

Real-Time Power and Intelligent Systems Laboratory

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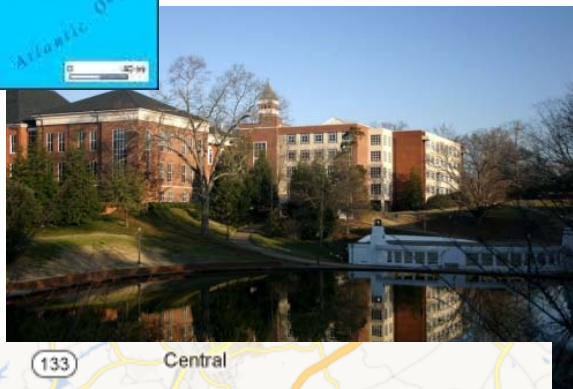
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<http://rtpis.org>

Acknowledgement: US NSF, US DOE and US AFOSR

Clemson University - An Overview



- ~20,000 students
 - 14,500 undergraduate
 - 5,500 graduate
- 5,000 faculty and staff
- 70 undergraduate degrees
- 100 graduate degree

CU-RTPIS Lab

- in the Sub-basement of Riggs Hall



Corridor

83 sf

Elevator

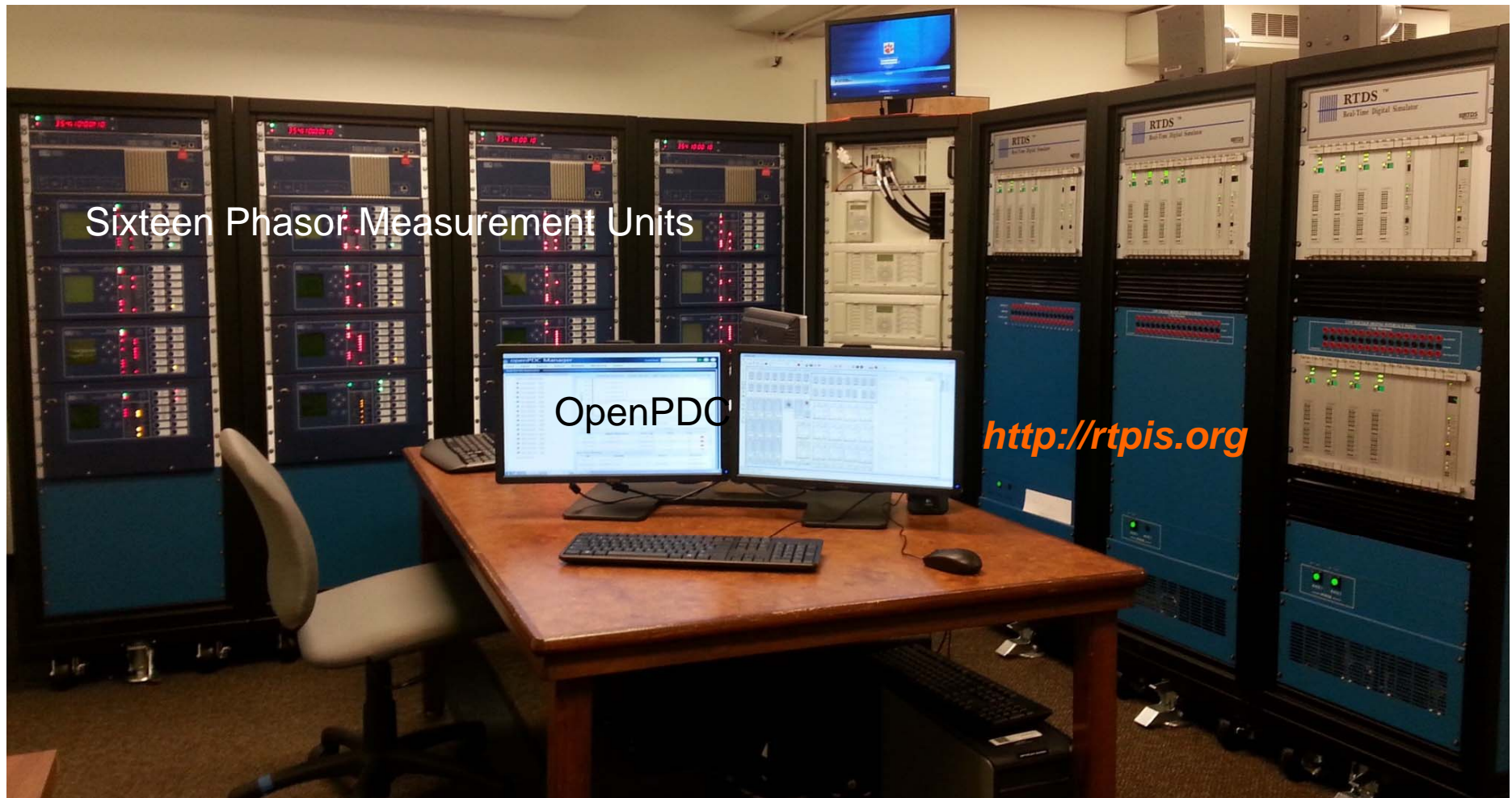
- Founded in 2004
- Emphasis:

***Research, Education and
Innovation-Ecosystem
Laboratory for
Smart Grid Technologies***

CU-RTPIIS Research Areas

- Adaptive Devices, and Intelligent Circuits and Systems
- Big Data Analytics and Visualizations
- Computational Methods and High Performance Computing Platforms
- Cyber-Physical Systems and Cyber-Security
- Hardware/Software-in-the-Loop Simulation
- Micro-grids and Nano-grids
- Plug-in Electric and Hybrid Vehicles
- Power Electronics
- Power System Computation, Control, Modeling, Operation and Stability
- Renewable Energy Systems
- Real-time/Faster than Real-time Large Scale Power System Simulation and Operational Intelligence
- Sensor Networks and Synchrophasor Technology
- Signal Processing
- Wide Area Systems

Real-Time Grid Simulation Lab





Real-Time Power and Intelligent Systems (RTPIS) Lab



Situational Intelligence Laboratory



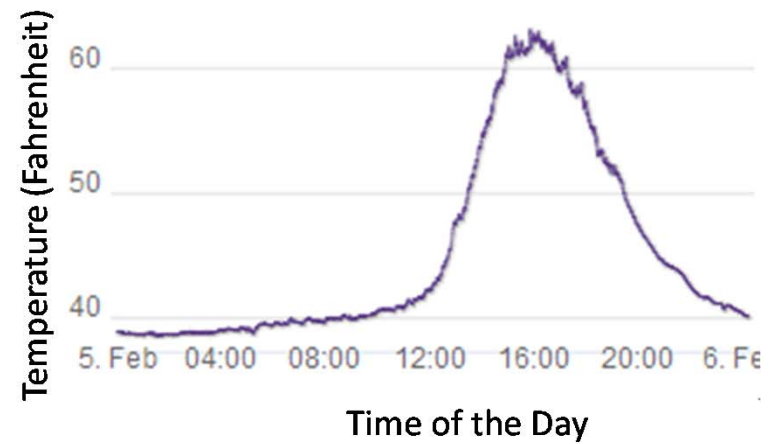
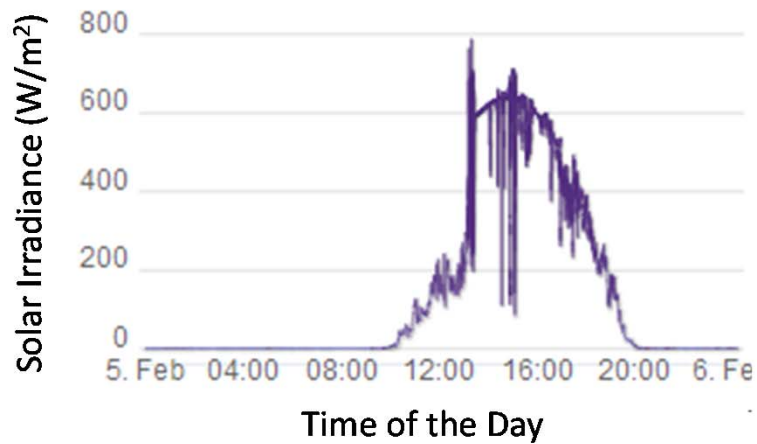
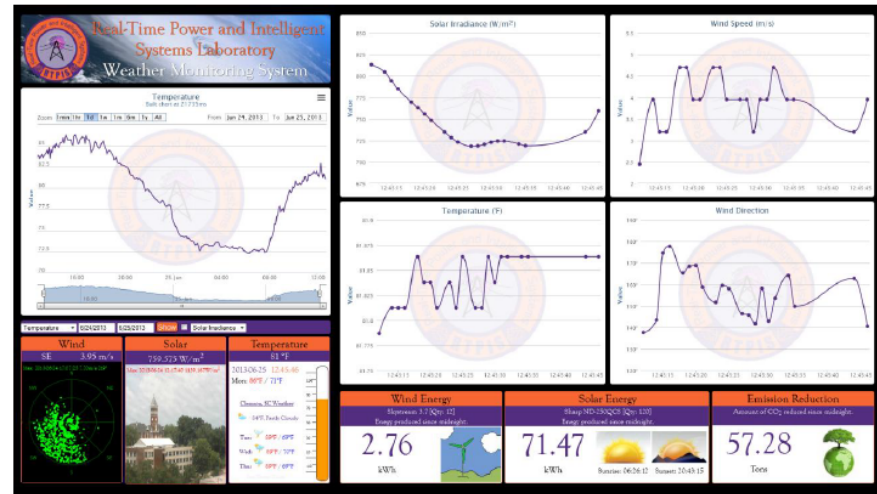
<http://rtpis.org>

