Power Neighborhoods –
Agent-based Control of Distributed Energy Resources

As the move towards a "smarter grid" continues to unfold the role of distributed energy resources and specifically their integration with the Smart Grid is becoming increasingly important. Even before the Smart Grid movement, there was little question that Distributed Energy Resources (DER) such as conventional distributed generation, renewable generation and curtailable loads, when integrated properly with the electric grid, can provide both economic and societal benefits. Economic benefits in the form of reduced energy costs for end users that employ DER are well documented. Other Smart Grid related societal benefits that include achieving a more robust electric grid, less vulnerable to terrorist attack, are evident but more difficult to quantify. But it is safe to say that maintaining the historically high reliability of the U.S. power system is a fundamental requirement for the U.S. economy. Landis Kannberg of Pacific Northwest National Laboratory stated at a recent DOE workshop that seamless penetration of DER into the power system would result in "enhanced stability, security, crisis management" but would require "ubiquitous communications and information flow and advanced, transactive controls, prognostics and diagnostics at all levels…" *Intelligent software agents* can provide the ubiquitous communications and transactive controls referred to by Mr. Kannberg.

Alternative Energy Systems Consulting (AESC) with support from Colorado State's Center for Networked Distributed Energy (CNDE) completed a DOE Phase I Small Business Innovative Research (SBIR) project that successfully demonstrated the feasibility of using intelligent software agents to coordinate the actions of multiple sites in response to dynamic price signals. These same agents were also able to quickly reallocate DER resources in response to a simulated signal indicating the eminent loss of all or part of the grid supplied power. These actions were made possible through implementation of "**power neighborhoods**" where agents independently establish bilateral agreements for the transfer of capacity between sites.

The power neighborhood concept is essentially a means to achieve a coordinated response to a centralized command or pricing signal in a way that distributes the decision-making to the site level. The end result is a portfolio response where the individual site responses are tailored to the needs of the site. This is a dramatic departure from centralized approaches that concentrate the decision-making for all site actions at a central control. The distributed approach used in the power neighborhood concept can readily be expanded to include any number of sites without any change to the basic communication or computing infrastructure. Lacking a centralized control algorithm allows sites to enter or exit the system in a true "plug and play" fashion.

The Opportunity

AESC is interested in exploring how the power neighborhood concept can be utilized in a variety of applications. We believe that this concept is applicable to various Smart Grid related applications where intelligent local responses can be aggregated to achieve a more global response. These potential applications include but are not limited to:

- Demand response programs,
- Demand response or electric demand shaping in a campus setting,
- Allocation or equitable distribution of DER assets in a power park or micro-grid setting.

- Dispatch of distributed generation assets to mitigate transmission or distribution system congestion.

Additional information on the SBIR project and the demonstration software that was developed to illustrate the power neighborhood concept follows.

DOE SBIR Phase I Project Description

The overall objective of the recently completed DOE funded Small Business Innovative Research (SBIR) Phase I effort was to successfully demonstrate the feasibility of using intelligent software agents for DER level control to facilitate acceptance of this approach in the power industry. During the course of the project, Alternative Energy Systems Consulting, Inc. (AESC) and its principal subcontractor, the Center for Networked Distributed Energy (CNDE) at Colorado State University envisioned a multilevel agent hierarchy called the Distributed Intelligent Agents for Decision Making (DIADM) network.

Distributed Intelligent Agents for Decision Making (DIADM)

The DIADM agent hierarchy developed during the Phase I effort consists of five basic operating levels as depicted in Figure 1. The lowest level agent capable of decision-making, the building agent resides at the Site level while the agent representing the RTO / ISO is the highest level agent.

