THE MANAGEMENT AND CONTROL OF DISTRIBUTED ENERGY RESOURCES

Terry E. JONES† and Geoffrey C. JAMES‡
† CSIRO Energy Transformed Flagship - Australia
‡ CSIRO Information and Communications Technology Centre - Australia
Terry.Jones@csiro.au and Geoff.James@csiro.au

INTRODUCTION

This paper proposes applying distributed agent technology to network control, outlines an implementation, and shows progress towards deployment in the Australian National Electricity Market. The aims are deployment of efficient, clean, distributed generation technology below 5 MW and improved control of load and demand side management options below 11 kV in the electricity network. This work will address the despatch of distributed assets, bringing potential solutions to the volatility of wholesale pool prices and an alternative way of dealing with network constraints during summer and winter peaks. It is the subject of a Flagship research program by the CSIRO, Australia’s largest research and development agency [1].

The idea of placing small generators close to load centres, or switching loads on/off to respond to price signals and network constraints is technically achievable and becoming more economically viable for businesses requiring greater supply reliability, flexibility and lower cost. Key issues are:

- Providing hardware and software for a low-cost connectivity platform for assets below 11 kV where traditional network control becomes uneconomic.
- Developing the distributed intelligence required to aggregate local responses to address the current problems of consumers and utilities.

Communications hardware based on commodity items and software based on distributed agent technology will provide the necessary connectivity and intelligence. The challenge is to aggregate and control the emergent behaviour of groups of DE assets, taking cognisance of the requirements from retailers and network businesses but also allowing the consumer to have control and choice in the way that his energy supply is handled. Agent-to-agent communication allows demand management to be coordinated across a large number of consumers, who can choose at any time to participate in aggregated demand responses to price signals and network constraints.

DISTRIBUTED INTELLIGENT AGENTS

Benefits of intelligent local control

Networked local intelligent controllers provide an economical alternative to extending SCADA to consumers below 11 kV. Availability of capable yet affordable consumer type devices allows local control of consumer loads and generators. Local controller and software becomes an “agent” when it includes decision making. The agent principle is to keep data, decision making, and control local as far as possible, allowing local autonomy in case of grid or communications failure, and giving priority to consumer interests. This is favourable to the uptake of the technology by a wide range of consumers who may not wish to submit their devices to direct control by other parties.

An agent can provide local efficiency but also interact with other agents for system-wide benefits. For example, groups
of intelligent agents can create aggregated supply and demand that has high value at times of peak demand. Aggregation also facilitates the formation of intelligent islands or mini grids that can be isolated from the grid and continue to provide services. Thus local autonomy gives greater flexibility to respond to grid contingencies.

Several business opportunities are enabled by an agent infrastructure: for example, aggregated supply and demand can be used by retailers to manage their exposure to wholesale electricity prices, or by network businesses to defer capital expenditure, and an agent network provides an affordable “last-mile” solution for SCADA companies. The first widespread deployment is likely to be in partnership with businesses of this kind and would offer a reward system to encourage consumers to participate in acts of aggregation that have network-wide benefits.

Agent-based software platform

It is a challenge to create a system of agents that can be deployed across a number of hardware platforms over a wide geographical area. The open-source Java Agent Development Environment (JADE) [2] is being used as a software toolkit to develop an industry-ready platform for distributed energy management. To effect both local and system benefits a three-level agent network is being developed.

- Resource agents are responsible for devices: loads or generators. The resource agents within a business cooperate to achieve local efficiency and to offer demand reduction or surplus supply where economically attractive.

- Customer agents represent points of business accountability: small-to-medium enterprises, hospitals or campuses, shopping malls, groups of domestic consumers, or individual households, according to need. A customer agent provides an interface for the business owner or manager to express policy, mediates with resource agents within the business, and interacts with customer agents in other business to aggregate large quantities of supply and demand.

- Broker agents assist with aggregation and present the resulting quantities of energy for use by market participants. Multiple brokers may be involved in assembling megawatt quantities of energy from a large number of kilowatt consumers, in order to achieve a timely and reliable response.

The agent software platform is being written jointly with Infotility Inc., whose real-time energy information platform enables subscription and publishing of highly relevant information when and where it is needed most. The architecture supports both server-based analytic applications and distributed intelligence which allows automatic business rule processing, on-the-fly analytics, data integration, and control at distributed end points [3].

HARDWARE DEMONSTRATION

Agent infrastructure

To provide a test environment for software and algorithms a selection of loads and generators are instrumented for agent control at the Energy Centre in Newcastle, Australia. The interacting set of agents will form a mini grid, coordinating demand and supply and reacting intelligently to NEM price signals, which can be showcased to attract further investment in the technology. Expanded demonstrations are under discussion with industry sponsors.

Three kinds of agent device are used in present demonstration, and all are either consumer-type devices or are headed that way, rather than specialist engineering hardware. This is to show that widespread deployment of agent technology below 11 kV is feasible now. The aim of the project is to produce software and algorithms to support such deployment on a range of hardware as appropriate to the circumstance; no particular hardware device is endorsed as a focus for future development. The devices used are described in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1 – Agent devices used in the present demonstration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device</strong></td>
</tr>
<tr>
<td>Motes and Flecks</td>
</tr>
<tr>
<td>Personal digital assistants (PDAs)</td>
</tr>
<tr>
<td>GPRS access points</td>
</tr>
</tbody>
</table>

Loads and Generators

Heating and cooling loads are the greatest users of power at the level of domestic and small-to-medium enterprise consumers. Two cool rooms and one zone of a heating, ventilation, and air conditioning (HVAC) system are under agent control. There are additional mote agents to provide information to support decision making. Three kinds of distributed generation are also being put under agent control: a gas micro-turbine, three photovoltaic arrays, and a wind generator. Table 2 shows the input data and output controls available to each agent.

