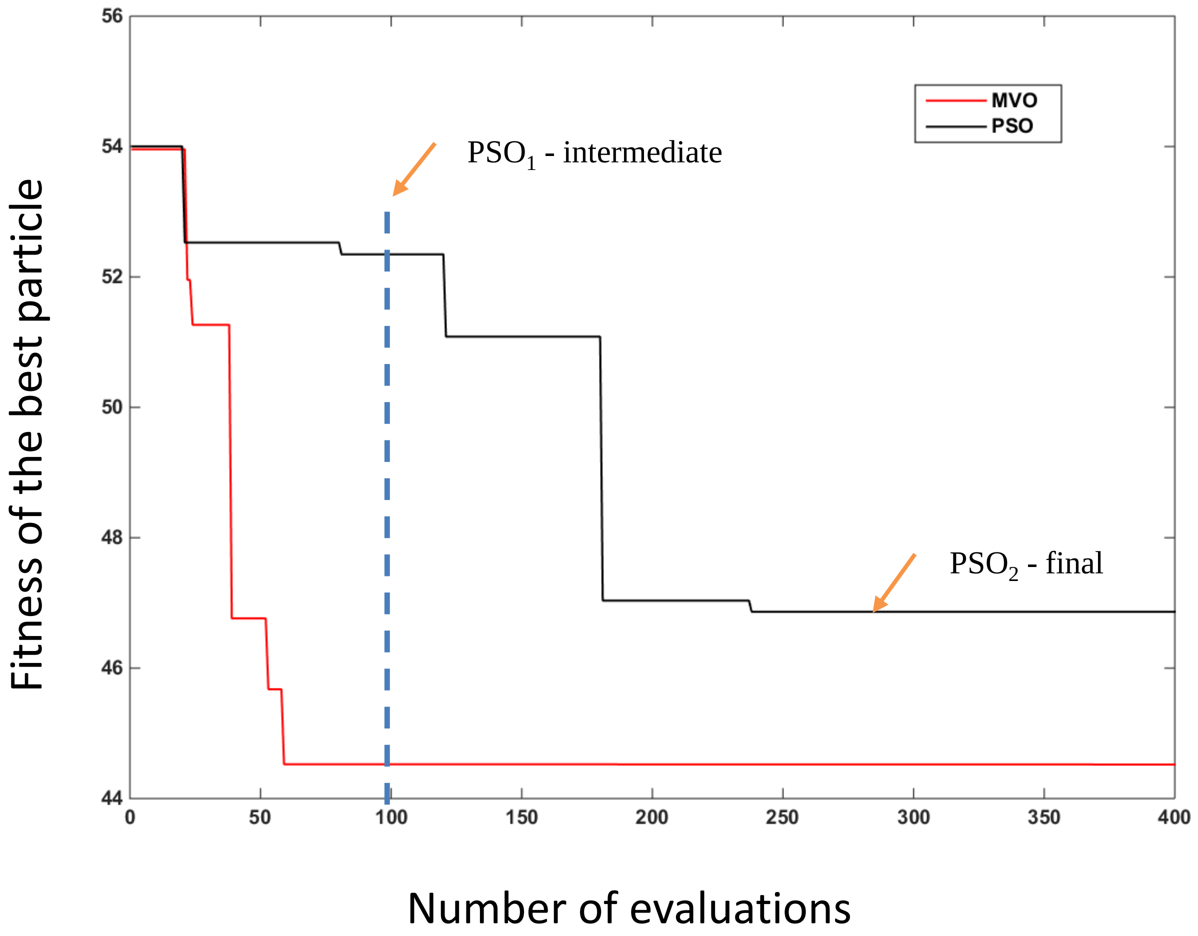
Speed deviation of G_1 for a three phase short circuit at Bus 8, duration 10 cycles – Operating Condition 1