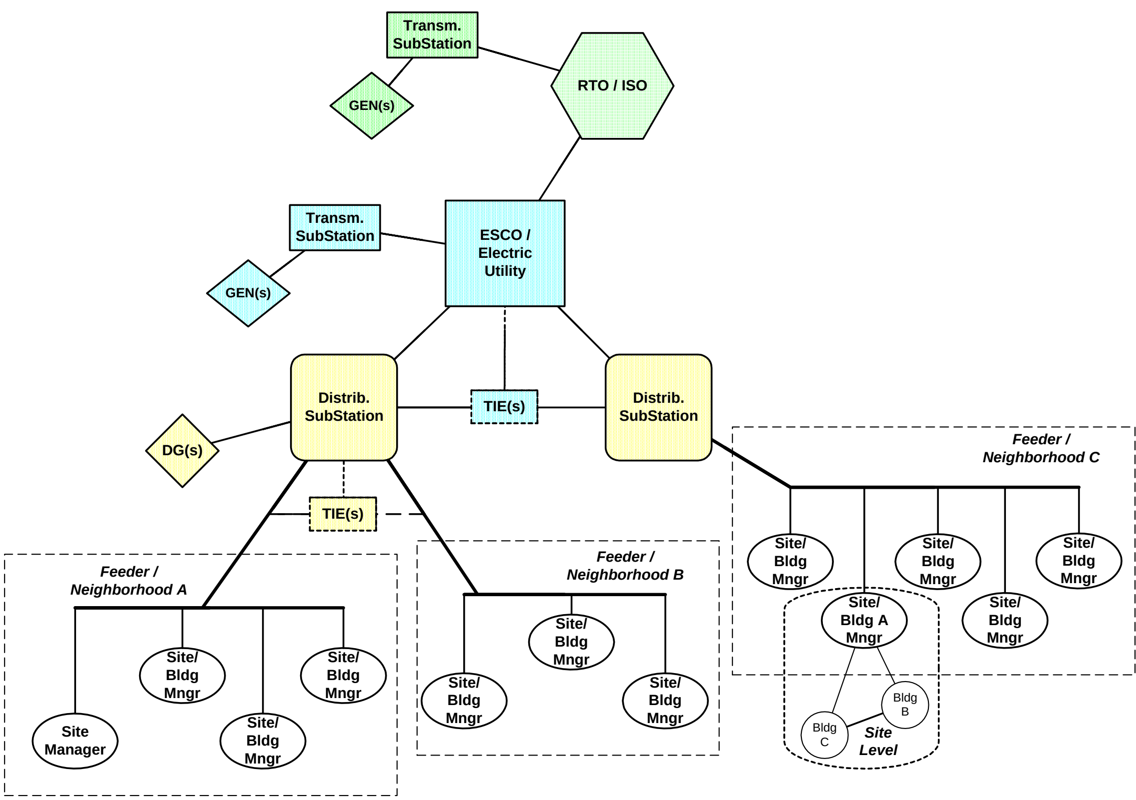


Figure 1 DIADM Hierarchy Connectivity

The lowest level in the hierarchy, the distribution substation level has been expanded to illustrate the "power neighborhood" concept in greater detail. The site level consists of one or more buildings each represented by a building agent. When multiple buildings are involved, a single building agent is designated as the "site manager" (SM) agent and this SM agent represents the interests of the site to external entities. Multiple sites located on a common distribution feeder become a "power neighborhood". Sites within a power neighborhood are able to buy and sell capacity to/from their neighbors and/or they may purchase capacity from the local ESP or another IPP. Multiple neighborhoods are connected to and governed by a distribution substation (DS) agent.

The DS agent manages an Internet-based auction board where neighborhood participants post auction sessions to buy and sell capacity. The DS agent represents the interests of the ESP and posts auction sessions for the sale of ESP power into the neighborhood. Any DG assets connected directly to the distribution system (not located at a site) capable of supplying power to the neighborhood are represented by their own agent and are able to access the auction board for any neighborhoods that are physically connected. Thus, the neighborhood auction process readily accommodates changing connectivity between adjacent feeders or neighborhoods. The DS agent monitors feeder connectivity and contracts or expands the auction board area so that affected neighborhoods may access additional or fewer auction sessions. Thus, this process may be used to facilitate adaptive islanding within the distribution system.

