Controlling Next-Generation Electric Power Grids using High-Speed Cloud Computing

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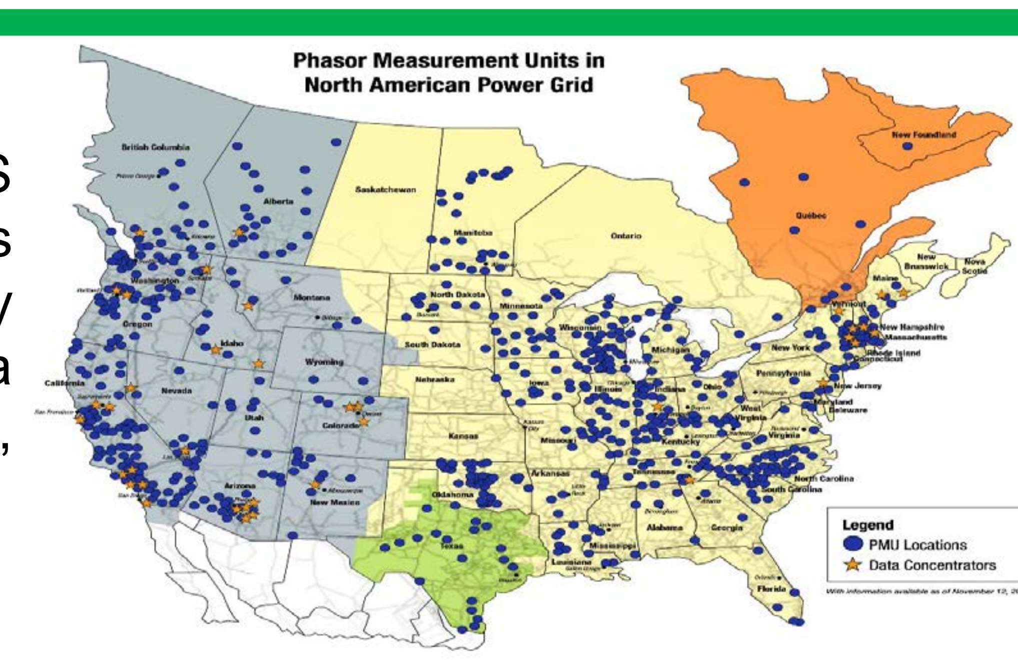
Funded by NSF projects CNS 1531099, 1531047, and 1531061

Introduction

With increasing trends in renewable penetration, smart loads, electric vehicles, etc. the US grid is becoming more vulnerable to instabilities. The Wide-area Measurement Systems (WAMS) technology using GPS-synchronized Synchrophasor measurements is an ideal way to control such instabilities and blackouts. The challenge, however, is the bottleneck in data communication and computation, which cannot be handled by today's Internet. In this project, we propose the use of cloud-computing networks such as GENI to combat this challenge.