RISE Cluster



<http://rtpis.org>

RT-WIL with the RTDS



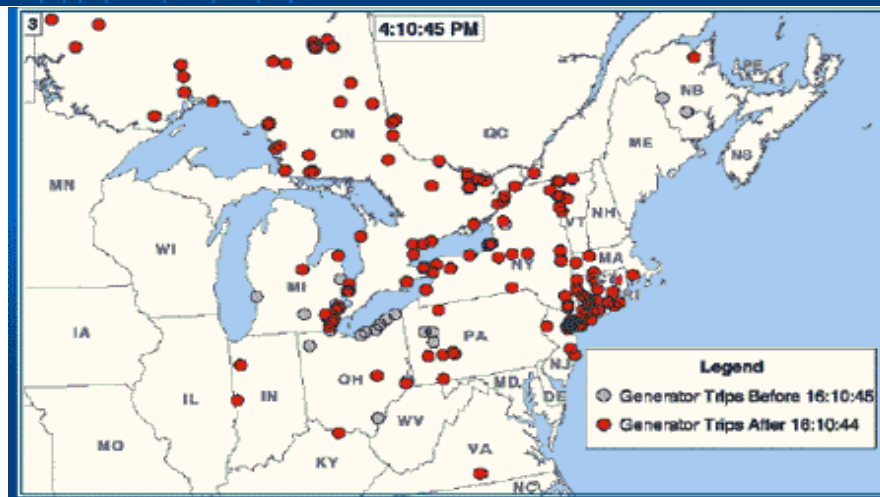
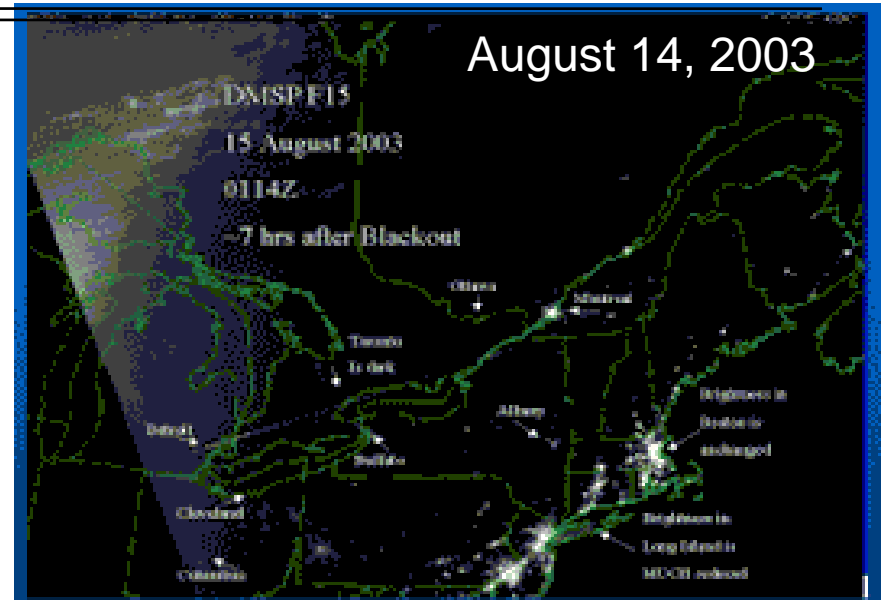
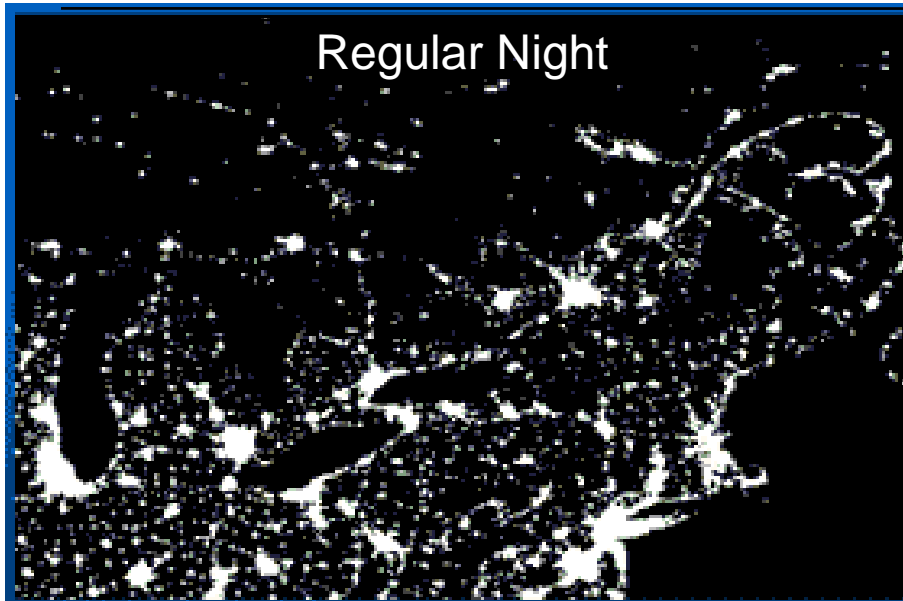
Smart Neighborhood



<http://rtpis.org>

Smart Neighborhood





- > 60 GW of load loss;
- > 50 million people affected;
- Import of ~2GW caused reactive power to be consumed;
- Eastlake 5 unit tripped;
- Stuart-Atlanta 345 kV line tripped;
- MISO was in the dark;
- A possible load loss (up to 2.5 GW)
- **Inadequate situational awareness.**

- Situational awareness (SA) is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future [Endsley].
- SA is an intermediate process in assessing the status of the system in order to make ‘intelligent’ decisions for future development.

- Latency – very important in building a data analytic architecture.
- Data Analytics Challenge
 - Operations
 - Energy trading
 - RT demand response
 - Asset management
- Complex Data processing and analytics environment:
 - Hierarchical to distributed
 - Multiple data classes
 - Latencies.

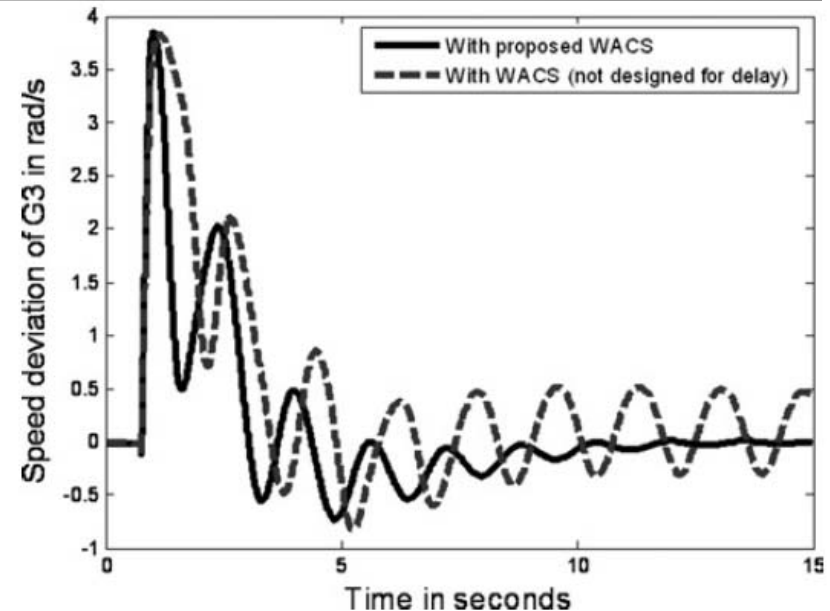


Fig. 6 Speed deviation of generator G3 with the proposed controller and WACS not designed for the delays for a three-phase short circuit at bus 10 (Fig. 1) for ten cycles (166.67 ms) duration

Ray S, Venayagamoorthy GK, "Real-Time Implementation of a Measurement based Adaptive Wide Area Control System Considering Communication Delays", IET Proceedings on Generation, Transmission and Distribution, Vol. 2, Issue 1, Jan. 2008, pp. 62 - 70.

IT-OT Convergence or Bankruptcy?

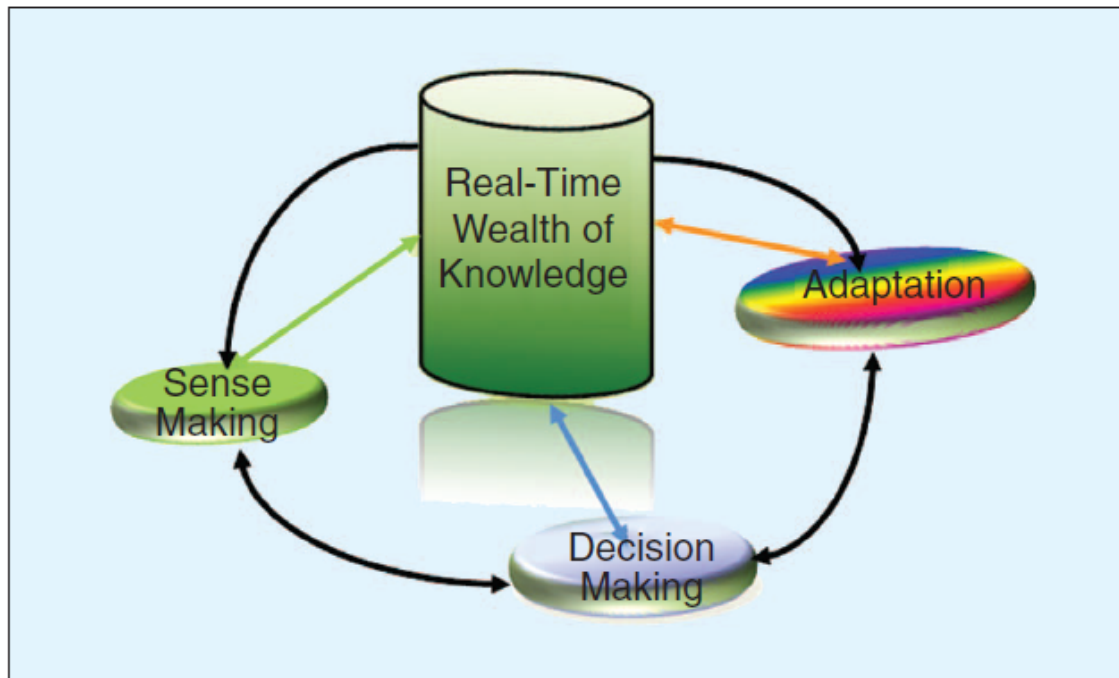


- It is the smart grid infrastructure and the associated use of the data in decision-making that will ultimately decrease operational costs related to improved forecasting of demand, better ability for customers to manage their loads, enhanced service delivery and reliability, and an infrastructure that will allow new cost-recovery mechanisms.
- This requires new models of data management including the movement away from siloed storage and access amid new cyber security concerns.
 - **Big Data Operational Analytics (BDOA)**
- It also calls for a renewed focus on analytics to breakdown big data into **descriptive**, **predictive** and **prescriptive** subsets.

