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Agenda

1. AESC Background
2. Agent / Project(s) Background
3. "Agents for Renewables" System Description
4. Demonstration Results

Intelligent Agents that Enable a Smarter Grid

CEATI International SOIG Workshop

March 14, 2012

AESC at a Glance

- Engineering consulting services company specializing in the energy industry
- Incorporated in CA in February 1994
- Currently, thirty-eight employees
- Personnel in Carlsbad, San Diego, Pasadena & Concord
- $ +7 million in revenues in 2011
- Primary Business Areas Include:

  Energy Efficiency

  Distributed Generation

  Technology Development

  Technology Evaluations

  Utility Engineering Support

see www.aesc-inc.com and
www.smartder.com

What is an Intelligent Agent?

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Intelligent Software Agents

- An Intelligent Agent acts on behalf of another and ….
- Executes autonomously & operates in real-time
- *Communicates/collaborates with other agents or users*
- *Is able to exploit domain knowledge*
- *Exhibits goal-oriented behavior*
- Think “real-estate agent”

Multi-agent (Agency) Advantages

- Provide distributed processing
- Agent complexity is kept low while agency intelligence is high
- *Agent-based solutions are more open and extensible*
- *More robust solution*

Agent-Based Project Highlights

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1. **1998 – California Energy Commission (CEC) Public Interest Energy Research (PIER) project, *Smart**DER Research.**

   Developed operating model, algorithms, and software, referred to as *Smart**DER, to manage Distributed Generation (DG) assets and peak loads utilizing real time pricing signals, weather data, and building performance inputs.

2. **2000 – California Energy Commission (CEC) Public Interest Energy Research (PIER) project, *Smart**DER Demonstration:**

   Follow on 'real world' demonstration of *Smart**DER technology, this pioneering effort demonstrated the viability of intelligent agents to effectively control DG assets and effectively manage peak loads in a complex Critical Peak Pricing (CPP) environment.

Agent-Based Project Highlights

3. **2003 – Department of Energy (DOE) Small Business Innovative Research (SBIR) Grant, Power Neighborhoods Aggregation:**

   Project demonstrating the potential of integrating DG assets at previously unrelated sites within a feeder or multiple feeders, and forming 'Power Neighborhoods' whose assets and loads were intelligently managed utilizing Intelligent Software Agents and a web-based auction hierarchy.

4. **2008 – California ISO (CAISO) & California Energy Commission (CEC), Renewable Generation, Dynamic Control & Capacity Management:**

   The CAISO required a solution that enhanced both the visibility and dynamic control of intermittently available generation and transmission resources.

"Agents for Renewables" Project Goals & Objectives

The GOAL was to successfully apply and demonstrate that agent technology with storage:

- Increases the capacity and use of existing transmission facilities for the benefit of the consumers in California.
- Control Flywheel storage technology to improve the dynamic control of the wind generation resources.
- Coordinate energy production and delivery from wind generation.

