"AGENTS FOR INTEGRATION OF STORAGE AND RENEWABLES" PROJECT RESULTS

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ABSTRACT

The recently completed "Intelligent Software Agents for Distribution Management and the Integration of Storage and Renewables" project is the latest of three successful CEC funded projects involving the use of agent technology. The first two projects successfully demonstrated that intelligent agents can manage the operation of distributed energy resources in response to dynamic electric rates. The project objective of this latest effort was to demonstrate that use of agent technology could expand the potential delivery of regional wind energy through integration with storage and via improved management of existing transmission facilities in California's Tehachapi wind resource area. The principal project participants included: AESC, SCE, CEC, CAISO, Beacon Power and BPL Global, Ltd.

During the project, the project team successfully developed a multi-agent system that was installed and tested on commercially ready hardware platforms. The agent-based system was demonstrated over a ten week period, during which it: operated autonomously to gather utility SCADA data on Tehachapi area transmission system assets, forecasted local wind generation, recommended actions for area capacitor bank operation, and operated a Beacon Power Corporation flywheel storage system installed in the region. The agents detected abnormal conditions using a Bayesian Belief Network (BBN), trained using load flow modeling results and actual data. Agent BBN use allowed operation in the presence of faulty or missing sensor data while agent collaboration enabled each agent to respond to problems throughout the coverage area. Additional analysis and testing is needed, however results indicate that dynamic operation of the system during a known wind generation curtailment period could have resulted in a significantly shorter overall curtailment period.

PROJECT DESCRIPTION

This paper describes the results of a recently completed research and development project funded by the California Energy Commission titled, "Intelligent Software Agents for Integration of Renewables and Storage". The overall project goal was to demonstrate that applying agent technology could expand the potential delivery of renewable energy and make greater use of existing transmission facilities located in the Tehachapi wind resource area in California.

At the time of project inception, the Tehachapi area grid consisted of a 66 kV sub transmission system that connects to a 230 kV system (see Figure 1). Both the 66 kV and 230 kV systems are owned and operated by Southern California Edison (SCE). Control of the 230 kV transmission system falls under the authority of the California ISO (Cal ISO) while control of the 66 kV sub transmission system is provided by SCE

At that time, the Tehachapi grid had over 340 MW of installed wind energy generation and only approximately 80 MW of local load, primarily concentrated in two large industrial users. The grid was characterized as a "weak grid" where the connected induction machine kW rating exceeds 40% of the short-circuit rating of the gateway substation (15% is the threshold for considering a grid "weak"). VAR transport and voltage control are major considerations in weak grids such as Tehachapi.

Coordination of VAR support provided by multiple wind farms with utility VAR resources or by storage assets with similar and additional capabilities is a significant consideration. The Tehachapi region is characterized by variable wind conditions, which further complicates the process. Coordination/control of local VAR assets therefore requires a level of distributed decision-making and control that was seen as a potential match for agent-based control technology. Improved voltage and VAR