MVO Results – Generator 3

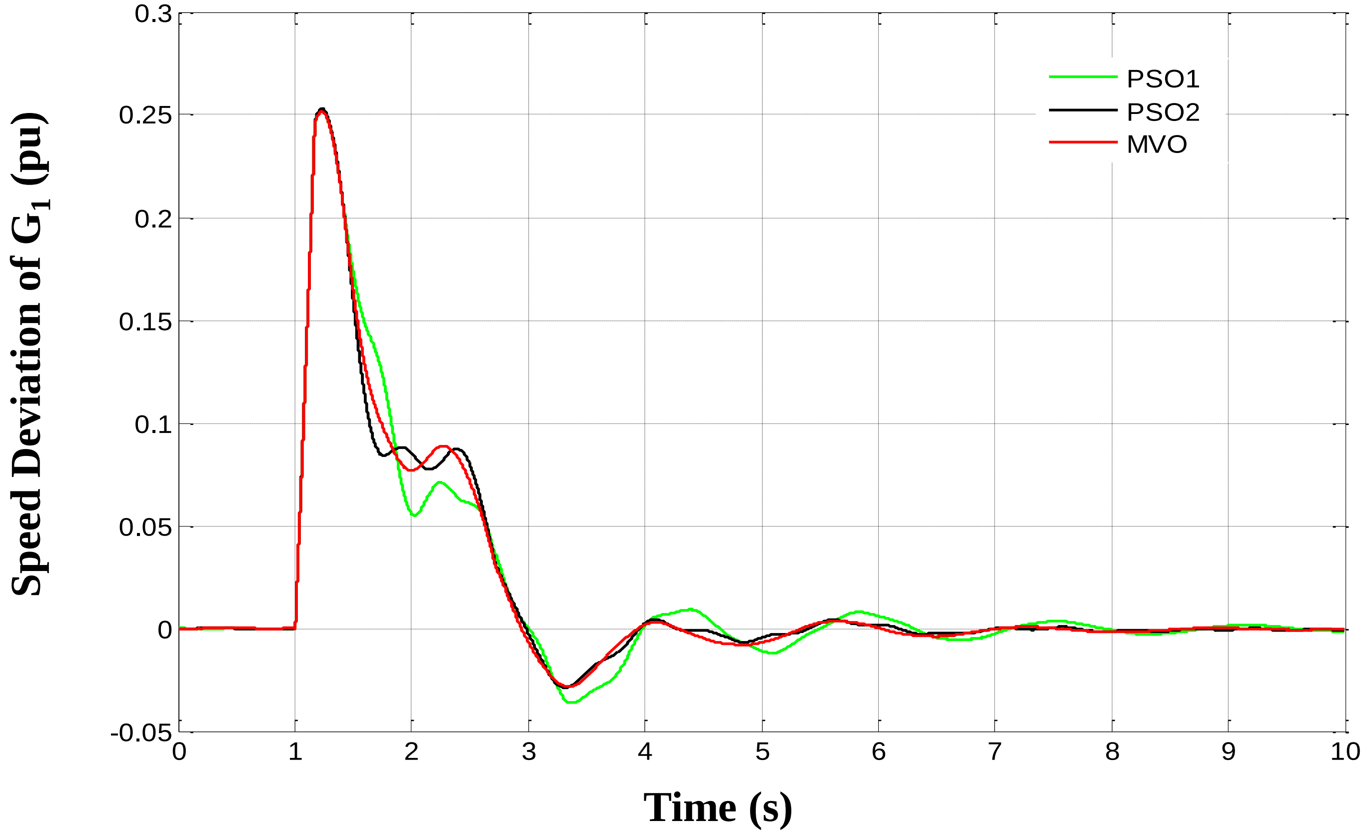


Speed deviation of G_3 for a three phase short circuit at Bus 8, duration 10 cycles – Operating Condition 3

Fitness Plot – PSO & MVO



PSO - MVO Comparison - Generator 1



Speed deviation of G_1 for a three phase short circuit at Bus 8, duration 10 cycles – Operating Condition 1