40 PMUs at 2008 →1000 PMUs at 2015

Power Grid Control with Cloud-Computing & Internet2

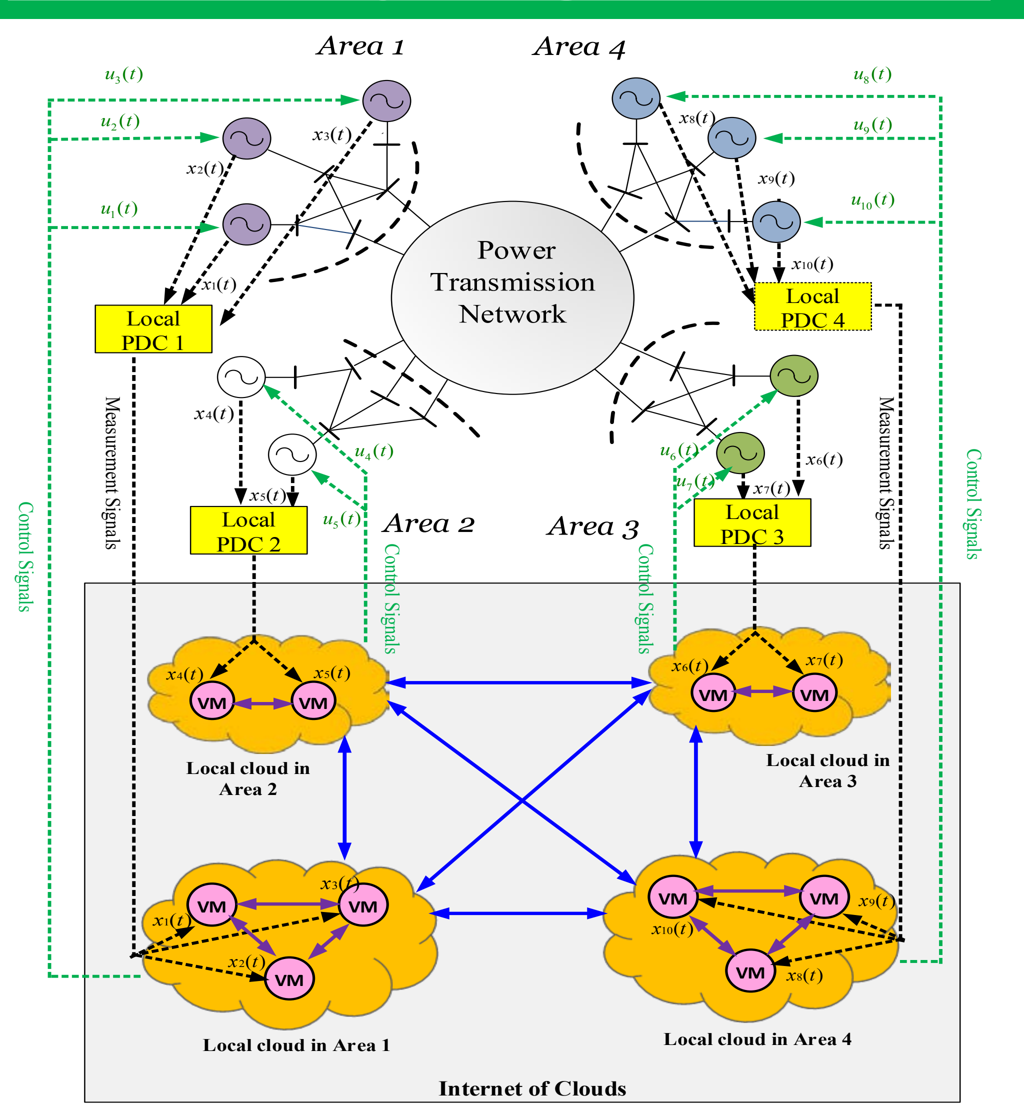
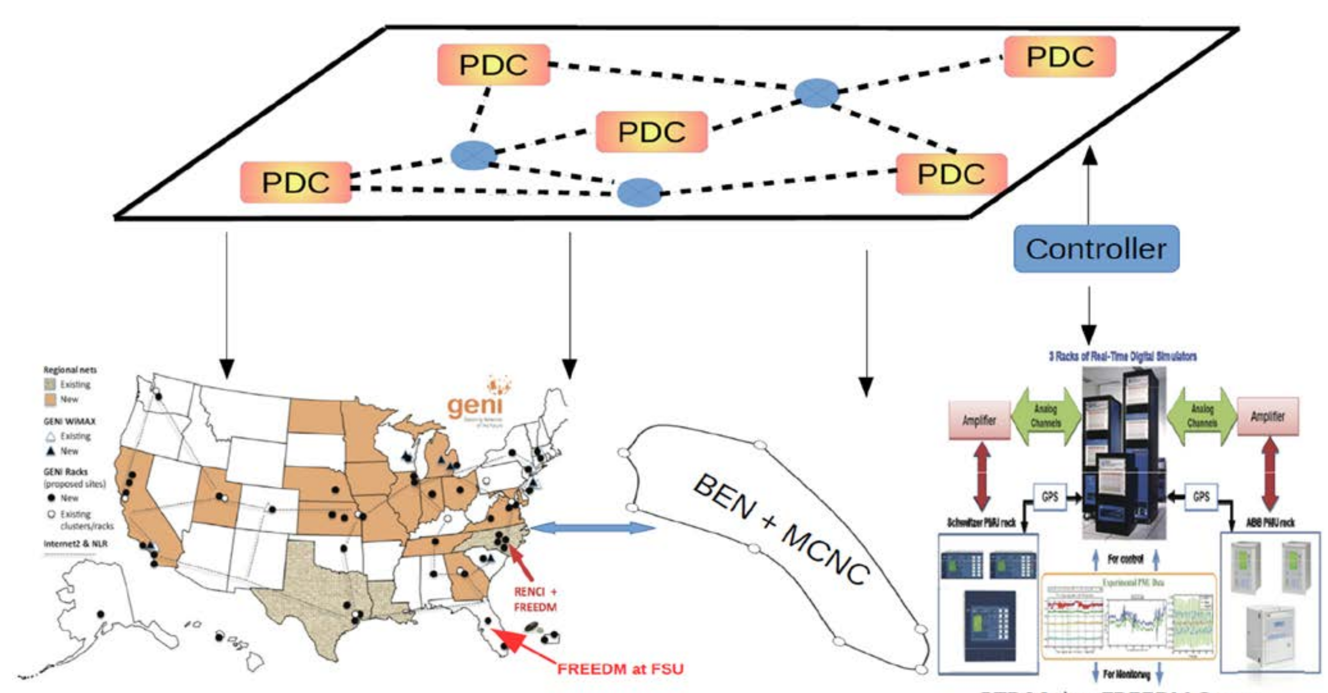