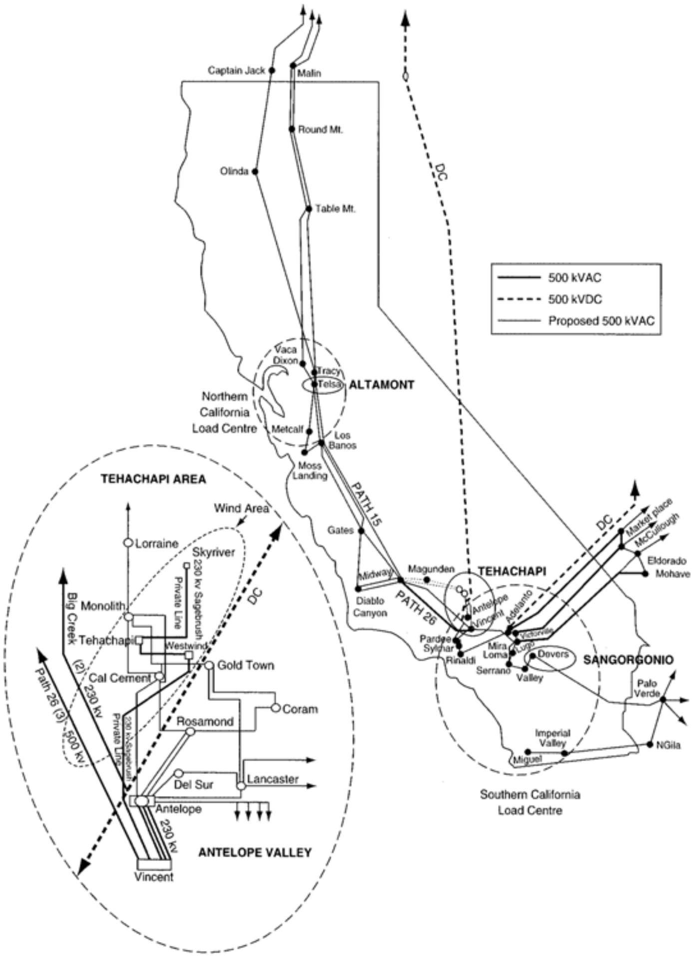

Figure 1 California and Tehachapi Area Grid [1]

control had the potential of increasing the overall transmission capacity of the existing system, which would in turn fulfill the primary project objective.

PROJECT RESULTS

The complexity of both the problem and the potential solution dictated a two-phase approach. In the first phase, the problem was characterized along with the requirements of the agent-based system that could address the problem. The second project phase then provided for implementation and demonstration testing of the agent-based system.

Project Phase 1 Results

The Phase 1 effort was successful in that the Project Team, with input from a Stakeholder's Working Group, was able to:

- Identify a project "target" with a quantifiable economic benefit and that appeared "doable" given the limited scope and resources of the project. An existing SCE operating order that provides for Tehachapi area wind generation curtailments due to thermal overload of a 66 kV sub transmission system path in the area was identified as the best near-term opportunity.
- Develop a System Requirements and Test Plan that identified more specific system requirements.
- Conduct feasibility testing of AESC agent technology on BPL Global's CentryWCC hardware platform confirming that operation of agents on the WCC was feasible.
- Define a multi-agent based system (MAS) that utilizes a Bayesian Belief Network (BBN) to monitor and evaluate the status of the 66 kV sub transmission system using a combination of SCE and CAISO provided data.
- Refurbish and successfully test the Beacon Power flywheel storage system in preparation for installation and operation during the demonstration period.

Project Phase 2 Results

The Project's Phase 2 effort began with configuration and development of the agent-based system and associated hardware (Task 8). During this task, AESC, Beacon Power, and BPL Global confirmed the ability of the agents to successfully:

- Gather and process the needed SCE SCADA data,
- Communicate with one another to coordinate their actions
- Recommend action related to capacitor bank & storage system operation,
- Generate a frequency regulation signal using the Cal ISO ACE and convert this to the necessary power command for use by the Beacon Flywheel storage system.
- Communicate with the Beacon Power flywheel storage system with testing to confirm that the flywheel storage unit accepted agent generated commands for charging and discharging of energy along with absorption or injection of reactive power.

The demonstration test period officially began on December 1, 2010 at 4 p.m. and ended on February 11, 2011 at 5 p.m. Overall, the agent-based system performed well during the demonstration period, during which:

- Data were collected at 5 second intervals over the 1753 hour period, representing a total of 1,244,880 five second intervals with an overall data collection rate of 95.7%.
- Overall, agent availability exceeded 99% during the demonstration period with the exception of the Storage GRA, which experienced lower availability due to

outages of the cell modem based communications (unique to Storage GRA). Other than the cell modem issues, the primary factors affecting agent availability were messaging issues associated with use of a centralized server-based messaging system and errors associated with retrieval of SCE SCADA data. It is important to note that both of these factors would not be evident with a system that had been fully integrated into the SCE network.