“The purpose of a business is to create a customer” – Peter Drucker

Models are the heart and lungs of advanced analytics.

It is a science and art to develop a model.

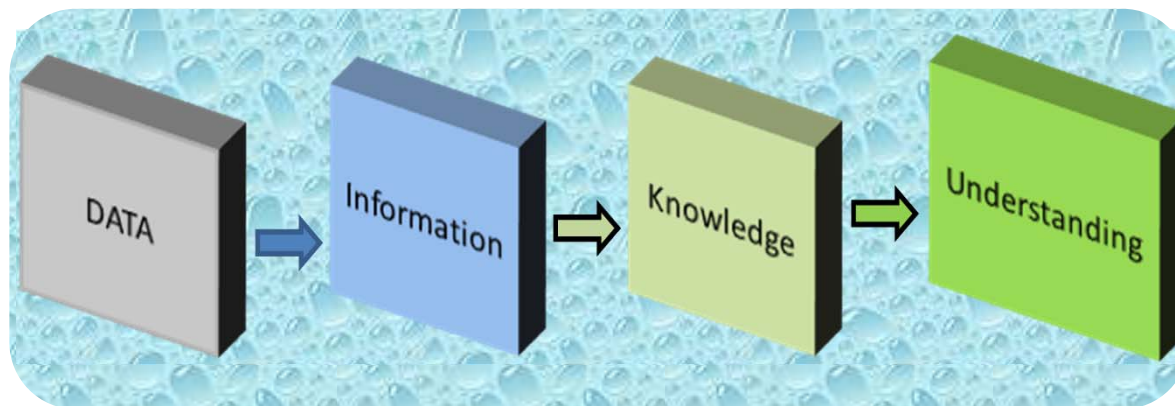


"Dynamic, Stochastic, Computational, and Scalable Technologies for Smart Grids,"
Computational Intelligence Magazine, IEEE , vol.6, no.3, pp.22-35, Aug. 2011.

FIGURE 1 CSTM – the integrated cycle of sense-making, decision-making and adaptation. The knowledge base is the domain of expertise evolved continuously with experience accumulated.

Mind the Gap

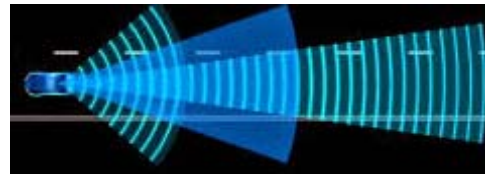
- The significant expertise deficit related to big data management, analytics, and data science is one of the major reasons utilities have not been able to effectively use smart grid data.
- Data scientists not only need to know how to data wrangle, they must also know how to operate a variety of tools on a variety of platforms fed with vast amounts of varied data.
- Energy-savvy data scientists are capable of changing the way the utility views the world and gets business done.



“Knowledge has to be improved, challenged, and increased constantly, or it vanishes.”

Peter Drucker

- Situational intelligence (SI) is looking ahead how the situations will unfold over time – *immersion into future*
- In other words, SA systems present situations based on some measurements of current states at time t . Whereas, SI uses SA at time t and predictions of future states to predict SA at a time $t+\Delta t$.
- Control centers need to handle big data, variable generation and a lot of uncertainties, and will need SI, that is to **derive SA** (information, knowledge and understanding) **at time t and project it into time $t+\Delta t$** .
- With SI technology implementations, real-time monitoring is possible.



Past to Future





US NSF Research Alliance/Partnership for Innovation Project: Situational Intelligence for Smart Grid Optimization and Intelligent Control – IIP #1312260

Objectives:

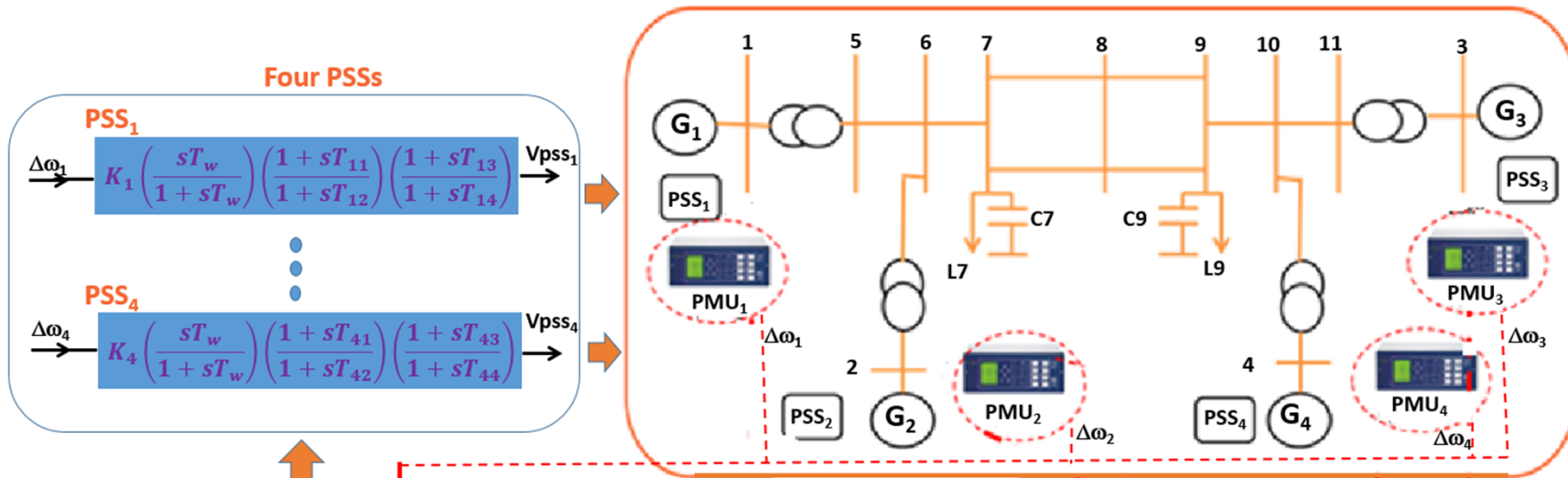
- Situation intelligence for real-time operations.
- Maximize penetration levels of variable and uncertain generation such as solar & wind power.
- Dynamic optimal energy & power management systems.
- Development of a rapid prototyping laboratory for real-time smart grid control centers.

Impacts:

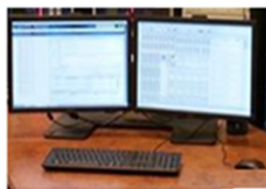
- Energy resilience by improved reliability, sustainability and economic value.
- Rapid restoration from outages.
- Softening of negatives effects of the climate change on the economy.

Partners & Supporters:

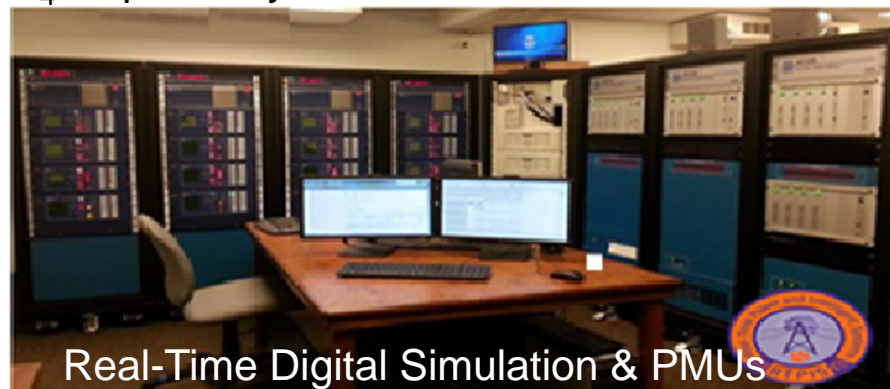




Tuning Algorithm
(MATLAB
Platform)



Time
Synchronized



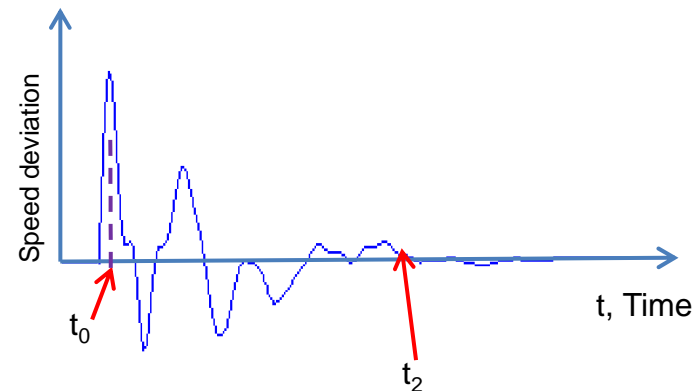
Real-Time Digital Simulation & PMUs

Speed deviations $\Delta\omega_1, \Delta\omega_2, \Delta\omega_3$ & $\Delta\omega_4$
of G_1, G_2, G_3 & G_4 respectively

“Multiple Power System Stabilizers Tuning Using Mean-Variance Optimization”, in *Proc. 2015 IEEE Intelligent Systems Application to Power Systems (ISAP)*, Porto, Portugal, September 11-16, 2015.