DIADM Demonstration Software Description

The DIADM software developed during Phase I is designed to demonstrate the agent-based "power neighborhood' concept of DER allocation at the distribution level. Site connectivity is depicted in Figure 2 below. The figure shows two neighborhoods or feeders connected to a single distribution substation. The feeders may be connected via a tie or breaker that separates them. Each feeder is populated with up to ten site level agents (only 6 are shown) that control on-site DER assets.

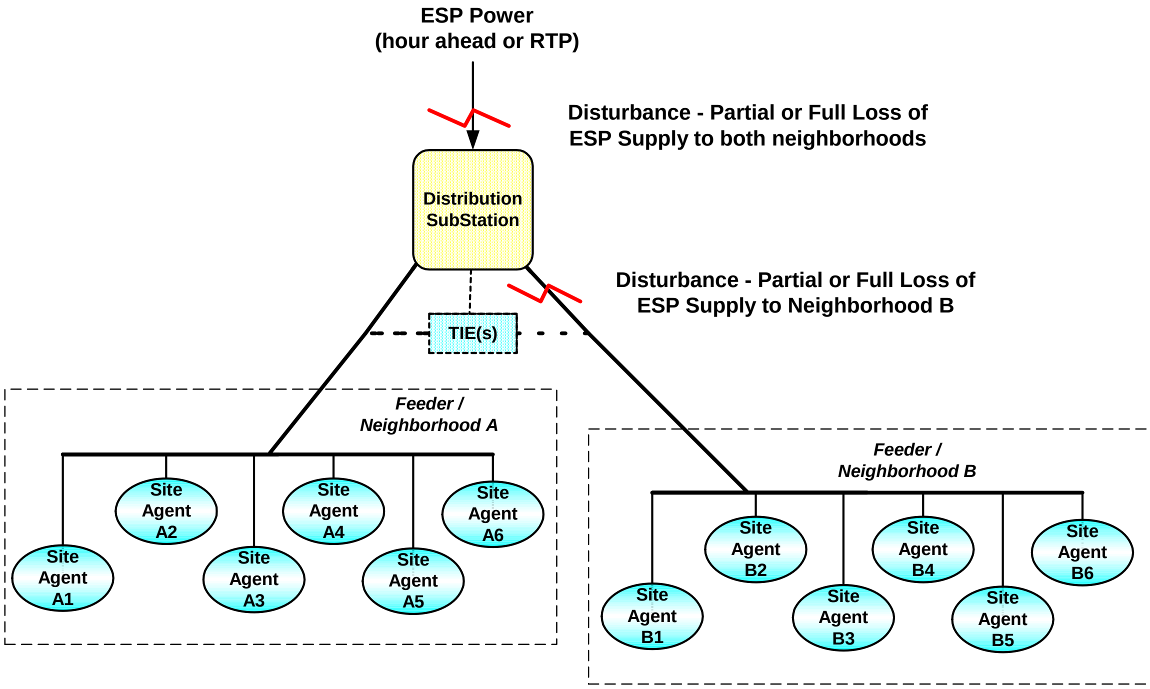


Figure 2: DIADM Simulation Neighborhood Configuration

The simulation software is designed to provide a two-part test sequence where the first part simulates resource allocation in response to an "hour-ahead" or real-time pricing environment. The second part of the test allows the user to specify one of four disturbances consisting of:

- 100% loss of Energy Service Provider (ESP) supply to one or both neighborhoods, and
- 50% loss of total ESP supply to one or both neighborhoods.