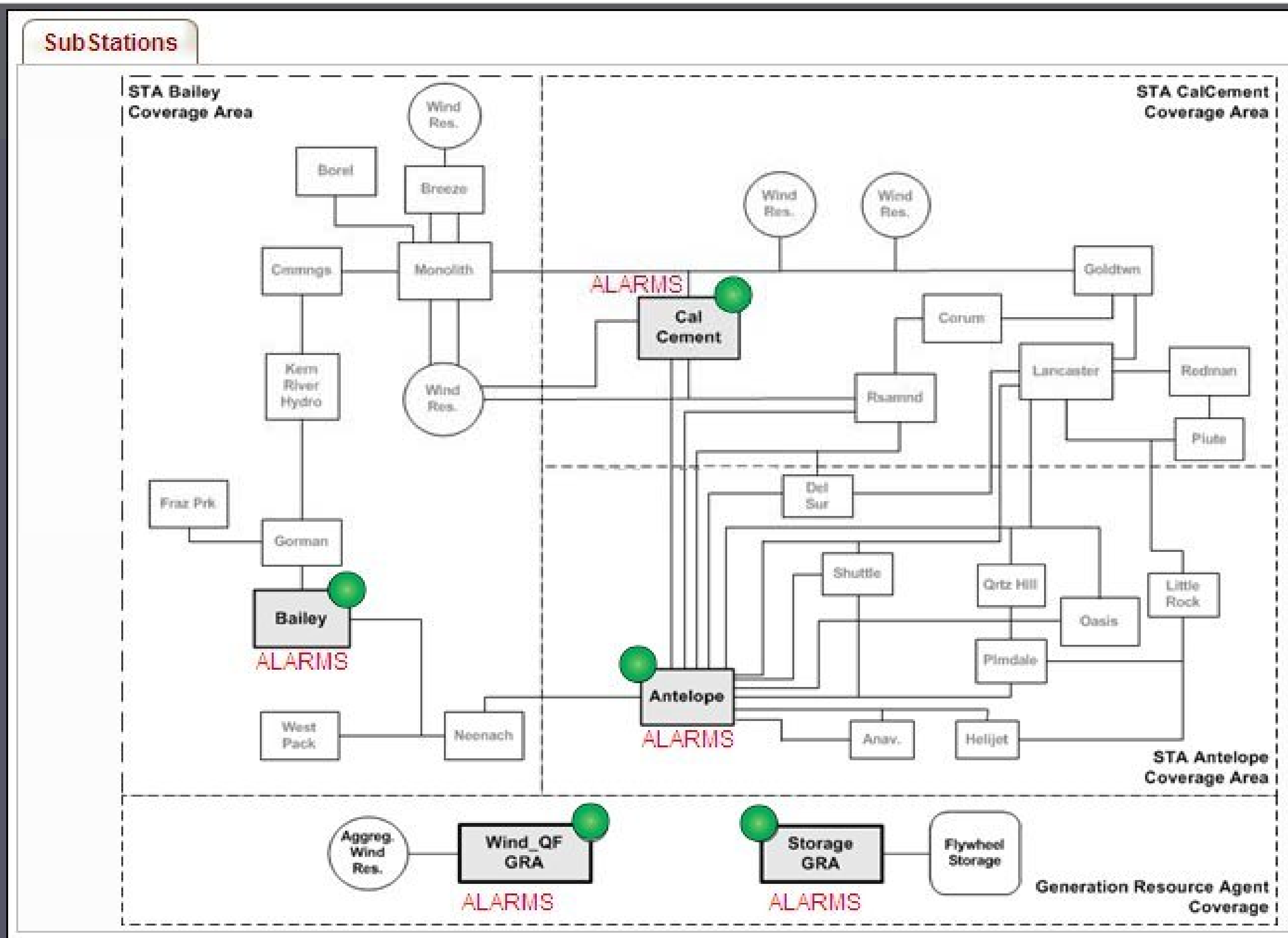
Targeted Opportunities after Phase 1 Investigation effort:

- 66 kV Subtransmission System Limitation Opportunities
  - ✓ Improve capacitor bank control to reduce Tehachapi area limitations resulting in wind curtailment events.
  - ✓ Coordinate wind farm assets (kW & kVAR) to mitigate curtailment
- Storage System Opportunities
  - ✓ "Behind the meter" location to facilitate installation
  - ✓ Assist with voltage / VAR control

"Agents for Renewables" Project Participants

- AESC (Prime) -- Agent Technology
- BPL Global Ltd – Communications / enerView / Power SG
- Beacon Power -- Flywheel Storage Unit
- Quanta Technology – Load Flow Modeling
- E-Marc Engineering – Field Support
- SCE (Engineering and Operations Support)
- CEC
- CAISO
- Western Wind (Wind Farm Operator)
- Stakeholder's Working Group

System Schematic



Three Sub-Transmission Agents (STA) and two Generation Resource Agents (GRAs), monitor and manage subtransmission, generation & storage assets assets.