PSS parameters

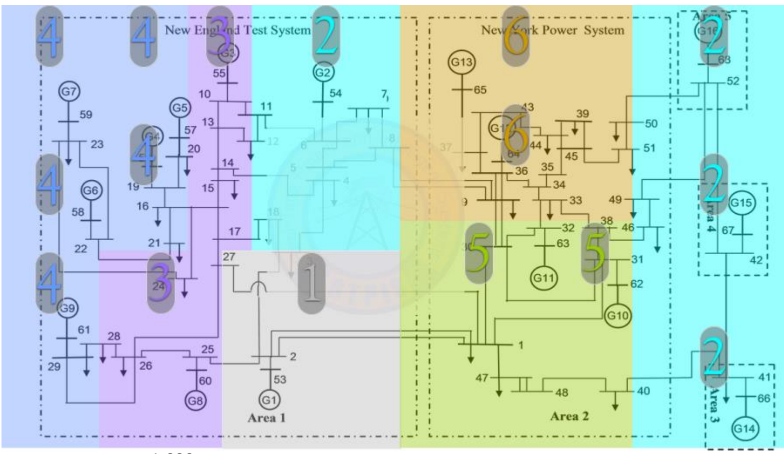
PSO Tuned Parameters

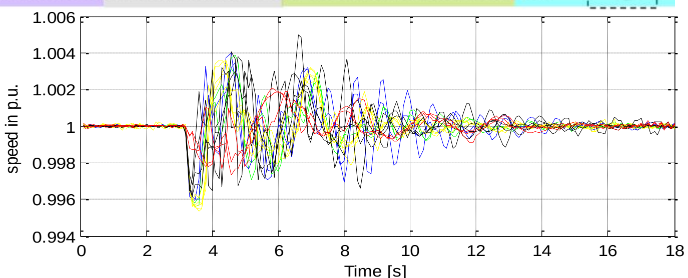
	K	T1	T2	T3	T4
Gen1	8.02	1.92	0.94	9.29	7.96
Gen2	7.75	0.30	0.27	9.11	5.03
Gen3	28.90	0.46	0.48	5.22	5.89
Gen4	26.17	0.35	0.34	2.40	3.67

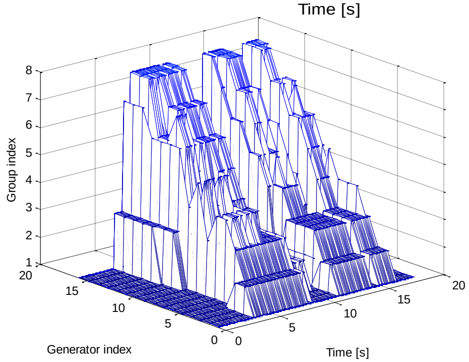
MVO Tuned Parameters

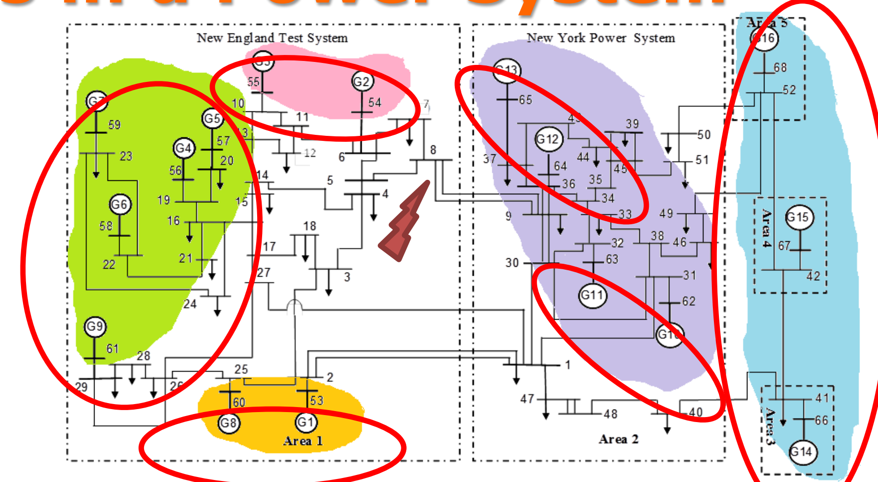
	K	T1	T2	T3	T4
Gen1	29.68	1.38	0.60	4.58	11.74
Gen2	22.23	1.41	0.73	1.54	3.44
Gen3	28.15	1.76	0.86	3.38	11.33
Gen4	17.36	1.07	0.92	9.73	14.76