To demonstrate how agent and therefore neighborhood actions are dependent on a variety of factors the user may also select the:

- Hour of the day for the hour-ahead auction,
- DG capacity as a percentage of the site peak load for sites so equipped,
- Curtailable & critical load capacities as a percentage of site load for sites so equipped,
- Cost of natural gas ($/MMBtu) & ESCO/ESP supplied power, and
- Status of the breaker that connects the two neighborhoods.

Once the agent, site and disturbance characteristics have been initialized the user may then initiate the test sequence. The resulting agent actions (i.e., auction sessions, bilateral transactions, etc.) can be viewed along with summaries of the test setup and results via the DS agent user interface.

Demonstration Test Description and Results

It should be apparent that there are a significant number of user inputs (agent/neighborhood setup, simulation setup etc.) that can be varied in order to observe agent actions under a wide variety of test scenarios. A representative scenario was selected for demonstration purposes. The neighborhood configurations (site loads, availability of DER assets, etc.) are shown in Figure 3. Both neighborhoods contain a mixture of large commercial sites both with and without DG, curtailable and critical loads. The simulation inputs consisted of a DG fuel price of $6.00 per MMBtu, an ESP price of $0.1120 / kWh, and

Distributed Intelligent Agent for Decision Making (DIADM) at Local DER Levels
DOE Grant DE-FG02-03ER83604

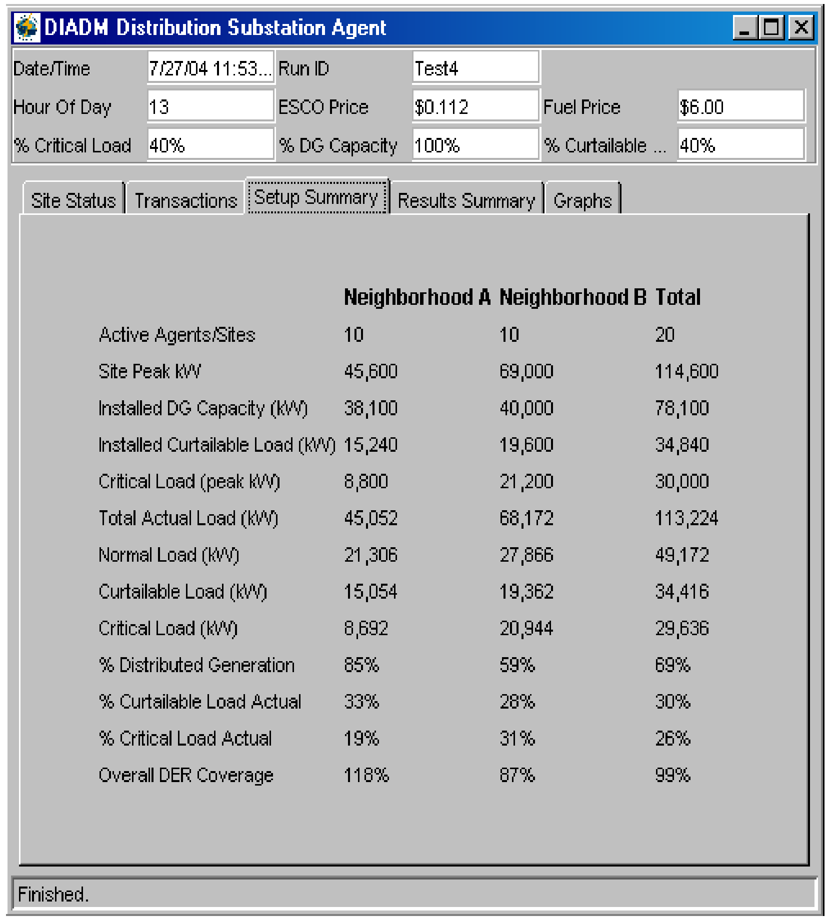
Neighborhood A						
Agent Name	Active	Size	DG	Curtailable Load	Critical Load	Load Type
A1	TRUE	7,000	TRUE	TRUE	FALSE	Large Commercial
A2	TRUE	7,600	TRUE	TRUE	FALSE	Large Commercial
A3	TRUE	6,500	TRUE	TRUE	TRUE	Large Commercial
A4	TRUE	4,500	TRUE	TRUE	TRUE	Large Commercial
A5	TRUE	3,500	TRUE	TRUE	TRUE	Large Commercial
A6	TRUE	2,000	FALSE	FALSE	FALSE	Large Commercial
A7	TRUE	2,000	FALSE	FALSE	FALSE	Large Commercial
A8	TRUE	4,000	TRUE	TRUE	TRUE	Large Commercial
A9	TRUE	5,000	TRUE	TRUE	FALSE	Large Commercial
A10	TRUE	3,500	FALSE	FALSE	TRUE	Large Commercial