Agent-based Management System Summary

- Agent connectivity and asset mix are driven by the physical configuration of the system (connectivity, available SCADA data, etc.).
- Each STA manages subtransmission system assets within the confines of its coverage area (i.e., capacitor banks, etc.).
- Each STA:
  - ✓ Continuously monitors parameters (SCE SCADA data) associated with its own physical environment and shares status information with other "connected" STAs within the control area
  - ✓ Uses a *Bayesian Belief Network (BBN)* to determine when action is warranted.
  - ✓ Takes or recommends action based on an "action table" developed based on SCE operating orders, load-flow modeling results and SCE Operator input – action when taken will be consistent for all STAs.
- Any STA can detect, and initiate an action in response to a condition.
- All actions occur within a 5 second window defined by the SCADA data update rate.

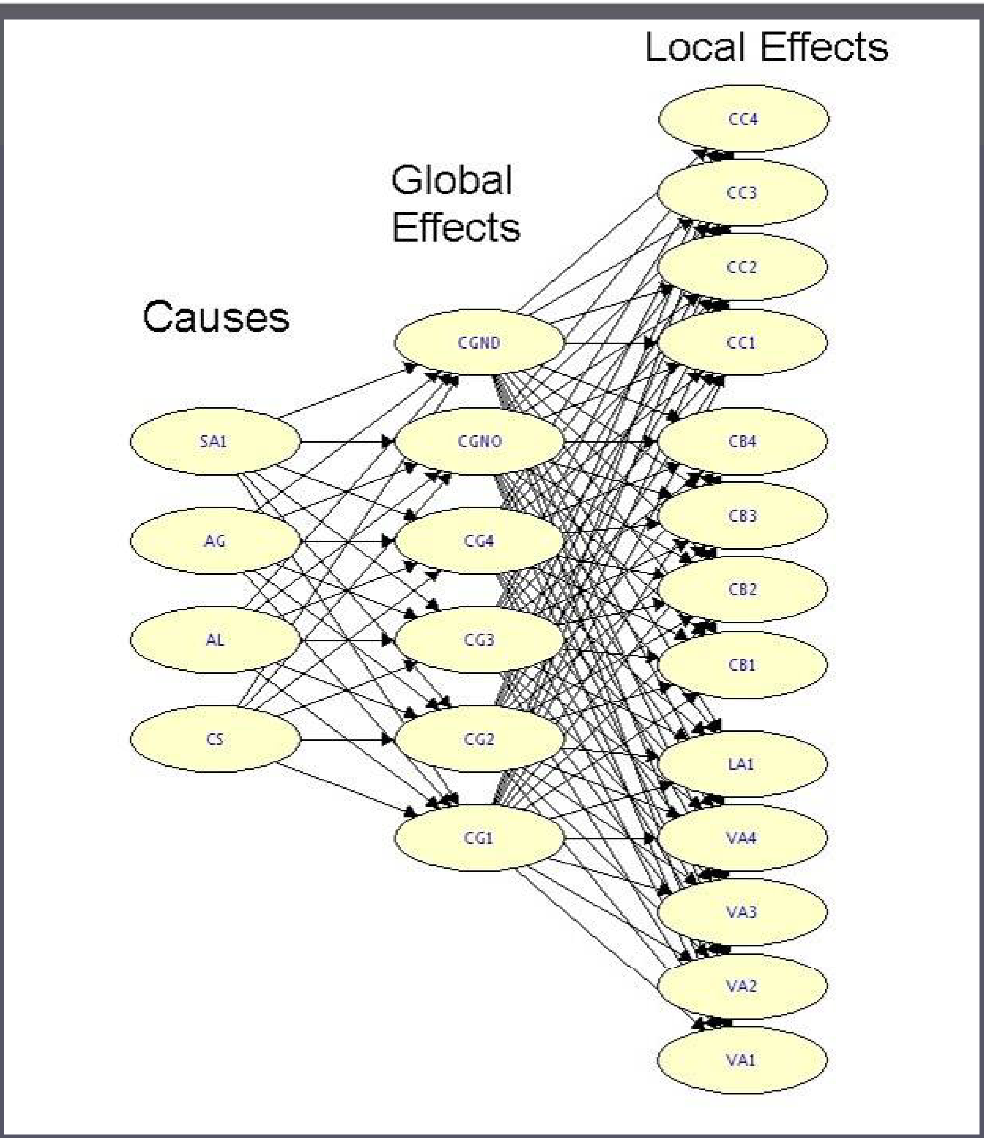
Agent-based Management System Summary cont'd