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,

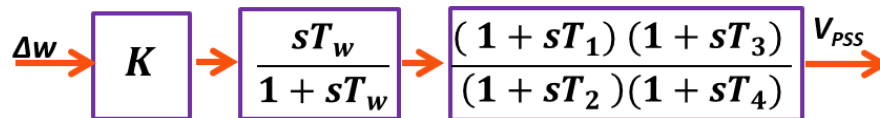
- Linear Compensators
e.g. - Lead-lag controller
- Non-Linear Compensators



The objective function, J for simultaneous tuning of PSSs:

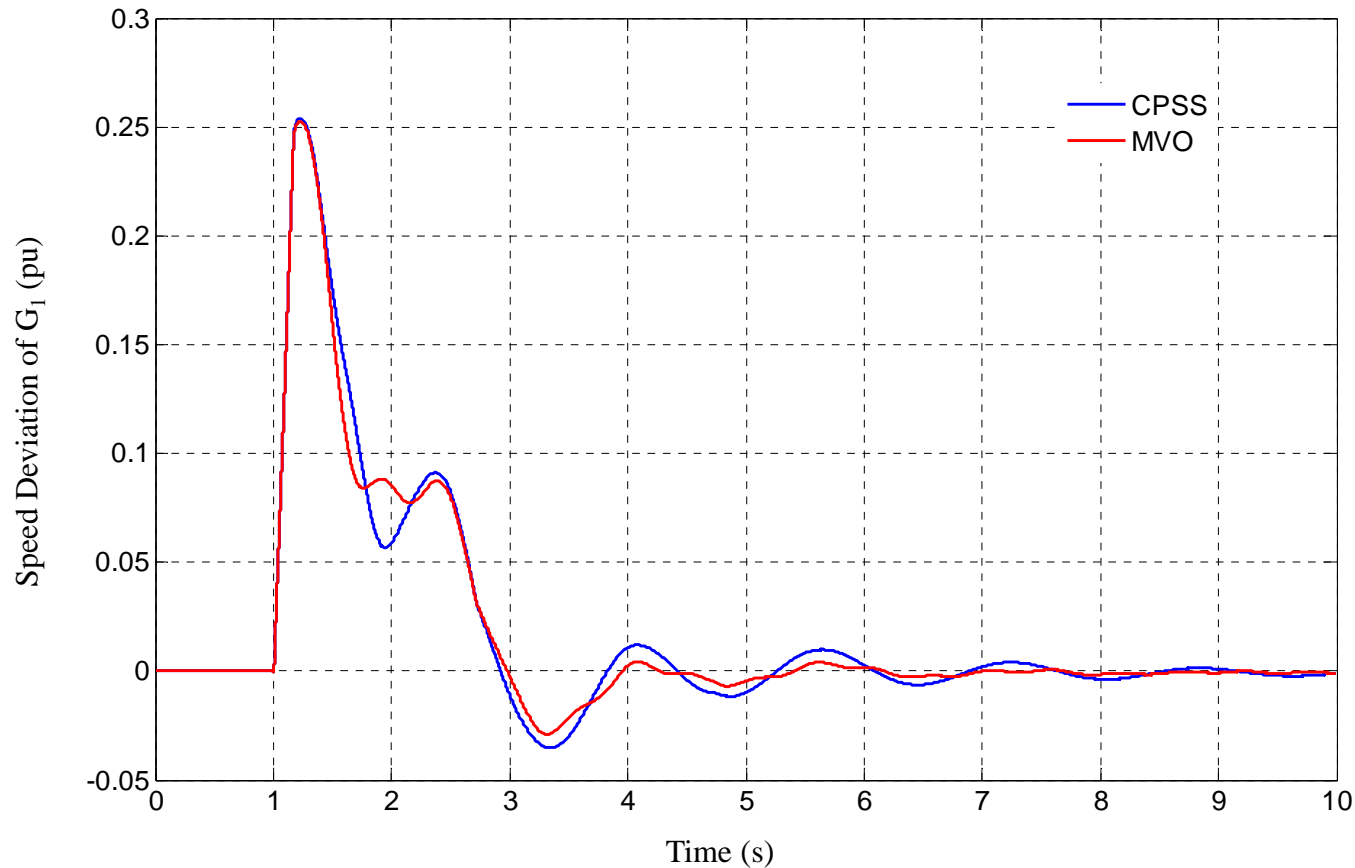
$$J = \sum_{i=1}^n \sum_{j=1}^N \sum_{t=t_0}^{t_2} (\Delta w(t)) \times (A \times (t - t_0) \times \Delta t)$$

- t = time,
- A = constant,
- N = Number of generators,
- n = Number of operating conditions
- t₀ & t₂ = start & stop time for area calculation respectively



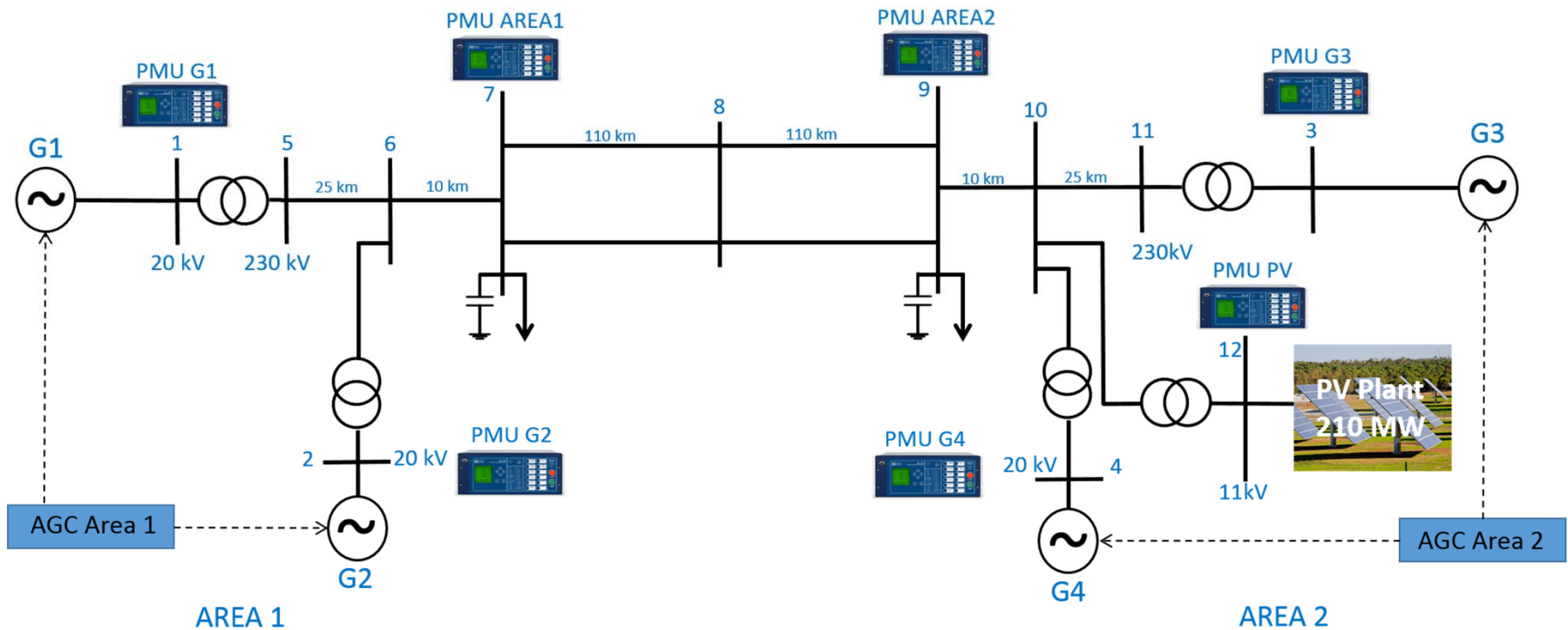
- K - gain
- T_w - washout time constant
- T₁, T₂, T₃ & T₄ - Phase compensation time constants