Online Coherency Analysis of Synchronous Generators in a Power System







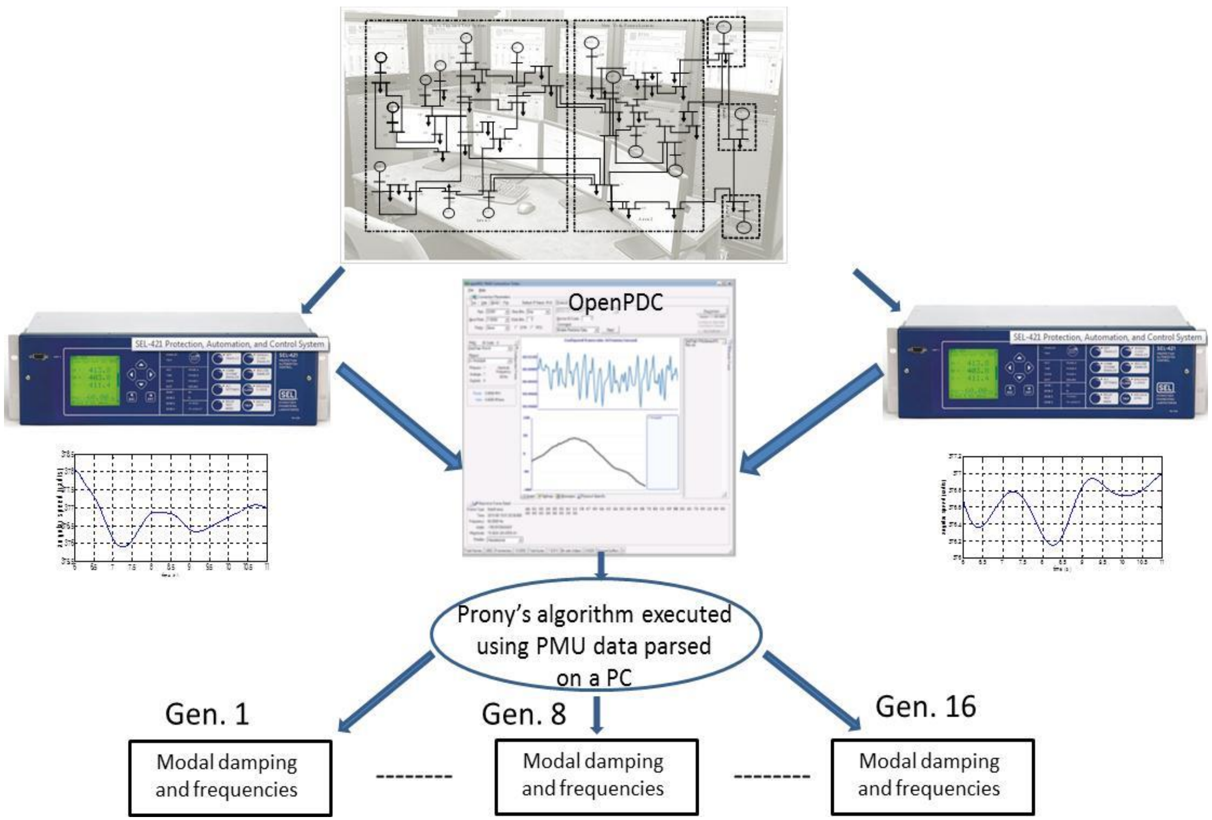


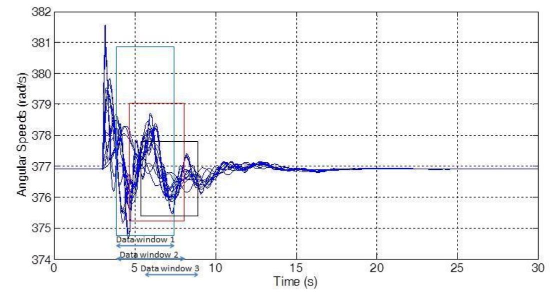
100ms three phase fault at bus 8

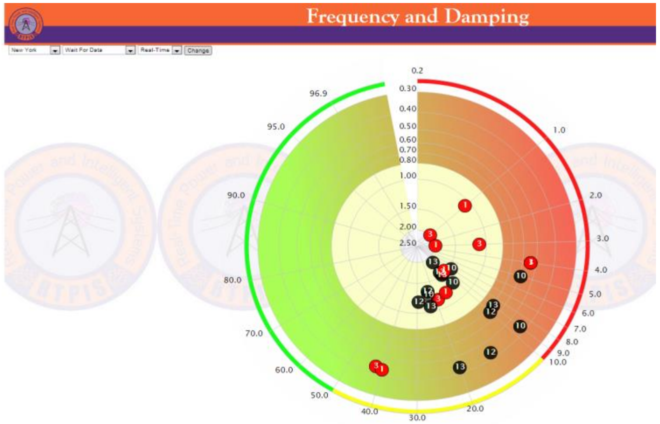
Group index	Offline Clustering during 0~18s	Online Clustering at 8s	Online Clustering at 10s	Online Clustering at 15s
1	G1, G8	G1,G8	G1,G2,G3, G8,G10,G11,G12,G13	G1,G8
2	G2,G3	G2,G3	G4,G5,G6, G7,G9	G2,G3
3	G4,G5,G6, G7,G9	G4,G5,G6, G7	G14,G15, G16	G4,G5,G6, G7,G9
4	G10,G11	G9		G10,G11, G12,G13
5	G12,G13	G10,G11		G14,G15, G16
6	G14,G15, G16	G12,G13		
7		G14,G15, G16		