Flywheel Storage System Operation

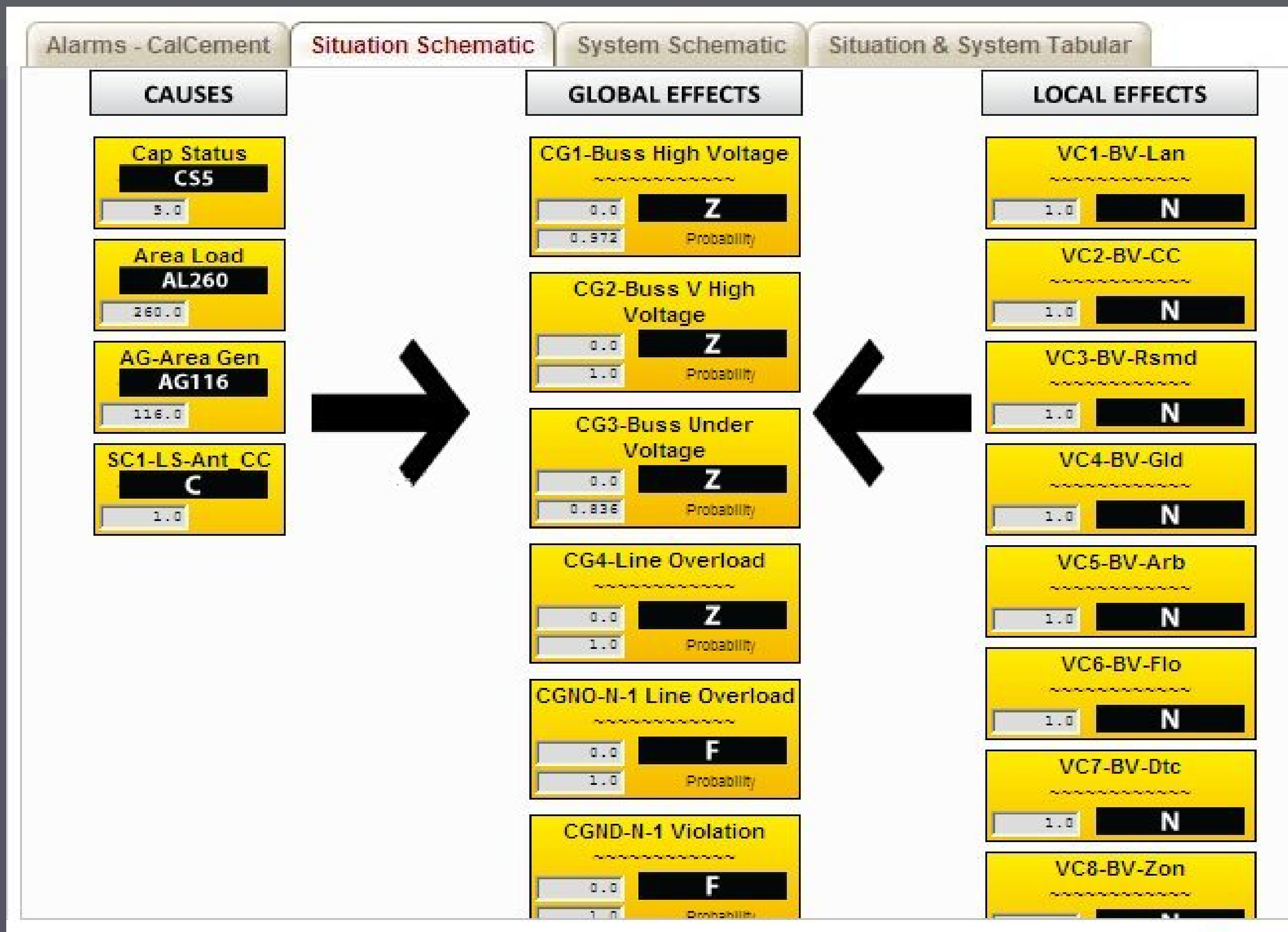
- The agent-based system will control the flywheel energy storage system.
- Specifically, a GRA located at the flywheel storage unit:
  - ➢ Develops a pseudo frequency regulation signal based on the CAISO ACE to operate the flywheel storage unit during "normal" operation.
  - ➢ Communicate with the STAs to:
    - provide flywheel storage unit status information
    - receive short term flywheel storage system operating commands as indicated by the system action table