- Wind generation levels, when compared with the region's 349 MW installed capacity, were relatively low during much of the demonstration period, which required minimal use of the area capacitor bank resources (six or fewer of the thirteen total available capacitor banks were on-line over 90% of the time).
- The Bayesian Belief Networks (BBN) used by the agents to detect and predict abnormal system conditions operated successfully during the demonstration period. These BBNs were initially configured with the help of simulated sub transmission system operating data developed using the output of a power load-flow model developed by the Cal ISO and refined by Quanta Technology (see Figure 2).

  Investigation of specific events that occurred during the demonstration period showed that the BBN performed well given the limitations of the configuration and training efforts. BBN performance was optimized over a limited range specific to operation when curtailment of area generation was most likely. BBN operation within this range was characterized by detection of system conditions either in step with, or in advance of operator actions. And, while additional analysis is needed, results appear to indicate that dynamic operation of the system during a known curtailment period (December 10-11, 2010) could have resulted in a significantly shorter overall curtailment period.
- Two powerful BBN capabilities were also demonstrated; first, was the ability of the BBN to "learn" from actual operating data and the second was the ability to operate in the presence of unknown data.
- The BBN was able to operate successfully outside of the original configuration range as a result of additional BBN training using data collected prior to and during the demonstration period (as opposed to simulated data created using the power load flow model). BBN performance outside of the original configuration range was less consistent. Additional modeling and statistical analysis is needed to configure and train the BBN to operate consistently across the full range of potential sub transmission system operation.

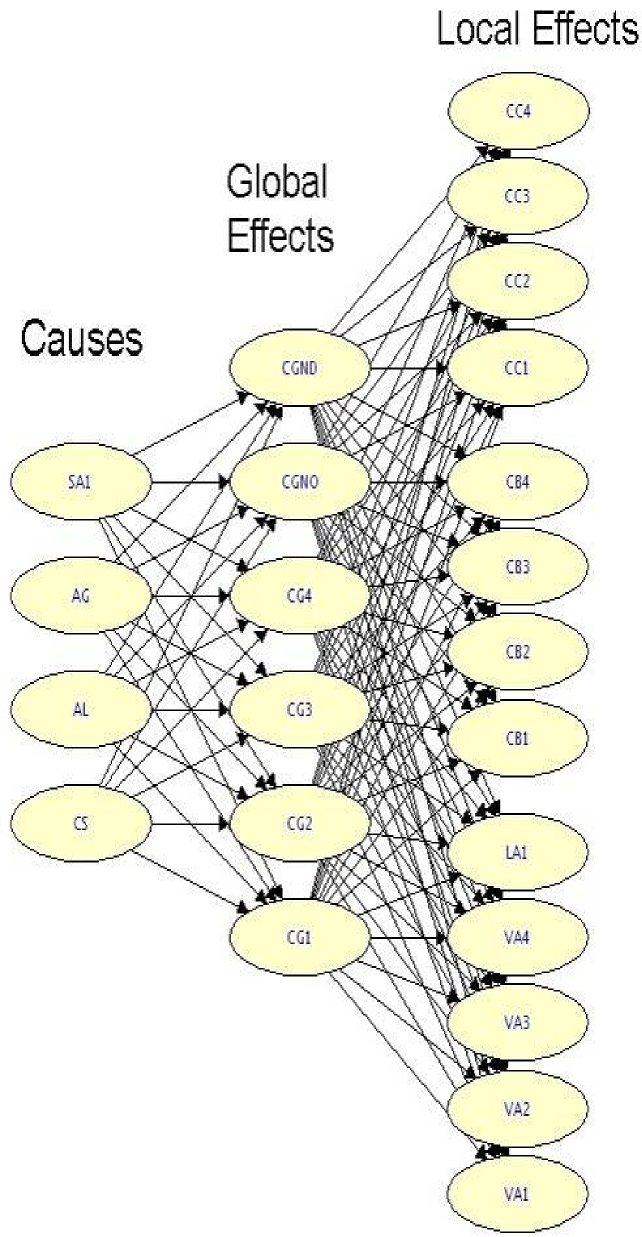

Figure 2 Example BBN -- STA Antelope

- The Beacon Power storage system operated under Storage GRA control continuously during the demonstration period (see Figures 3 and 4).
- The storage system operated in Frequency Regulation mode 97% of the time with just 3% of overall operation in Hybrid mode (frequency regulation with modified reactive power output at the request of the STAs).