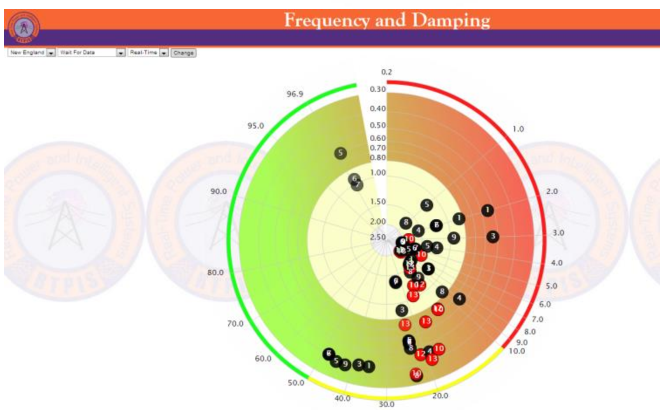
Ke Tang, Venayagamoorthy GK, “Online coherency analysis of synchronous generators in a power system”, *IEEE conference on Innovative Smart Grid Technologies (ISGT)*, February 2014, Washington DC, USA.

Online Modal Analysis of Synchronous Generators



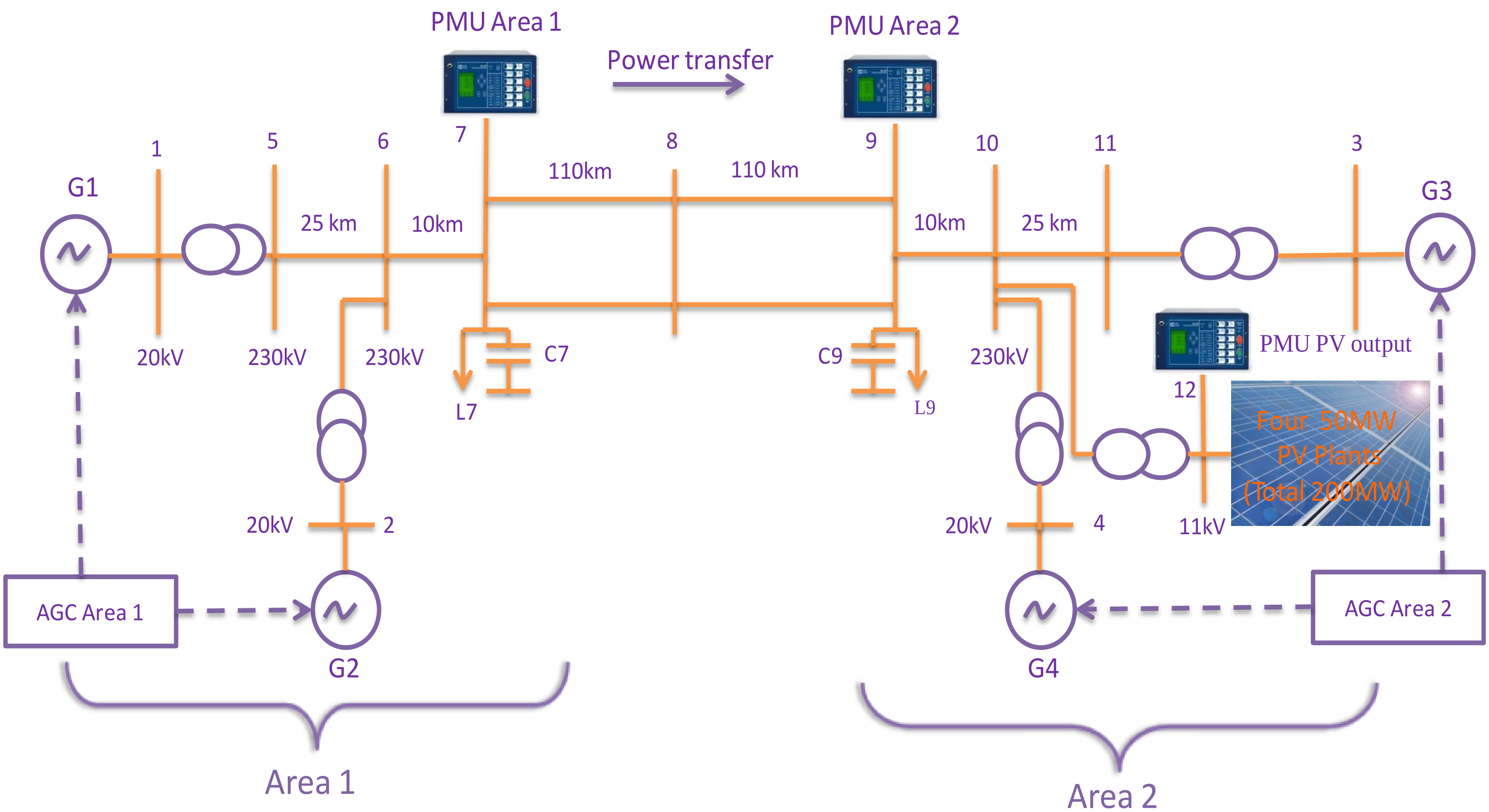






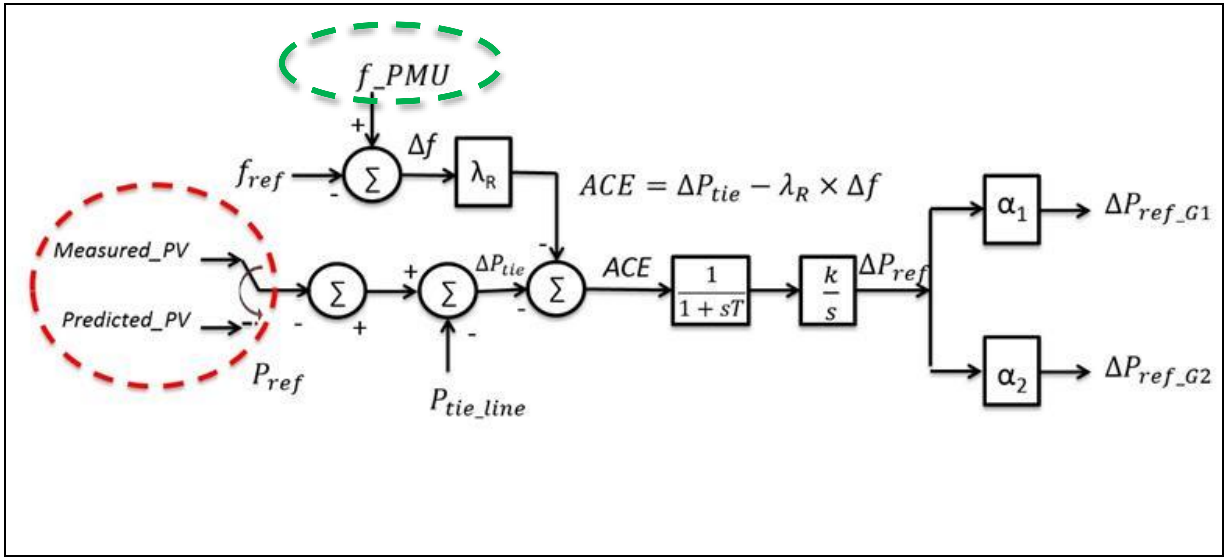
Saraf P, Venayagamoorthy GK, Luitel B, "Online oscillation monitoring of synchronous generators using parallel-prony analysis", *IEEE conference on Innovative Smart Grid Technologies (ISGT)*, February 2014, Washington DC, USA.