Bayesian Belief Network (BBN)

- A network of cause and effect “nodes” (each node with multiple states)
- “Connection“ strengths based on probabilities
- Probabilities developed based on “training” (simulated or actual data or set manually based on experience.
- BBNs are robust in that inputs can be missing/unknown and the system will continue to operate



BBN Status Display Example



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Agent-based Management System Summary cont'd

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Actionable Conditions and Associated Actions

Condition	Priority	Threshold	Delay (sec)	Potential Actions (in order of occurrence)
Line Overload	1	> 1 P.U.	60	Curtail Wind & Storage – Absorb Energy
Very High Voltage	2	> 115%	15	Deactivate cap bank, Storage - Absorb Max VARS
Under Voltage	3	< 95%	60	Activate cap bank, Storage – Inject Max VARS
High Voltage	4	> 105.9% (66kV) > 110% (12kV)	120	Deactivate cap bank, Storage – Hybrid, Storage – Abs Max VARS
N-1 Overload	5	NA	30	"Consider Action"
N-1 Violation	5	NA	30	"Consider Action"

- Capacitor bank actions and curtailment are recommendations (action table).
- Flywheel storage system actions are implemented.

System Photos

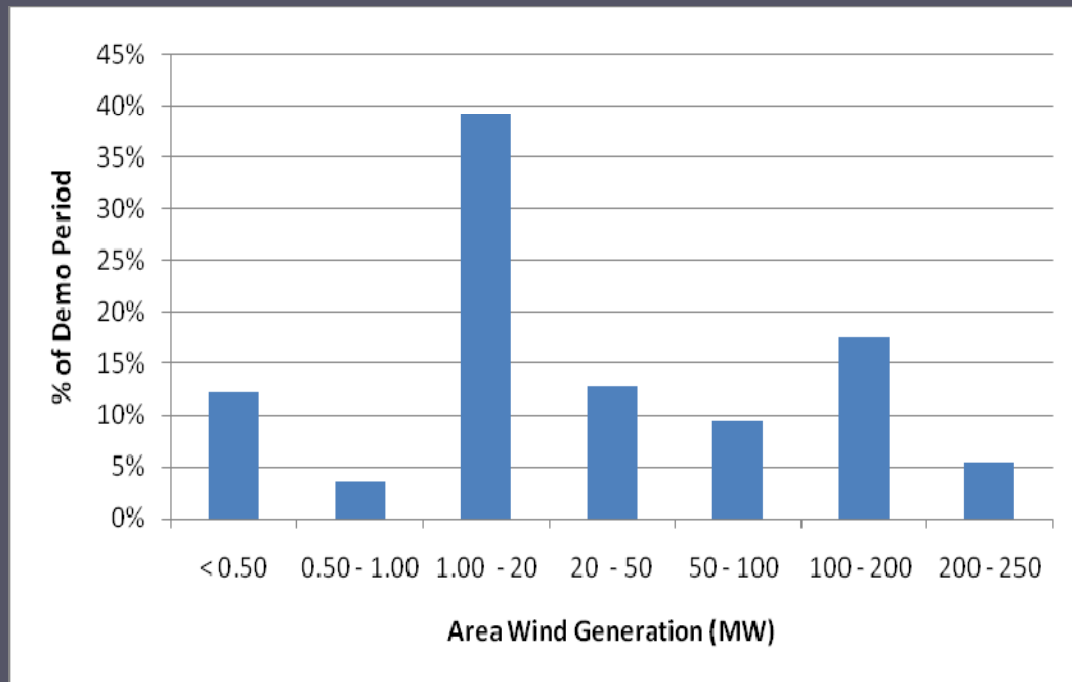
Tehachapi Installation – Control Enclosure w/ Flywheel Unit in Ground

System Photos

Tehachapi Installation – Centry WCC / GRA Agent above
Flywheel Master Controller

Demonstration Results

- The demonstration period began on December 1, 2010 at 4 p.m. and ended on February 11, 2011 at 5 p.m.
- Area wind generation levels were relatively low with levels below 20 MW 55% of the time and over 200 MW just 5.5% of the time.
- Minimal capacitor banks were needed with 6 banks or less operating over 90% of the time.