Neighborhood B						
Agent Name	Active	Size	DG	Curtailable Load	Critical Load	Load Type
B1	TRUE	9,000	TRUE	TRUE	TRUE	Large Commercial
B2	TRUE	10,000	FALSE	TRUE	TRUE	Large Commercial
B3	TRUE	8,000	TRUE	TRUE	FALSE	Large Commercial
B4	TRUE	5,000	TRUE	FALSE	TRUE	Large Commercial
B5	TRUE	5,000	FALSE	FALSE	TRUE	Large Commercial
B6	TRUE	4,000	FALSE	TRUE	TRUE	Large Commercial
B7	TRUE	5,000	FALSE	FALSE	TRUE	Large Commercial
B8	TRUE	5,000	FALSE	FALSE	TRUE	Large Commercial
B9	TRUE	8,000	TRUE	TRUE	FALSE	Large Commercial
B10	TRUE	10,000	TRUE	TRUE	TRUE	Large Commercial

Figure 3: Neighborhood Configuration Summary

a disturbance corresponding to the total loss of ESP supply to Neighborhood B. The critical and curtailable load levels were both set for 40%, the DG capacity was set for 100% and the time of day was 1300 hours. The resulting loads and DER asset levels are summarized in the DS agent setup summary screen shown in Figure 4.

As the setup summary shows, both neighborhoods have ten sites/agents. The total load for both neighborhoods at the time of the test, 1300 hours, was 113,224 kW. The total DER and DG percentage coverage values for each neighborhood and for the combined neighborhoods are of particular interest. Neighborhood A has an overall DER coverage in excess of 100% indicating that a it could accommodate a total loss of grid supplied power if the neighborhood agents can reallocate the DER assets amongst the various sites. Neighborhood B with a DER coverage value of 87% cannot support a total loss of grid supplied power without help from its neighbor. Note that these values will vary based on the time of day since site load and therefore the amount of excess DG capacity will vary.