Fig.1- Envisioned architecture of wide-area communication

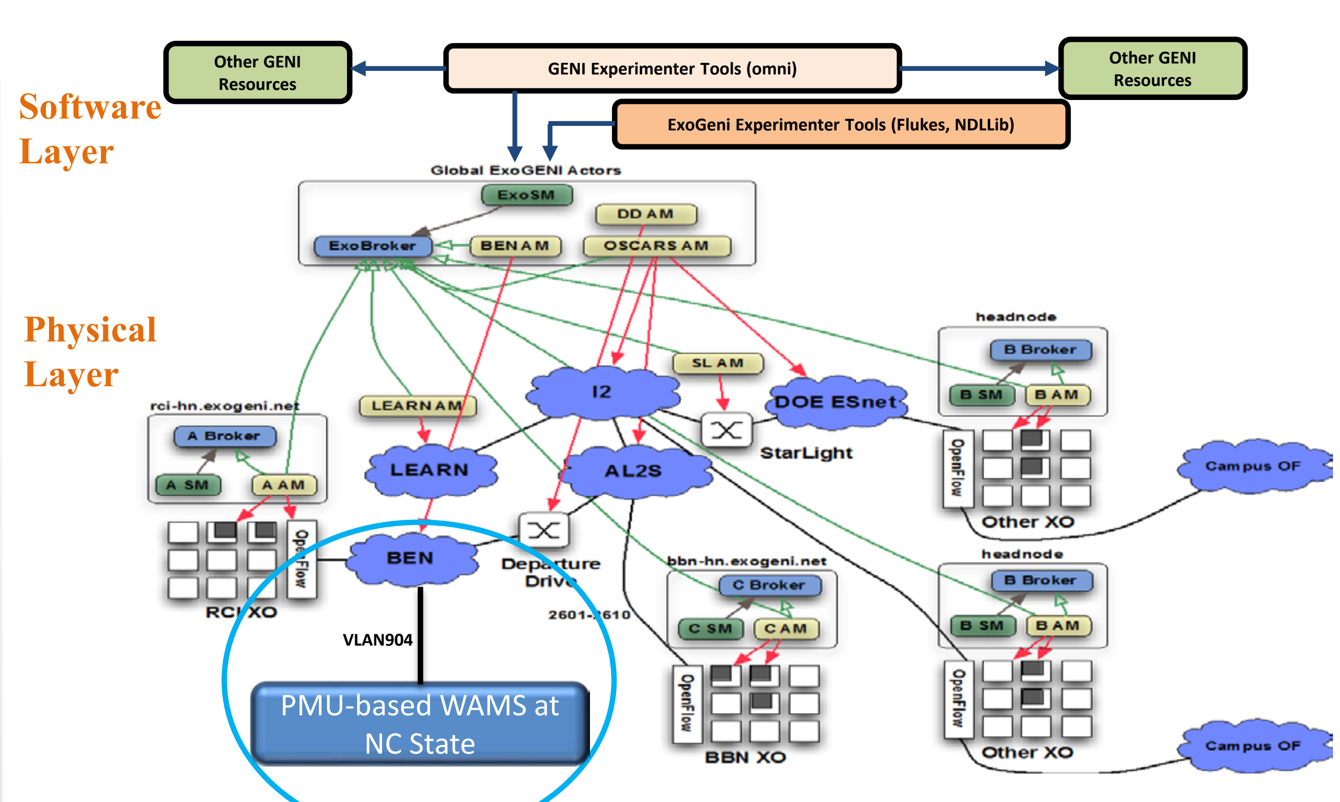
- Phasor Measurement Units (PMU) of any utility first send data to local phasor data concentrators (PDCs) through a virtual private network (VPN).
- The PDCs then route the PMU data-streams to virtual machines (VM) in a cloud computing platform such as ExoGENI.
- The VMs belonging to each company may form a sub-cloud of their own.
- Each VM then communicates to other VMs, both inside (intra-area) and across (inter-area) the sub-clouds, over a multi-hop Software Defined Network (SDN) such as Internet2 to compute the wide-area control signals in a distributed fashion.