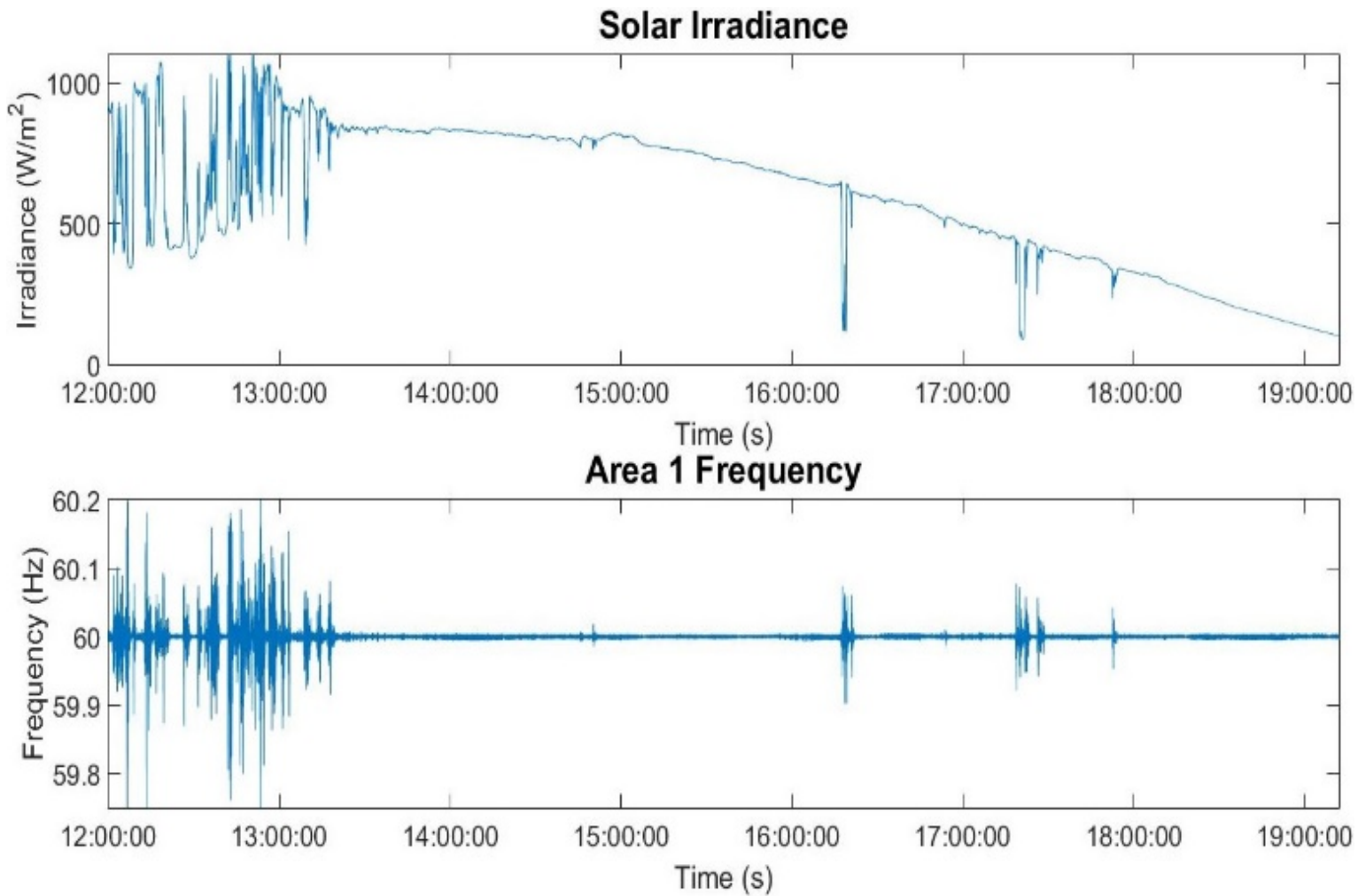
STATE-OF-THE-ART INDUSTRY POWER SYSTEM STABILIZERS NEED TO BE ADAPTIVE

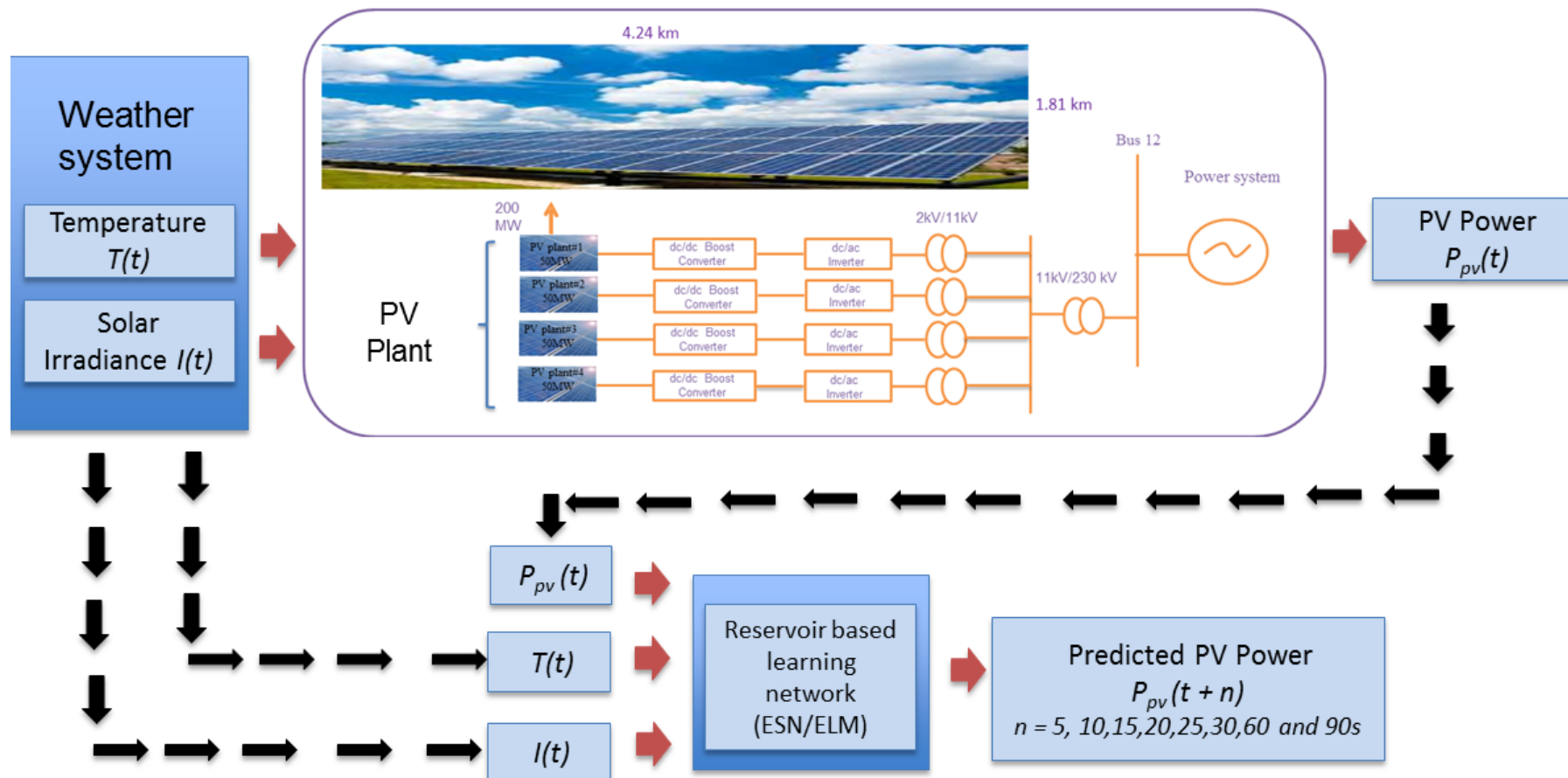


Speed deviation of G_1 with 10 cycles fault duration
– Operating Condition 1 (Area 1 load at bus-7 967MW and
Area 2 load at bus-9 1767MW)