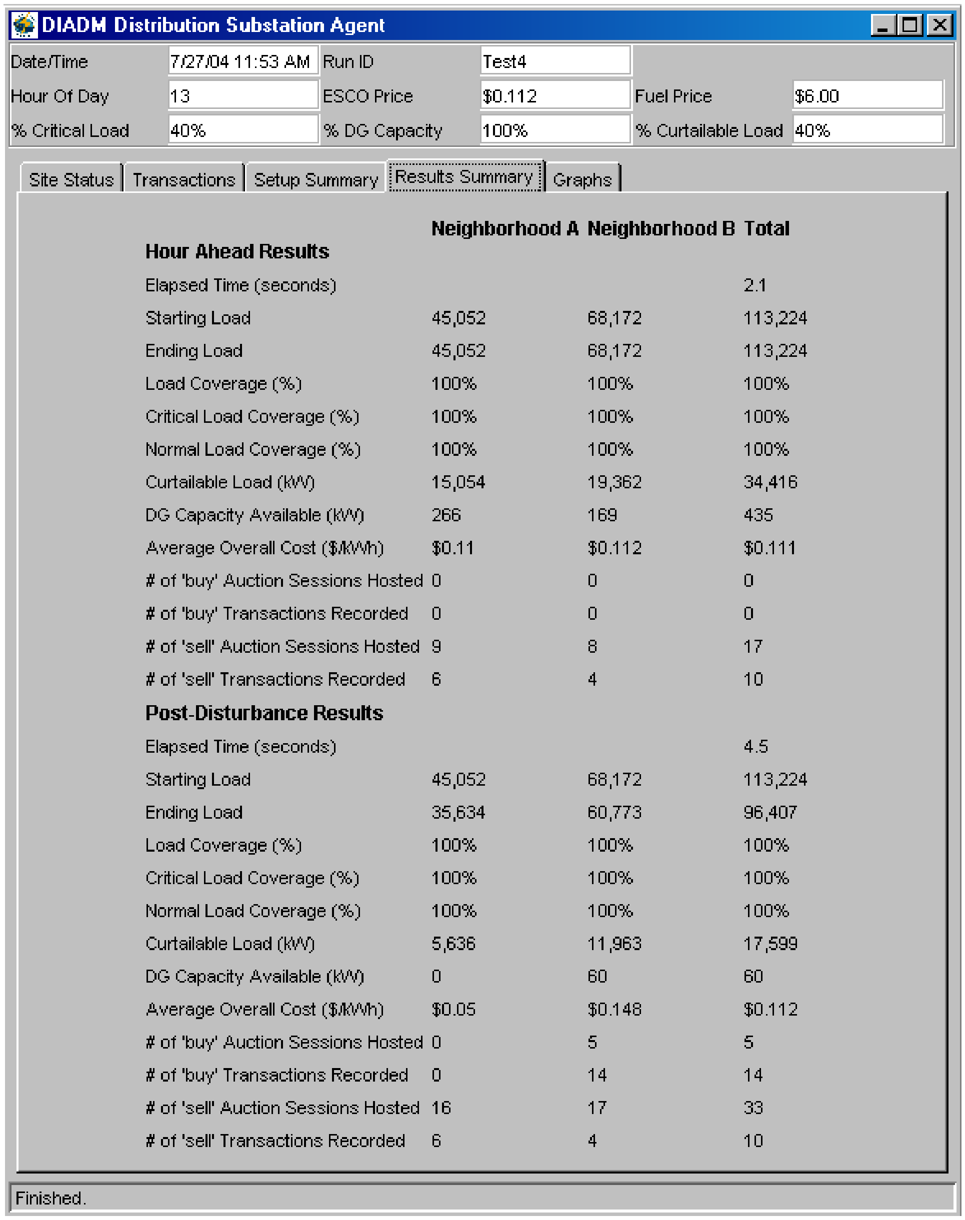
	Neighborhood A	Neighborhood B	Total
Active Agents/Sites	10	10	20
Site Peak kW	45,600	69,000	114,600
Installed DG Capacity (kW)	38,100	40,000	78,100
Installed Curtailable Load (kW)	15,240	19,600	34,840
Critical Load (peak kW)	8,800	21,200	30,000
Total Actual Load (kW)	45,052	68,172	113,224
Normal Load (kW)	21,306	27,866	49,172
Curtailable Load (kW)	15,054	19,362	34,416
Critical Load (kW)	8,692	20,944	29,636
% Distributed Generation	85%	59%	69%
% Curtailable Load Actual	33%	28%	30%
% Critical Load Actual	19%	31%	26%
Overall DER Coverage	118%	87%	99%

Figure 4: Neighborhood Setup Summary

Test Results

As noted previously the demonstration software test sequence is divided into two parts. The first part, or Hour Ahead auction portion, consists of agent actions in response to the site load and the prevailing electricity and fuel prices. The second part, or Post Disturbance portion, is the agent response to the disturbance signal, in this case a signal indicating that Neighborhood B will lose 100% of grid supplied power. The test results are summarized in the DS agent interface screens shown in Figures 5 and 6 below.