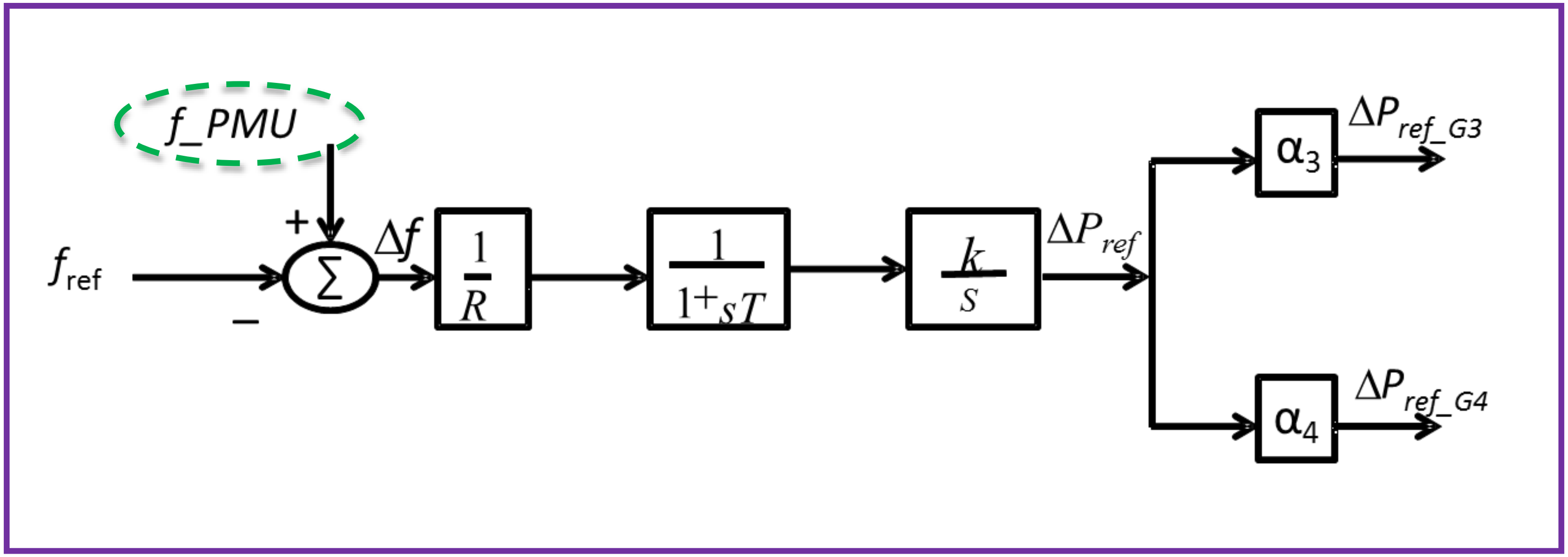
Power System with PV Plants



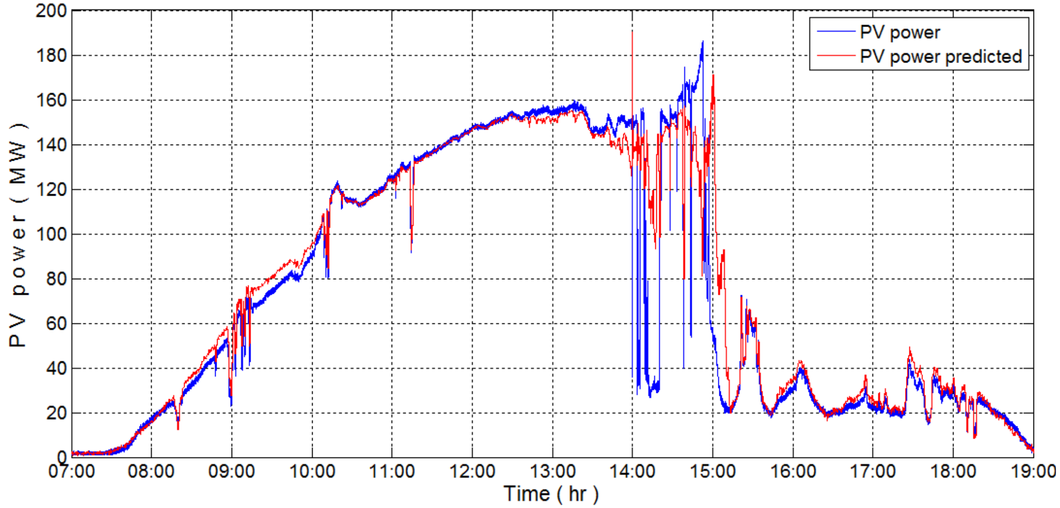
Jayawardene I, Venayagamoorthy GK, "Comparison of echo state network and extreme learning machine for PV power prediction", *IEEE symposium on Computational Intelligence Applications in Smart Grid*, Orlando, FL, USA, December 2014.