Two-Area Four-Machine Test System with 210MW PV Plant



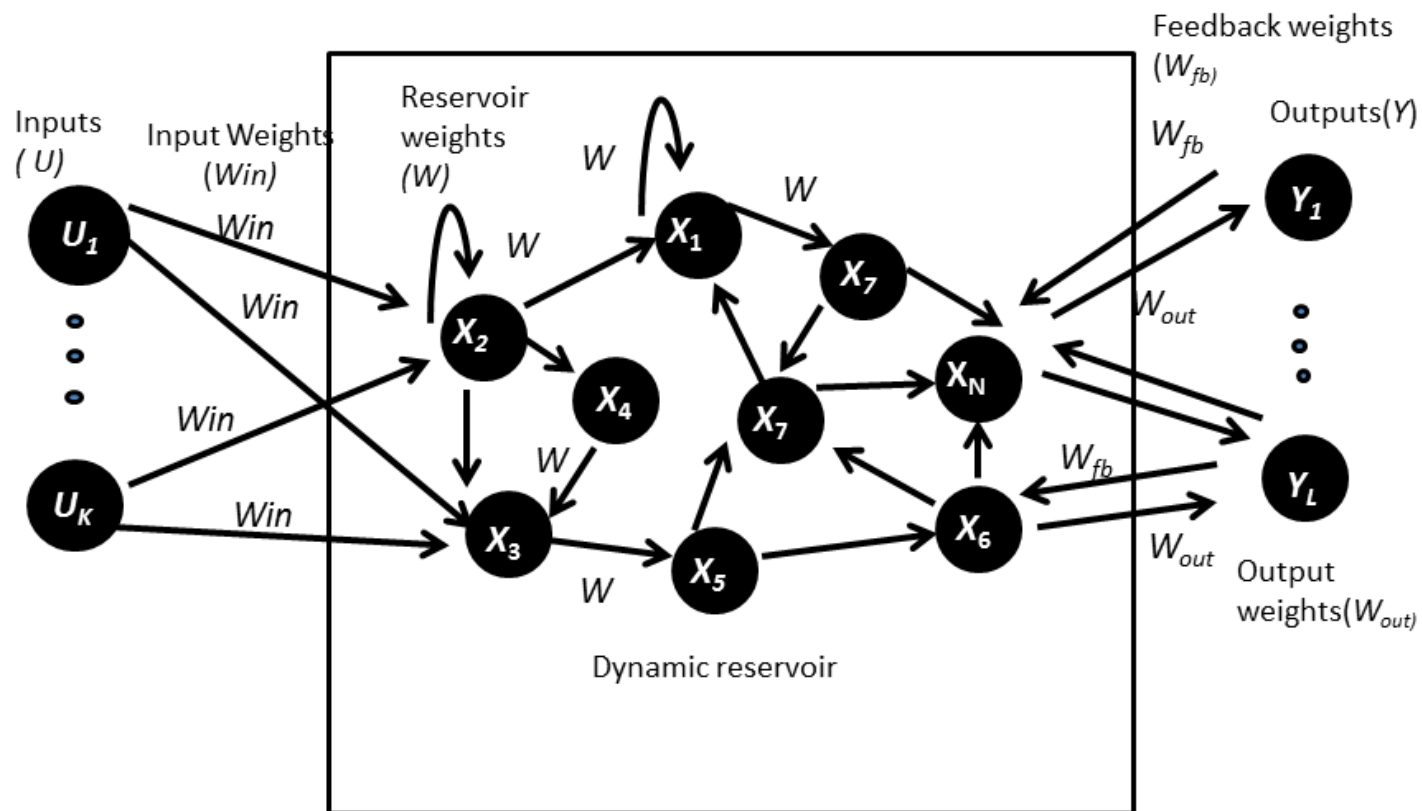




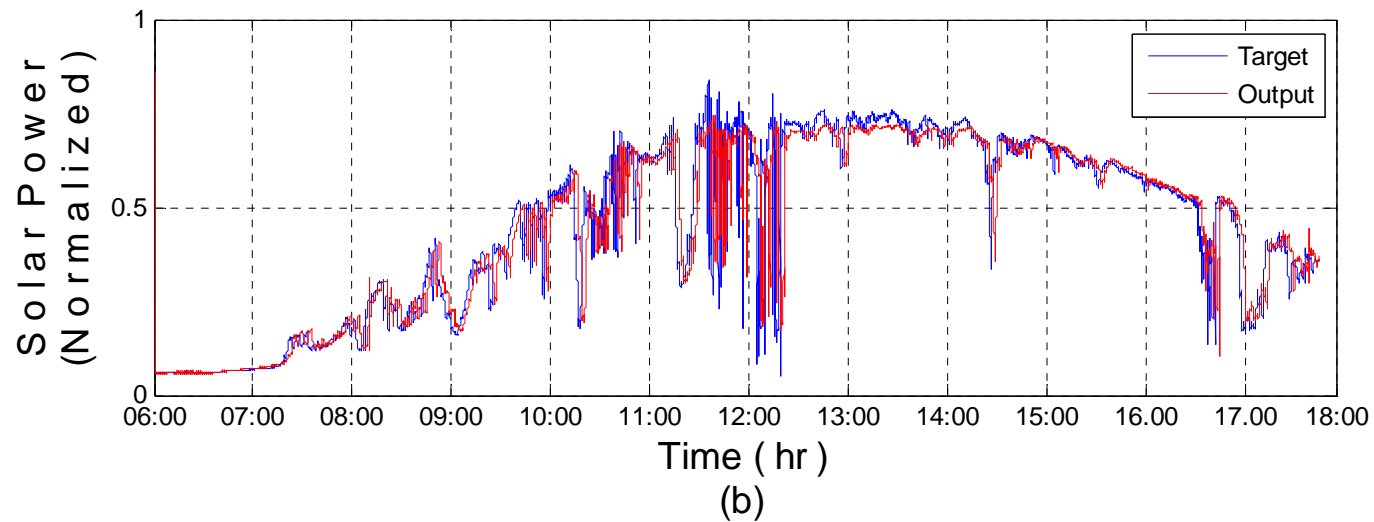
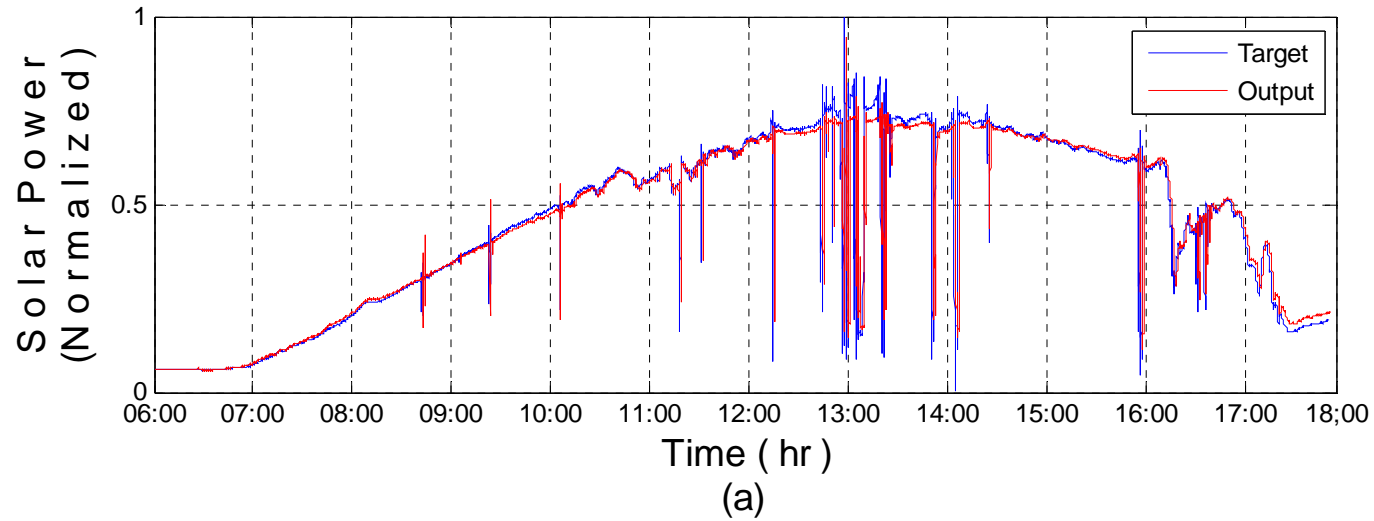
“Reservoir Based Learning Network for Control of Multi-Area Power System with Variable Renewable Generation”, *Neurocomputing*, vol. 170, December 2015, pp. 428-438

Prediction of PV power - Reservoir Network

Echo State Network (ESN)

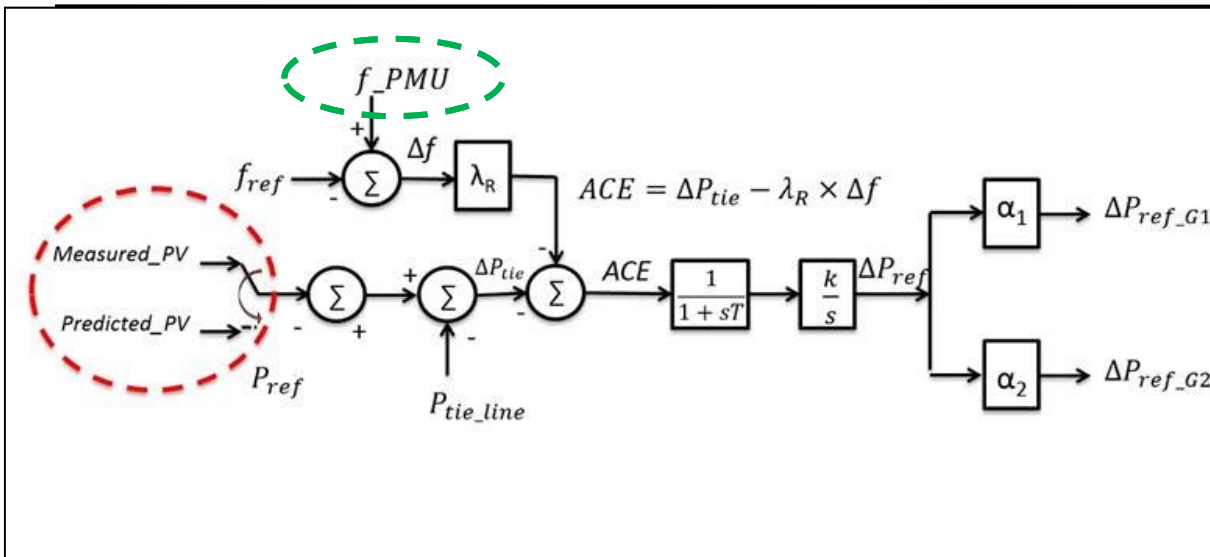


Prediction of PV power - ESN

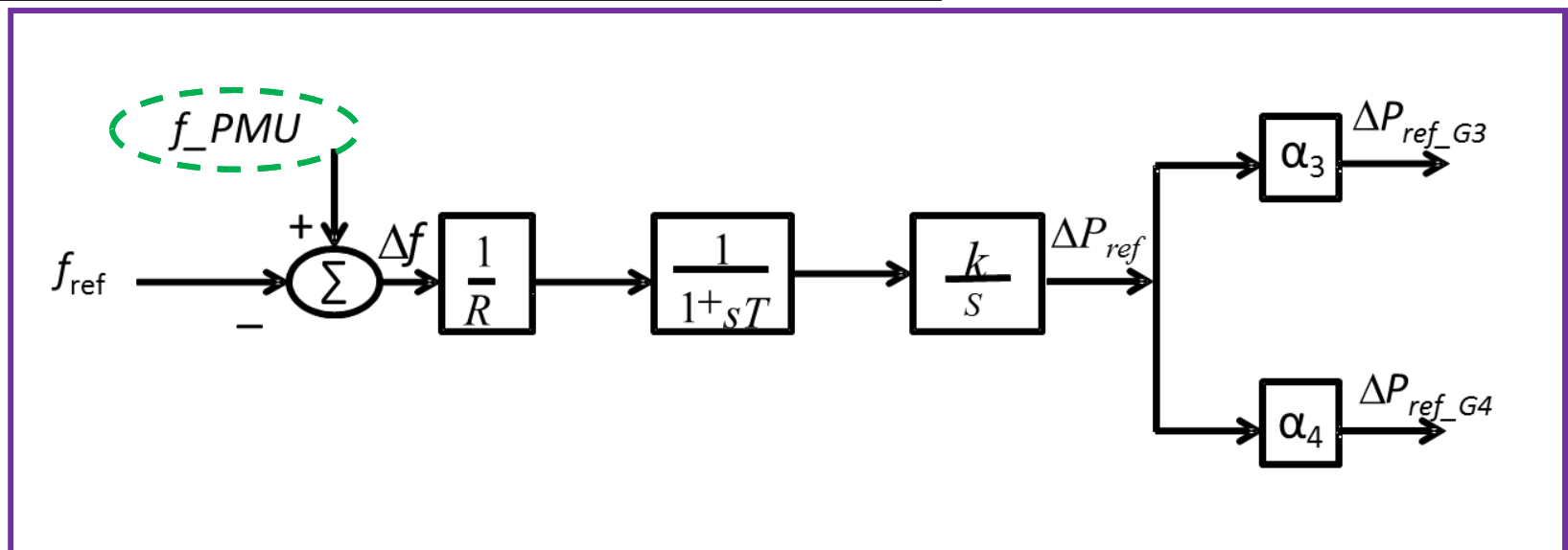


Short Term Prediction of PV power

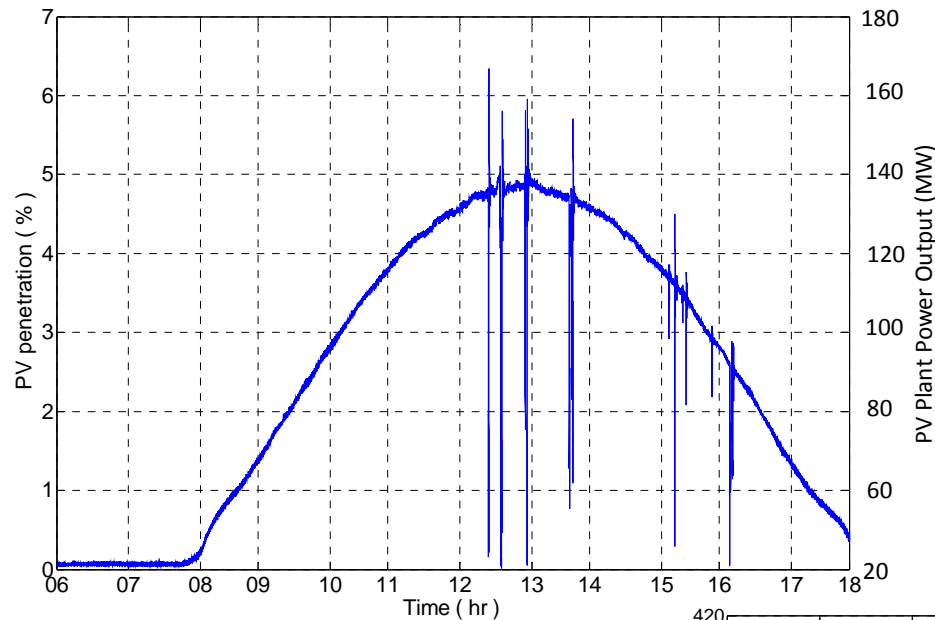
Prediction at time t for time instant	Testing MAPE	
	ESN (%)	ELM (%)
t+5	1.1954	4.4389
t+10	2.3811	4.5701
t+15	2.5328	4.6934
t+20	3.0215	4.7822
t+25	3.6592	4.5902
t+30	3.9442	4.3882
t+60	6.0993	6.3959
t+90	7.6080	8.6509