Figures show that the agents were able to complete transactions covering all of their load in hour-ahead auction portion of the test in approximately 2 seconds using a total of 17 individual site auction sessions for the sale of capacity. No sessions for the purchase of capacity (“buy” auctions) were used. At the end of the hour-ahead auction sequence only 435 kW of the initial 78,100 kW of installed DG capacity remained. The post disturbance response, involving the loss of all grid supplied power to Neighborhood B shows rapid load curtailment in both neighborhoods. In this case a combination of buy and sell auctions is utilized by the agents to reallocate the DER assets in less than 5 seconds. To accomplish this, Neighborhood A sells the excess DG capacity that remained after the completion of the hour-ahead auction and also curtails load to create excess capacity that is then sold to sites in Neighborhood B.



DIADM Distribution Substation Agent

Date/Time	7/27/04 11:53 AM	Run ID	Test4		
Hour Of Day	13	ESCO Price	$0.112	Fuel Price	$6.00
% Critical Load	40%	% DG Capacity	100%	% Curtailable Load	40%

Site Status | Transactions | Setup Summary | Results Summary | Graphs

	Neighborhood A	Neighborhood B	Total
Hour Ahead Results			
Elapsed Time (seconds)			2.1
Starting Load	45,052	68,172	113,224
Ending Load	45,052	68,172	113,224
Load Coverage (%)	100%	100%	100%
Critical Load Coverage (%)	100%	100%	100%
Normal Load Coverage (%)	100%	100%	100%
Curtailable Load (kW)	15,054	19,362	34,416
DG Capacity Available (kW)	266	169	435
Average Overall Cost ($/kWh)	$0.11	$0.112	$0.111
# of 'buy' Auction Sessions Hosted	0	0	0
# of 'buy' Transactions Recorded	0	0	0
# of 'sell' Auction Sessions Hosted	9	8	17
# of 'sell' Transactions Recorded	6	4	10
Post-Disturbance Results			
Elapsed Time (seconds)			4.5
Starting Load	45,052	68,172	113,224
Ending Load	35,634	60,773	96,407
Load Coverage (%)	100%	100%	100%
Critical Load Coverage (%)	100%	100%	100%
Normal Load Coverage (%)	100%	100%	100%
Curtailable Load (kW)	5,636	11,963	17,599
DG Capacity Available (kW)	0	60	60
Average Overall Cost ($/kWh)	$0.05	$0.148	$0.112
# of 'buy' Auction Sessions Hosted	0	5	5
# of 'buy' Transactions Recorded	0	14	14
# of 'sell' Auction Sessions Hosted	16	17	33
# of 'sell' Transactions Recorded	6	4	10

Finished.

Figure 5: Tabulated Auction Results -- 1 p.m. Test Case

Neighborhood B site agents curtail load to satisfy their own needs and also sell excess curtailment to other site agents within the neighborhood. Note that the agents in the affected neighborhood, Neighborhood B, use both buy and sell auctions while the unaffected neighborhood agents in Neighborhood A, use sell auctions exclusively. The overall price paid for power in each neighborhood, which begins the post disturbance portion nearly equal is markedly different following the disturbance response. Neighborhood A is able to reduce the overall cost of its power through the sale of capacity created via curtailment while Neighborhood B is able to cover its load with help from its neighbors, but at a higher cost.