Figure 3 Beacon Storage System Installation

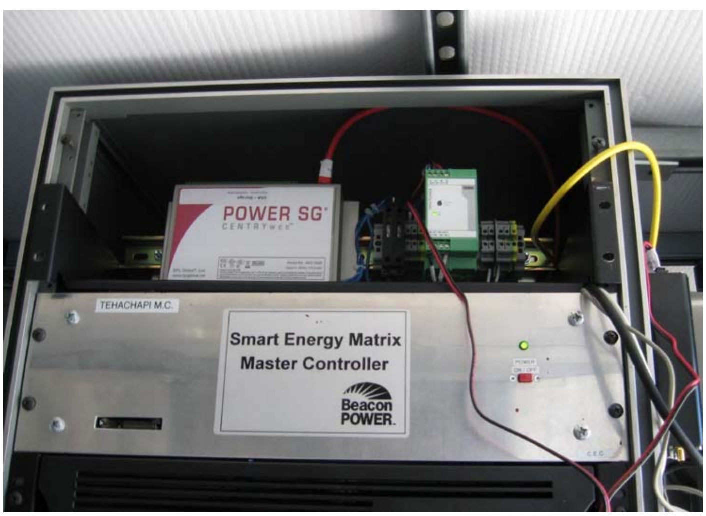

Figure 4 Storage System Controls

SUMMARY AND CONCLUSIONS

To summarize, this CEC funded project was highly successful. During the project, the project team successfully identified a significant opportunity to demonstrate the feasibility of the agent-based approach. The system that was subsequently configured and implemented performed well during the demonstration although it was constrained by the limits of the initial modeling and configuration effort.

The following additional effort is therefore recommended to more fully demonstrate the concept and prepare it for commercial application.

- Complete the effort to fully integrate the agent-based system into the SCE communication network to enhance system reliability. This would eliminate the need for cell modem based communication as well as the need for server-based SCADA data retrieval.
- Complete the effort to implement a true Peer-to-Peer communication capability to eliminate the need for centralized server-based communications.
- Enhance agent processing capabilities to include monitoring of sensor data quality to both establish a "normal" baseline for all inputs as well as identify and deal with bad or unknown sensor data.
- Implement automated BBN training to more readily accommodate changing area conditions.
- Review all communication protocols for compliance with recently enacted IEEE standards such as IEEE 61850 and IEEE 1613, which are applicable to substation based networks and communication devices.

REFERENCES

1. "Wind Power in Power Systems", T. Ackerman, page 258

AUTHOR BIOGRAPHY

Gerald L Gibson, P.E. is Vice President of Alternative Energy Systems Consulting, Incorporated. AESC works for utilities and private companies providing technical and management services in the areas of energy efficiency and application of intelligent energy systems. Mr. Gibson leads AESC R&D efforts involving the use of intelligent software agent technology for coordination of distributed energy resources including conventional generation, load curtailment, renewable generation and storage technologies. Mr. Gibson and AESC have been developing and demonstrating agent-based technology in the utility/energy industry on a variety of successful projects dating back to 1997. He has worked closely over the years with the California Energy Commission but has also been involved with DOE and EPRI sponsored projects. Most recently he completed a project involving the use of agent technology to assist with coordination of transmission, wind and storage assets in California's Tehachapi wind resource region.

Mr. Gibson is a member of ASME, IEEE and AEE and is a registered Professional Engineer in California. He has authored and presented numerous articles and reports on the application of advanced computing technologies to utility/energy applications.

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