“Reservoir Based Learning Network for Control of Multi-Area Power System with Variable Renewable Generation”, *Neurocomputing*, vol. 170, December 2015, pp. 428-438



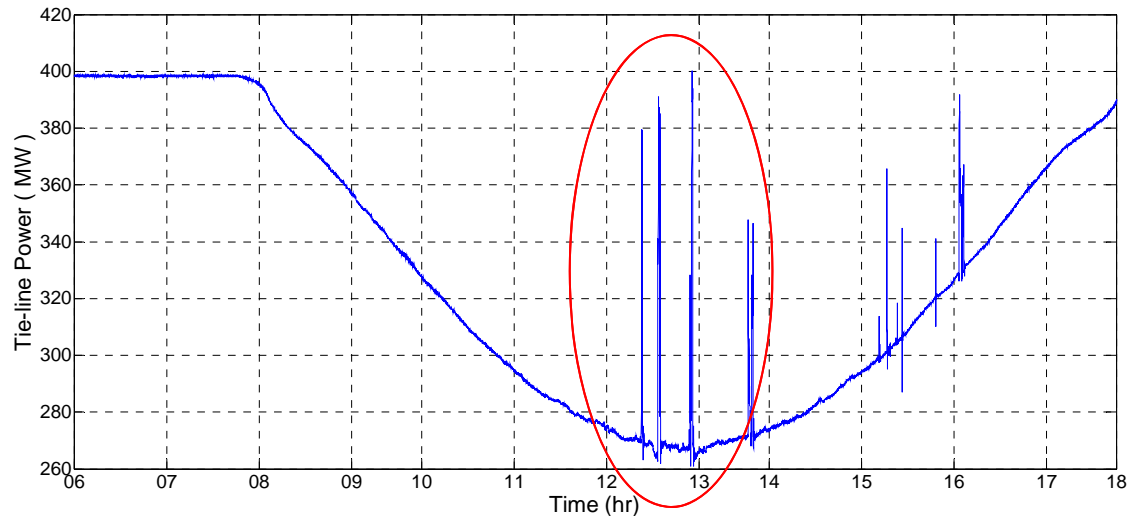
PV Power and Tie-Line Power Flow



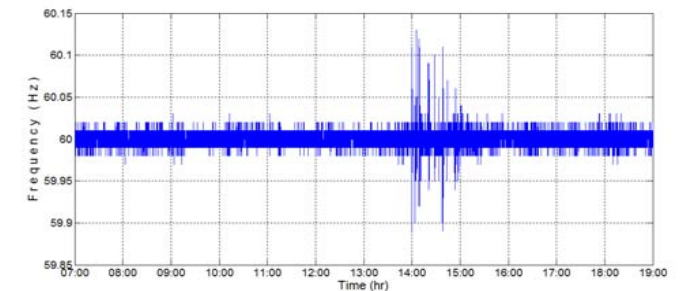
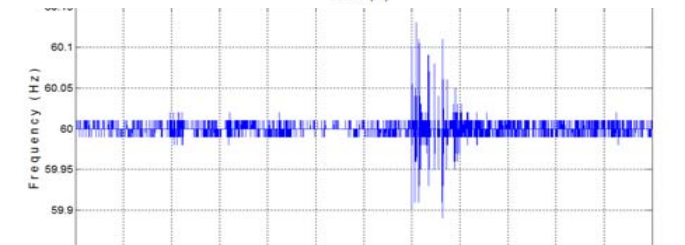
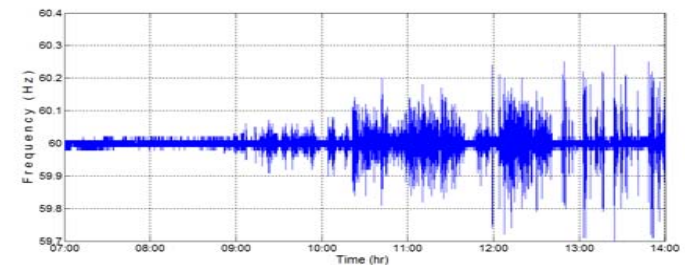
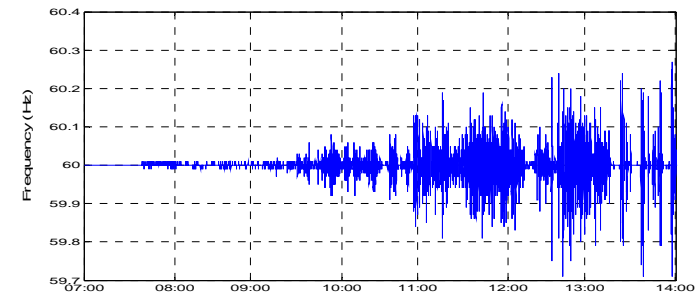
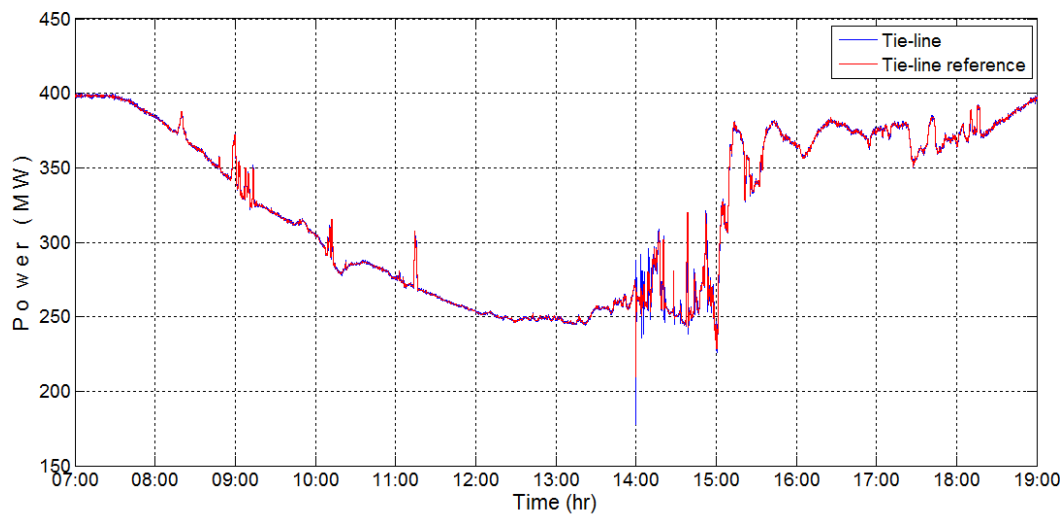
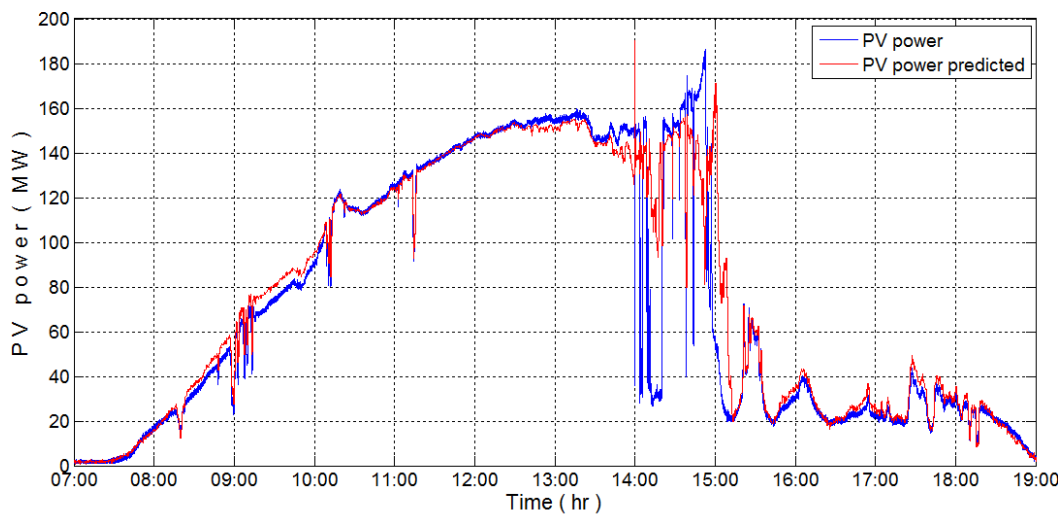
Tie-line power flow with the PV plant operation on October 21, 2014 between 06h00 and 18h00.

130 MW drop

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



Tie-Line Power Flow Control



PMU measurements make near real-time operations possible.

However, PMU based operations also make the power system sensitive to network disturbance and cyber-physical attacks.

Side-channel analysis can be used to detect a Man-In-The-Middle (MITM) attack.