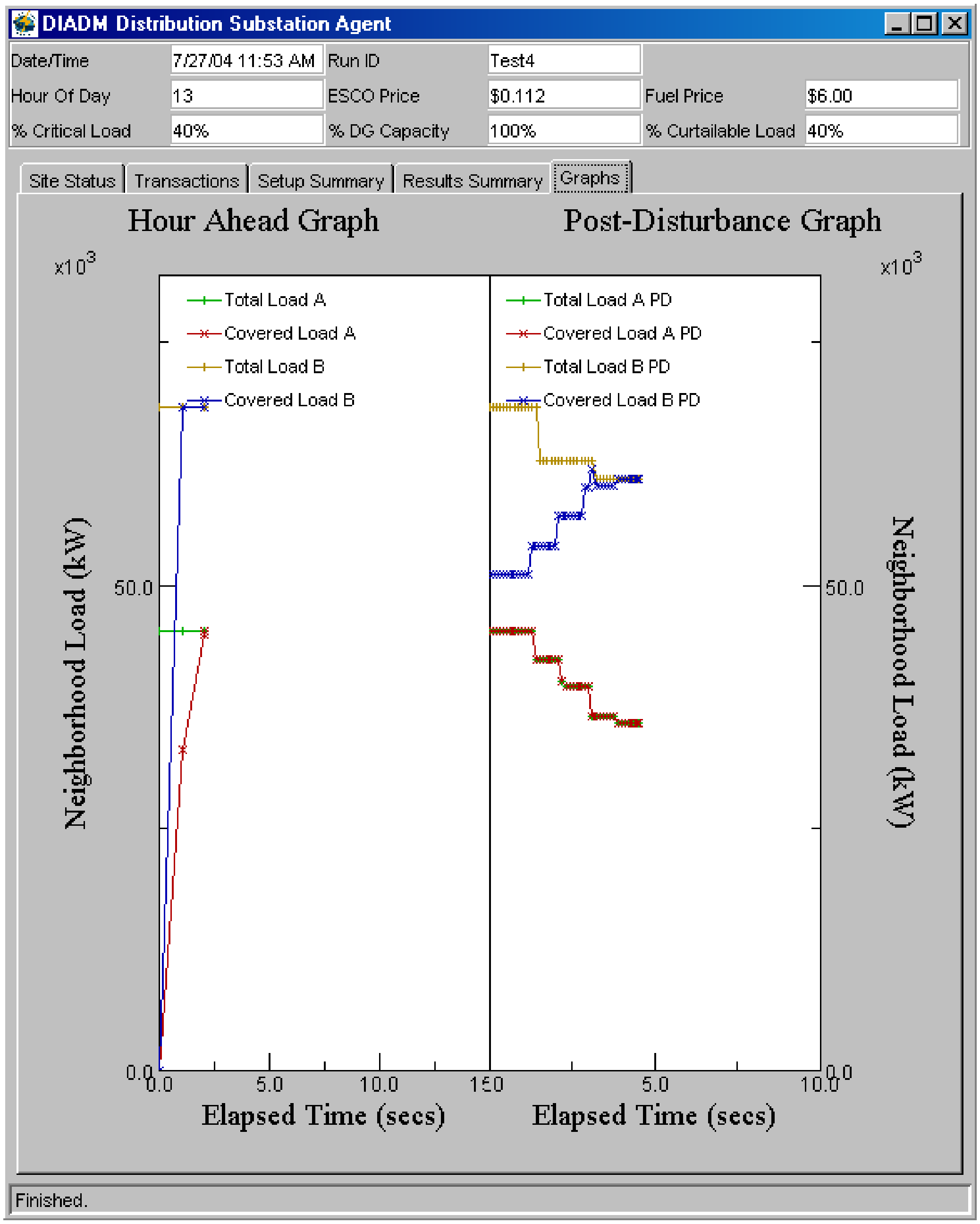


Figure 6 Graphical Test Results – 1 p.m. Test Case

Significance of Results

The sample test results described above are typical of the agent responses/actions that were observed during the SBIR project. The test results clearly show that agents operating without a central authority can independently develop bilateral transactions via an auction based process. Agents via the auction based power neighborhoods were able to allocate existing DER assets in both a routine hour-ahead market and in response to an impending disturbance.

Please contact AESC to schedule a demonstration of the power neighborhood demo software or for additional information on applying our power neighborhood technology to your application.

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