Demonstration Results cont'd

- Agent availability was measured based on an agent's ability to accomplish its overall mission (software had stopped functioning or was functional but unable to complete their data retrieval and processing functions).
- Based on these broad criteria, the agents still achieved a high level of availability. With the exception of the GRA Storage agent, the agents were available over 99% of the time.
- Factors affecting availability included messaging issues, cell modem outages (Storage GRA, eDNA data retrieval issues, and routine log file collection).

Agent	December	January	February	Total Availability
STA Antelope	99.6%	99.0%	99.8%	**99.4%**
STA Bailey	99.5%	99.0%	99.7%	**99.3%**
STA Cal Cement	99.6%	99.0%	99.6%	**99.4%**
GRA Wind	99.9%	99.3%	100.0%	**99.7%**
GRA Storage	93.1%	83.4%	99.46%	**90.1%**

- A more fully integrated system would not experience messaging, eDNA or routine log file collection issues (all were specific to the demo).

Demonstration Results Cont'd

Storage system operation summary:

- Operated in Frequency Regulation mode 97% of the time, 'Hybrid' mode operation for remaining 3%.
- Was depleted approximately 7% of the time and was at full charge just 4% of the time. The average power output command provided to the storage system by the Storage GRA was 0.001.

Operation	December	January	February	Overall Demo Period
Frequency Regulation	96.7%	97.8%	97.1%	97.0%
Hybrid Mode (Freq Regulation + Mod. VARS)	3.3%	2.2%	2.9%	3.0%
Depleted (Stored Energy < 500 Wh)	6.1%	7.2%	7.0%	7.0%
Full Charge (Stored Energy > 25000 Wh)	4.6%	3.6%	2.4%	4.0%

Demonstration Results Cont’d

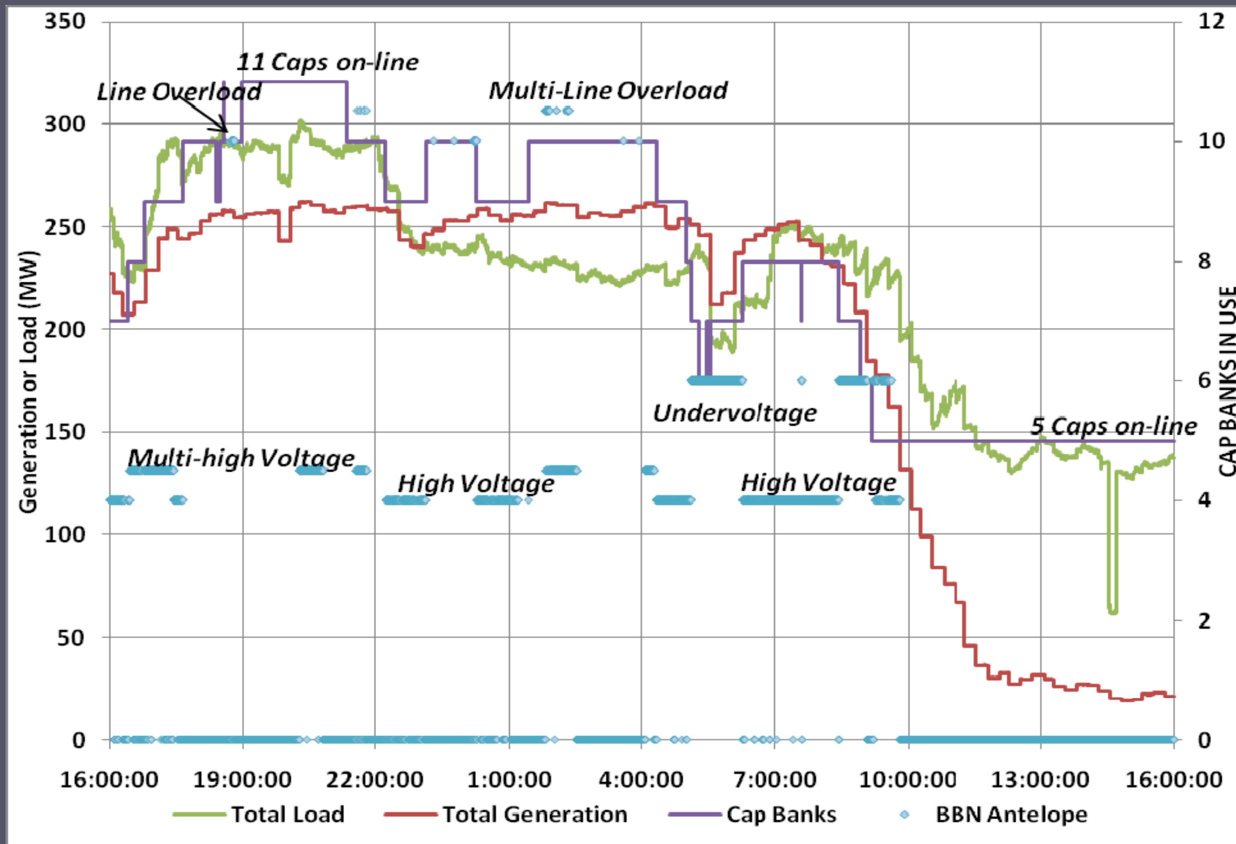
BBN Performance Summary:

- The BBN performed well given the limitations of the configuration and training efforts that consisted of Tehachapi area sub transmission system operation with:
  - 5 or more capacitor banks on-line;
  - 260 MW or more of area load; and
  - 116 MW or more of area generation.
- BBN performance was optimized over a limited range that was specific to conditions when curtailment of area generation was most likely to occur. Operation within this range was characterized by detection of system conditions either in step with, or in advance of operator actions.
- The BBNs were able to operate successfully outside of the original configuration range as a result of BBN training using data collected prior to and during the demonstration period (as opposed to simulated data). However, BBN performance outside of the original configuration range was less consistent.
- Additional modeling and associated statistical analysis is needed in order to configure and train the BBN to operate consistently across the full range of potential sub transmission system operation.

Demonstration Results Cont'd

BBN Performance Summary continued:

- The BBN detected one known curtailment event that officially began on 12/10/2010 at 18:58 and ended on 12/11/2010 at 09:49.
- Indications are that managed curtailment would have been significantly briefer.
- BBN control of storage would also have come into play lessening the need for curtailment.
- More study is needed.



Demonstration Results Cont'd

Two powerful BBN features were also demonstrated.

- BBN Operation with missing or unknown data

  At one point in the demonstration two faulty sensors were detected. One was replaced with an alternate SCADA point . One point could not be replaced and the STA simply entered this BBN input as "unknown". The BBN was subsequently able to operate normally.

- BBN Ability to "learn" system behavior

  On 14 different occasions during the demonstration period one or more of the BBNs encountered an operating scenario (combination of BBN inputs) that it had not previously encountered. The condition was "flagged" by the STA for action by AESC. When this occurred AESC updated the BBN training using actual data from the period in question. The BBN configuration was updated to include the new training and the issue was resolved.

- An automated system that takes advantage of both of these features would provide for more robust operation.

Conclusions

To summarize, the CEC PIER project was highly successful. During the project, the project team successfully:

- Identified a significant opportunity to demonstrate the feasibility of the agent-based approach.
- Specified and implemented a multi-agent system (MAS) that operated reliably during the demonstration period.
- Configured and implemented a MAS that subsequently performed well during the demonstration, although it was limited by the boundaries of the initial modeling and configuration effort.
- Demonstrated powerful BBN capabilities, the ability to learn and the ability to operate in the presence of missing or unknown data.

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