PMU Man-In-The-Attack

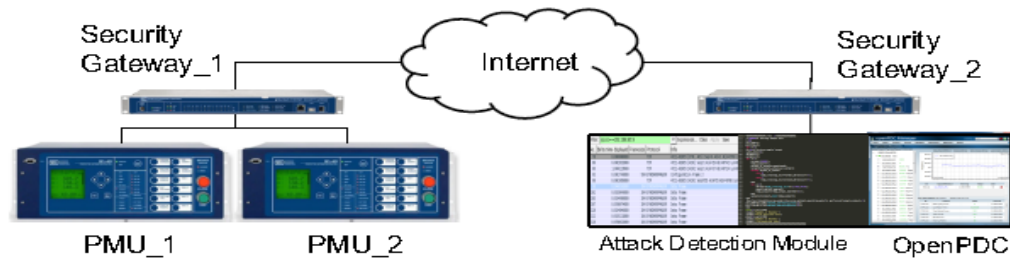


Side-channel analysis extracts information by observing implementation artifacts.

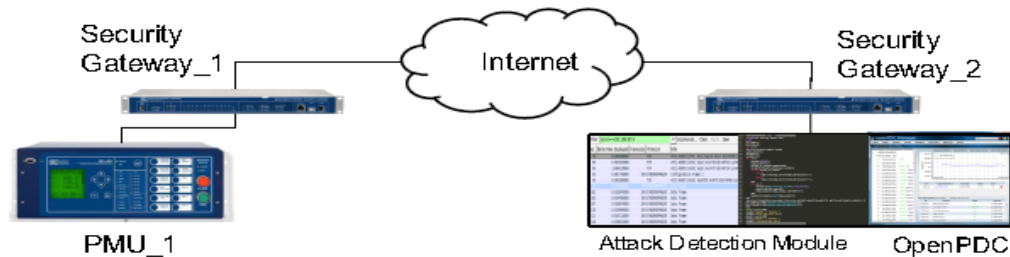
The side-channels in PMU traffics are used to identify normal traffics.

Alarm significant deviation from normal patterns and further identify MITM attacks.

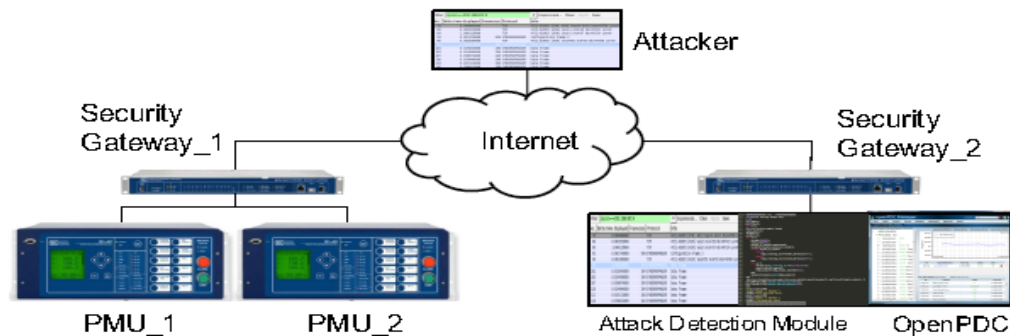
Experimental results confirm the effectiveness of a method to make PMU based operation less vulnerable to attack in practical network configurations.



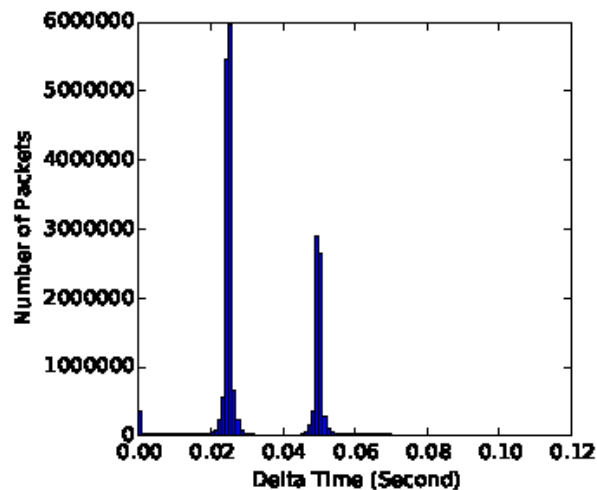
(a) Normal operation



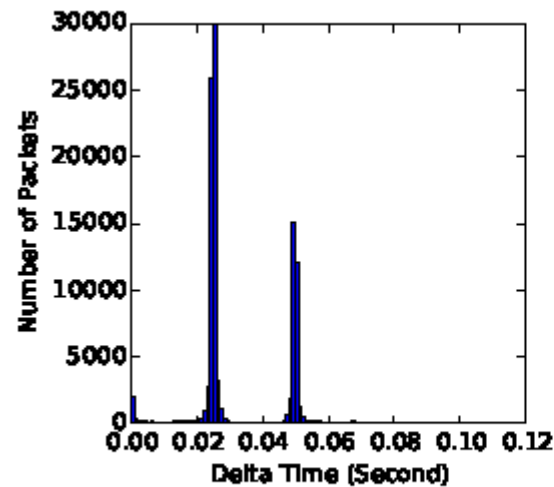
(b) PMU connection issue



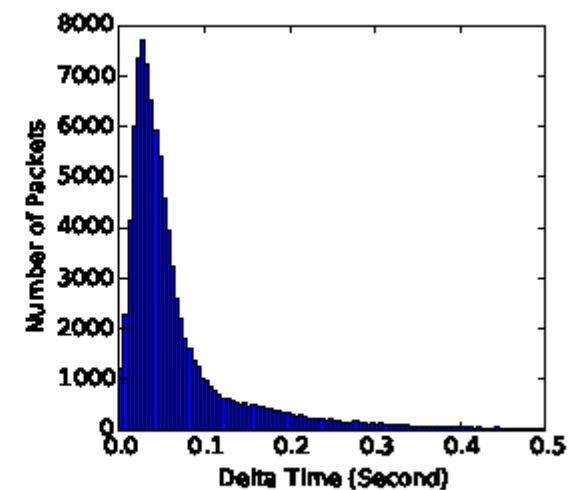
(c) MITM attack

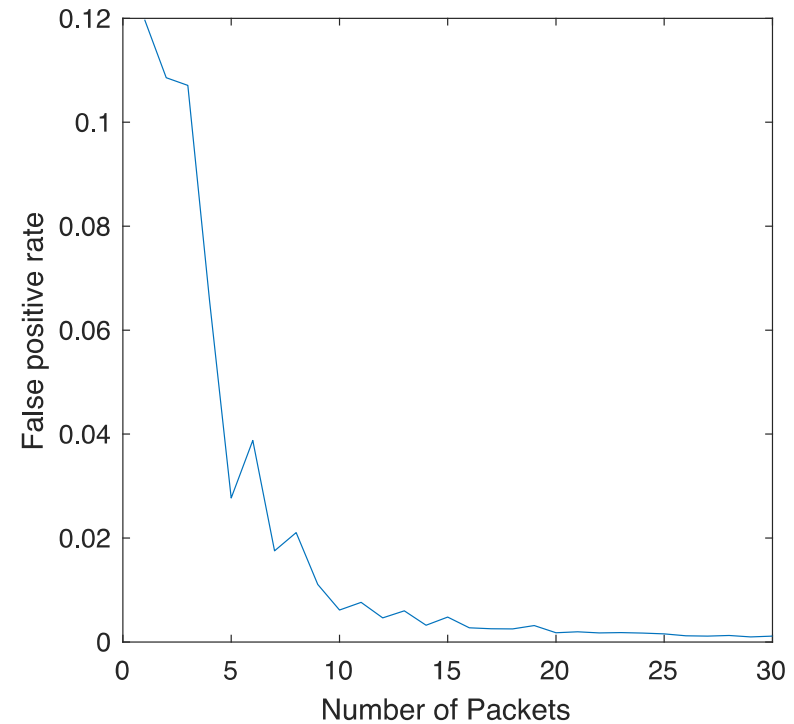
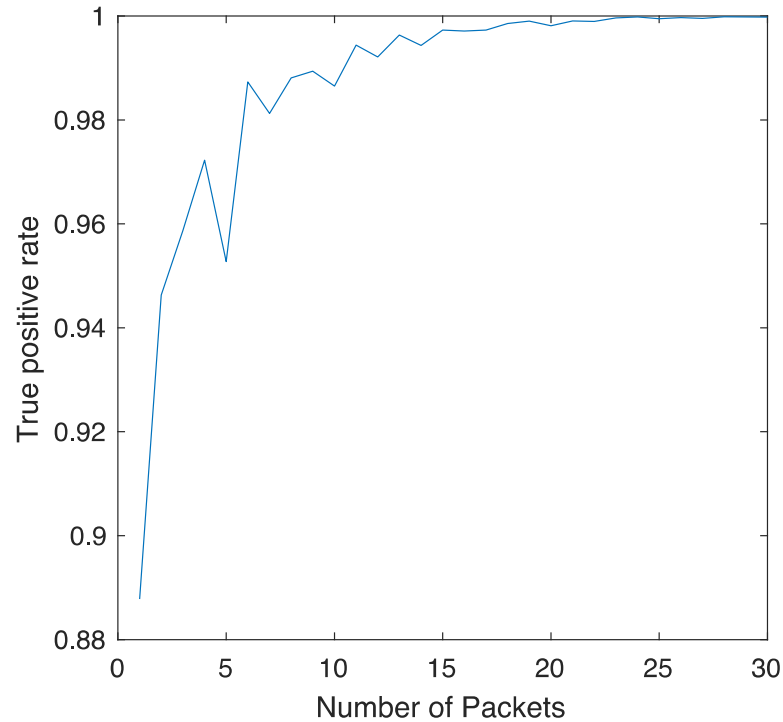


(a) PMU connection issue.



(b) MITM attack.





For 30 packets:

FPR < 0.0001

TPR > 0.9999

One false alarm is expected for every 10000 seconds





Thank You!

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