ExoGENI-WAMS Testbed for Control and Cyber-Security

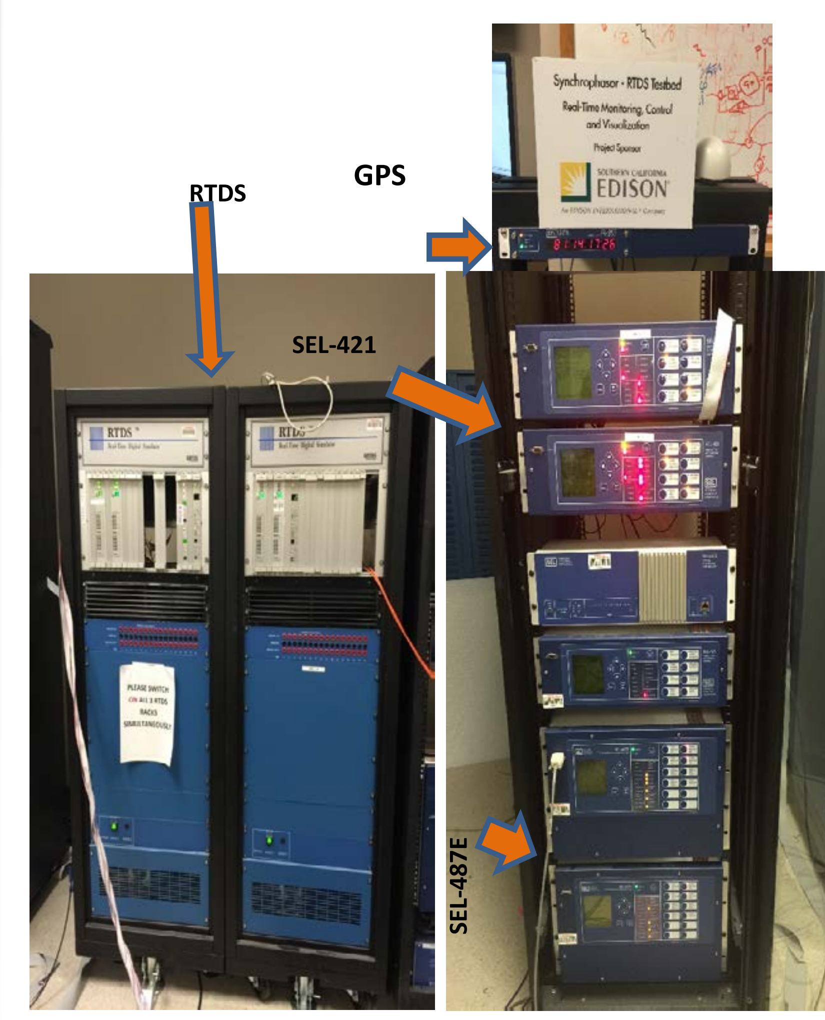


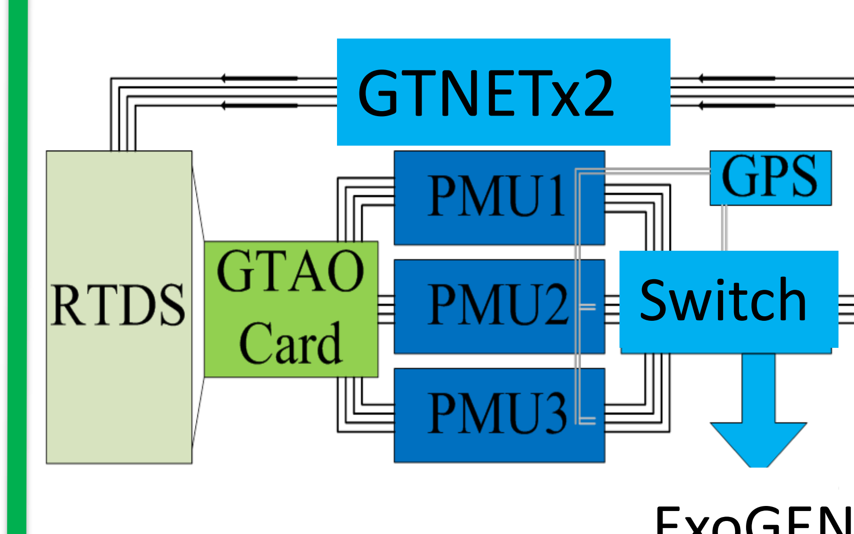
US-wide ExoGENI network (PoP at RENCI) **Testbed at NC State**

ExoGENI Cloud Computing Platform

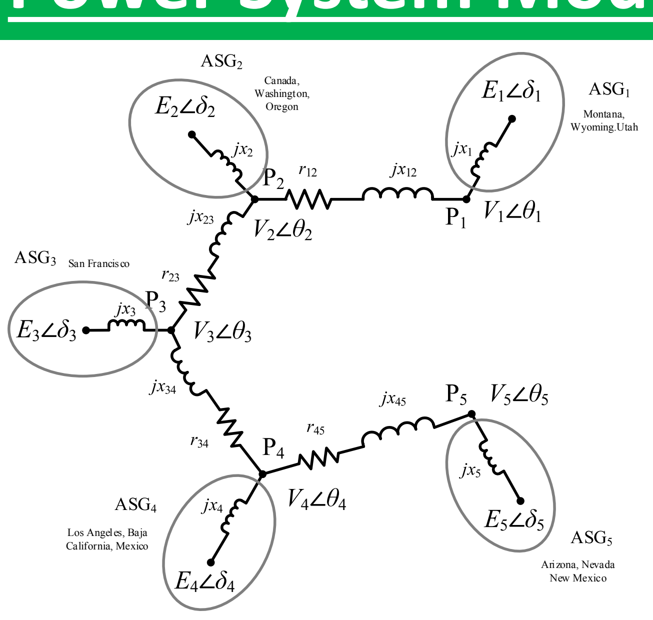


RTDS-PMU based WAMS





Power System Models and Control



Design of damping controller

$$x^T Q x = [\Delta\delta(t)|\Delta\omega(t)|\Delta E(t)]\begin{bmatrix} Q_\delta & 0 & 0 \\ 0 & Q_\omega & 0 \\ 0 & 0 & Q_E \end{bmatrix}\begin{bmatrix} \Delta\delta(t) \\ \Delta\omega(t) \\ \Delta E(t) \end{bmatrix}$$

$$u_i = \sum_{j=1}^{5} K_{i,j}\delta_j + \sum_{j=1}^{5} K_{i,j+5}\omega_j + \sum_{j=1}^{5} K_{i,j+10}E_j$$

Note: K is a full matrix, this indicates that every VM will need to communicate with every other VM to exchange state information.