In addition to these resource agents, there are information
agents that provide predictions of weather conditions and wholesale electricity price to assist intelligent decision making. For example, predicted temperature determines heating/cooling requirements, predicted solar intensity and wind speed determine generating capacity, and electricity price determines the economic value of local generation and load shifting or curtailment. Load power constraints can be calculated from estimated heating and cooling requirements for some period into the future. A simple but extensible model for a heating/cooling load has been adopted [4] and is being developed into a constraint calculator.

**TABLE 2 – Agents’ input data and output controls**

<table>
<thead>
<tr>
<th>Agent</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool room #1</td>
<td>Interior air temperature Door open/closed</td>
<td>Switching compressor and fan</td>
</tr>
<tr>
<td>Cool room #2</td>
<td>Interior air temperature Door open/closed Product name and temperature</td>
<td>Switching compressor and fan</td>
</tr>
<tr>
<td></td>
<td>(Several products have attached mote agents for monitoring and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>intelligent control)</td>
<td></td>
</tr>
<tr>
<td>HVAC</td>
<td>Room temperature (There is a mote agent in each room in the HVAC zone)</td>
<td>Adjusting set points for zone</td>
</tr>
<tr>
<td></td>
<td>Room occupancy (Using a motion sensor with X10 power-line</td>
<td></td>
</tr>
<tr>
<td></td>
<td>communications) Hot/cold preference of occupants (Wall-mounted button to</td>
<td></td>
</tr>
<tr>
<td>Micro-turbine</td>
<td>Power output delivered Turbine RPM Turbine status</td>
<td>Requesting a power output</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>Power output after A/C inverter Solar intensity (Always connected)</td>
<td></td>
</tr>
<tr>
<td>Wind generator</td>
<td>Power output delivered Turbine RPM Turbine status Wind speed</td>
<td>Stowing/unstowing</td>
</tr>
</tbody>
</table>

**AGGREGATION OF RESPONSE**

**Aggregating supply and demand**

Resource agents responsible for individual loads and generators in a business should aggregate to provide a combined response for the business. What comprises a business may be interpreted broadly: a small-to-medium enterprise, a building, a campus, a hospital, a group of houses, or a single house would all be suitable units for presenting a combined response. Algorithms for this level of aggregation need not be highly scalable and can presume agents with common goals, so that benefit to the group takes priority over benefit to the individual. The joint task that load and generator agents should achieve is minimising the total cost of operation while providing, when required, a reduced demand or increased supply for a given period. Any change in demand or supply will have a market-dependent monetary value and so becomes another ingredient in the cost minimisation.

A customer agent participates in this system to set policy, and interacts with customer agents of other businesses. The customer agent also provides the primary user interface for the business owner to view system functions and to express his or her preferences. The interplay between user control and agent automation will be an important factor in the successful uptake of this technology, and will be investigated carefully during trial deployments.

Customer agents should form appropriate groupings to provide aggregated supply and demand of megawatt quantities for strategic use by market participants. Algorithms for this level of aggregation must be highly scalable, to 100,000 agents and more, and cannot presume common goals in the sense above. This does not preclude cooperative algorithms, however, and a range of strategies for distributed optimisation are available – some of which promise improved performance over centralised algorithms due to the intrinsic parallelism of multi-agent systems [5]. Customer agents interact with each other and also with broker agents to interface to the market, to market participants such as retailers and network businesses, or to dynamic groups of customer agents, as necessary to achieve timely and firm aggregation.

Fig. 1 illustrates these two layers of aggregation. The focus for demonstrations in 2005 is aggregation among load and generator resources within a business, providing a combined response for the business’s customer agent. This is a distributed optimisation problem: minimising the overall cost to the business while satisfying the operating constraints of all available resources and, when required, making an additional quantity of power available for trading through a broker. Groups of loads and generators can be optimised using, for example, genetic algorithms [6]. A faster optimisation algorithm is being developed that is capable of producing fresh solutions in real-time according to changing price signals, generating capacity, and load constraints. An additional challenge is distributing the optimisation across a set of participating resource agents.

**Simulation**

A simulation environment is being developed to allow algorithm development to proceed independently of the agent software platform. It includes the loads and generators described in Table 2 above and, to provide input to the optimisation, it simulates the predicted and actual behaviour of important parameters that determine operating constraints: temperature, solar radiation intensity, wind speed, gas price, and electricity price. The algorithms being developed with the help of this simulator aim to calculate optimal power consumption and production strategies for each load and generator during a specified future time interval. The user interface to the simulator is shown on Fig. 2.
ACKNOWLEDGEMENTS

The authors are managing this multi-disciplinary project and are indebted to the project team: Vadim Gerasimov, Ying Guo, Jiaming Li, Jun Ma, Doug Palmer, Glenn Platt, Hailun Tan, Ken Taylor, John Ward, and Sam West.

REFERENCES

[3] Contact David Cohen (dave@infotility.com) and see http://www.infotility.com.

Figure 1: Two layers of aggregation of supply and demand. Although only one broker agent is indicated, there may be a wide choice to support different market participants and aggregation of different kinds of customer or resource.

Figure 2: Screen shot of the simulator showing six agents and their power profiles, load or supply, over a 24-hour period. The present time is at the centre of each graph; to the left of the centre is the observed behaviour of the load or generator and to the right appears the desired future behaviour.