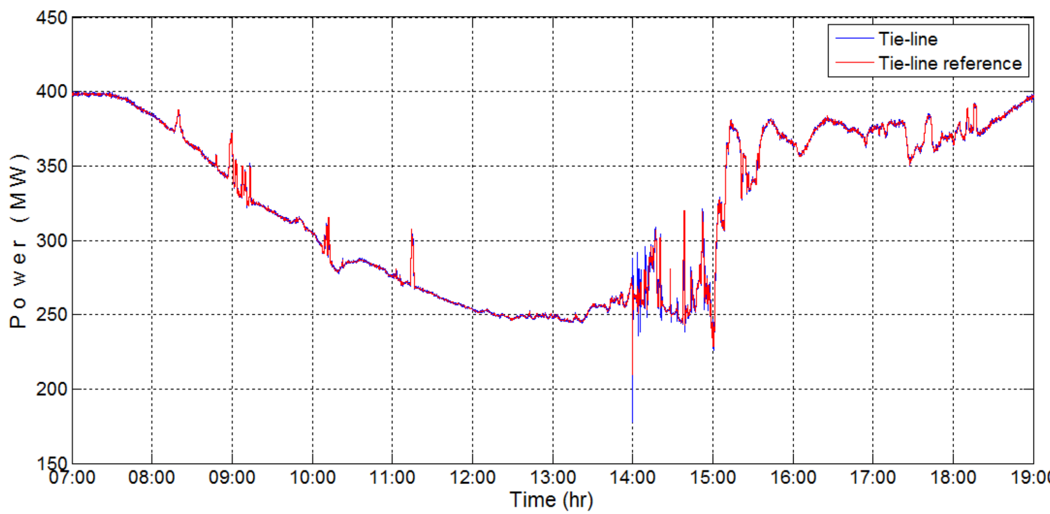
Areas 1 and 2 AGCs

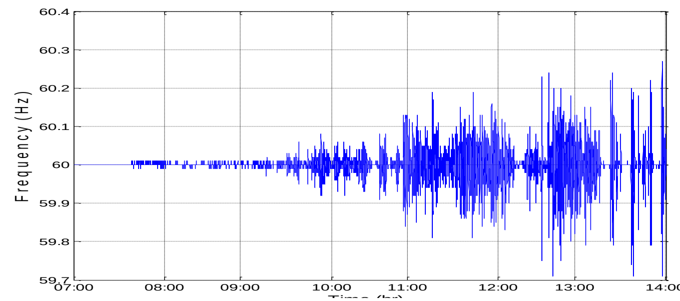


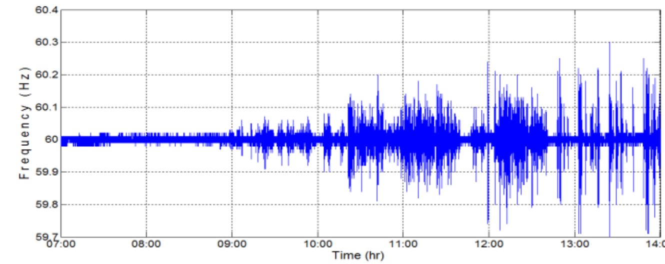


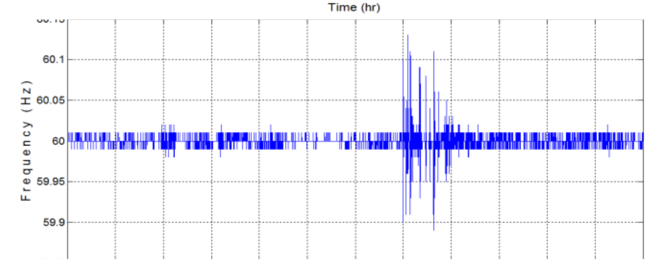
Tie-Line Power Flow Control

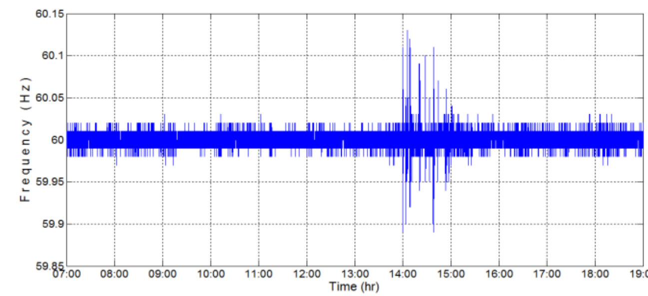












Summary

- Overview of the research, education and innovation-ecosystem activities in smart grid at the RTPIS Laboratory (http://rtpis.org) at Clemson University.

- Real-time simulation and implementations allow for rapid prototyping of new technologies developed in research labs.

Thank You!

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