Swing + Excitation Dynamic Equations

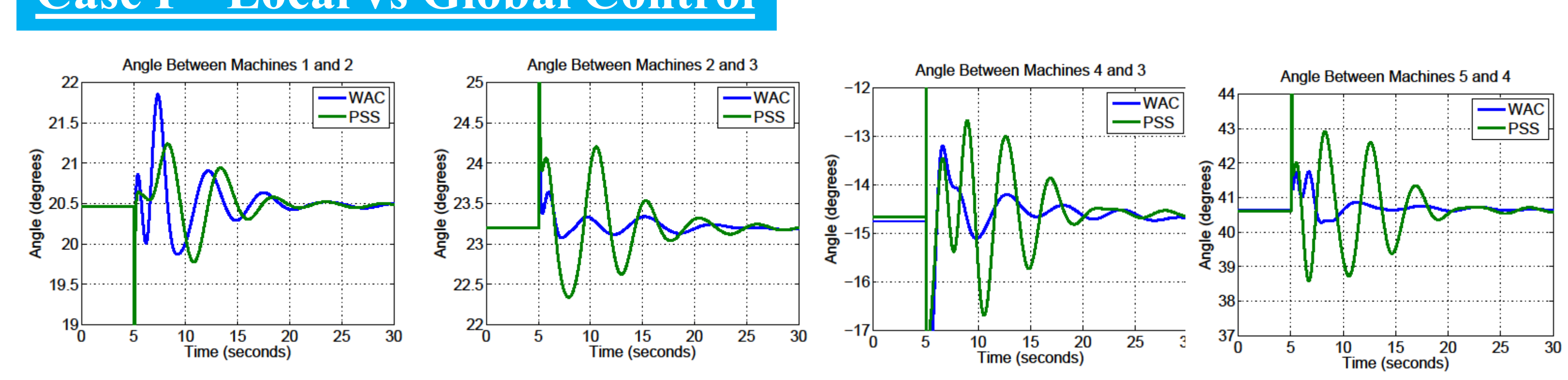
$$\dot{\delta} = \omega_i$$

$$M_i\dot{\omega}_i = P_{m_i} - E_i^2 G_{L_i} - D_i\omega_i - \sum_{k=1,k\neq i}^{n} E_i E_k (G_{ik}\cos(\delta_i - \delta_k) - B_{ik}\sin(\delta_i - \delta_k))$$

$$\tau_i \dot{E}_i = -\frac{x_{d_i}}{x'_{d_i}} E_i + U_i + \frac{x_{d_i} - x'_{d_i}}{x'_{d_i}} \left(\sum_{k=1}^{n} K_{i,k} E_k \cos(\delta_i - \delta_k)\right)$$

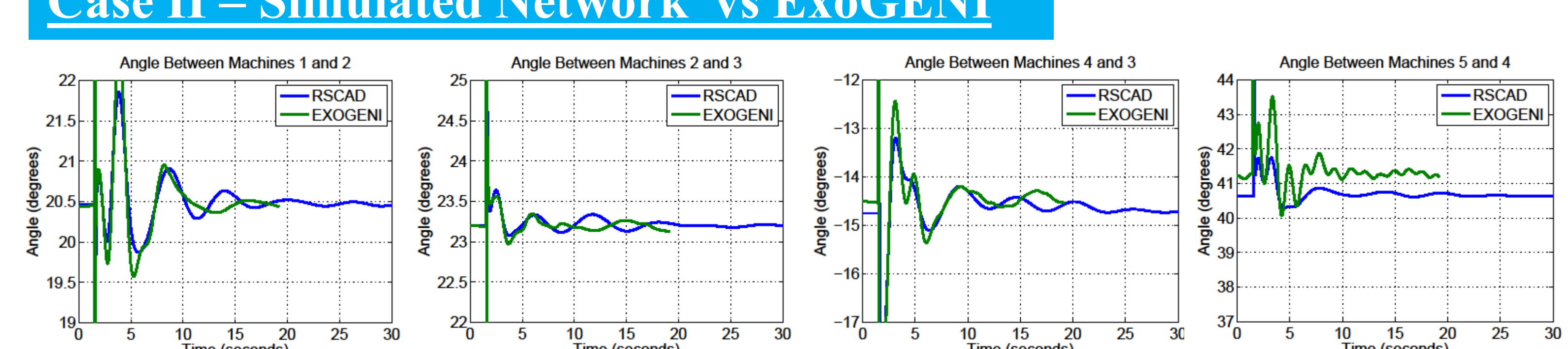
Case Study on US West Coast Grid

Case I – Local vs Global Control



WECC Transient Response, PSS vs WAC

Case II – Simulated Network vs ExoGENI



WECC Transient Response, RSCAD vs ExoGENI