IBM Research GmbH

Saeumerstrasse 4
CH - 8803 Rüschlikon
Switzerland

Subject: Adding Gridwise description to Section 2.2 of Ecogrid Deliverable D1.2b

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Authors: Olle Sundström, Dieter Gantenbein, Carl Binding

1. Background

See email conversations on below dates:

- 15/11/2011 Agreement on contributing information on GridWise projects to section 2.2 in D1.2b.
- 19/10/2011 Request to deliver to sections 2.2, 3.1, and 5.2 for D1.2b

2. **Previous experience with real-time markets:** Pacific Northwest GridWise Testbed Demonstration Projects (PNW-GWTDP) and Pacific Northwest Smart Grid Demonstration Project (PNW-SGDP)

This section explains the techical details and the experiences gained in the the completed PNW-GWTDP (2005-2007) and the ongoing PNW-SGDP (2010-2014). The full description of the two projects can be found in the *EcoGridEU D1.1 report*.

2.1 Projects Description and Objectives

The two projects of interest in the initial PNW-GWTDP are the Grid-Friendly Appliances (GFA) project [4] and the Olympic Peninsula (OP) project [3]. The objective in the GFA project was to demonstrate a set of tools that are suitable for the upcoming smart grid. The GFA project applied grid frequency controlled appliances to shed load in the system. More relevant though is the OP project where a price-based control scheme was implemented to investigate how distributed resources perform when responding to near real time requirements of the grid. The objective of the OP project was also to show a communication framework for such a price-based approach. Finally, the economic impact and the incentive structure to get customer participation that is needed were also investigated. The grid-friendly devices in the GFA project included 150 new residential clothes dryers and 50 retrofitted residential water heaters. The price responding devices in the OP project included 40 high pressure water pumps with a total peak load of 150 kW, two distributed diesel generators with a peak power of 175 respectively 600 kW, and 112 homes equipped with a smart home gateway accounting for approximately 75 kW of controllable appliances.

The PNW-SGDP is an ongoing five year demonstration project launched in 2010. The project includes 60’000 metered customers in five US states. The goal is to demonstrate large scale participation of distributed energy resources in the emerging smart grid. The concepts developed in the OP project will be further developed and enhanced to accommodate this scale up. Essentially, the aim is to develop standards and communication protocols that can facilitate large integration of wind and other renewable energy sources in the grid. An important topic is to quantify the costs and benefits of the approaches taken.

2.2 Concepts

This section outlines the details of the GFA, OP and PNW-SGD projects. For EcoGridEU the concepts developed in the OP project and more importantly the concepts that are later on enhanced in the PNW-SGDP are the most relevant. Therefore, the focus of this section is on those parts. A short overview of the GFA concept is described for completeness.

Automatic frequency response

The GFA project uses the grid frequency as a control signal to power on/off the controlled devices. In the project, water heaters and clothes dryers were used as manageable loads. In the case of the dryers, only the heating sub-system was controlled; the electrical motor was unaffected. In the GFA a low pass filter tracks the (slower) frequency changes; high-frequency noise is discarded. When the reported frequency drops below 59.95 Hz, the relay output signal is activated. A timer is started when the frequency recovers to 59.96 Hz or above. The timer provides some hysteresis to the set-up. It is re-armed whenever the frequency falls below the critical value and set to, at least, 16 seconds.

The cost of the controller is reported to approximate 44 US$ and must be built into the controlled appliances. Data communication via wireless in-house communication channels towards a DSL router/modem has been used to collect data from the controller. Note that in the case of the GFA project, control is local and frequency based.

Price-based control

In the OP project [3], a 5 minute shadow market was created. In this market each distributed energy resource places a bid for electricity. This bid is based on the historic average price over the past 24 hours and the standard deviation of this price. The creation of the bids was automated and the end consumers could only specify a desired set-point. The end consumer could for example specify comfort or economy for the house heating system, where comfort represents a consistent temperature and economy represents a larger variation and thus more controllability. For house heating a temperature set-point is specified and together with the current observed temperature, and the temperature limit, which is not to be exceeded, the bidding price is automatically computed. This bid price is posted to the market where it may be cleared at price level, i.e. the bid is accepted and the thermostat's set temperature is then adjusted to the value.

Hierarchical Transactive Control

In the PNW-SGDP the concepts used in the OP project are being enhanced. For the PNW-SGDP it is important to include multiple objectives in optimizing of the usage of the grid. The project proposes a hierarchical transactive control that provides a flexible method for combining multiple objectives and constraints, such as local congestion, operational objectives, and economic objectives. Hierarchical transactive control is based on a two-way communication that uses two types of signals. For the downstream (toward demand) communication a value signal is used. This signal can be a price signal, but it does not have to be the price that is used for billing purposes. Thus, any type of incentive signal is also considered. For the upstream communication (toward generation) a demand signal from the demand to the generation is used.

The hierarchical transactive control is also based on a hierarchy of simple transactive control nodes. These nodes essentially distribute value signals and aggregate demand signals while including local node-related objectives. Such objectives can be: avoiding transmission grid congestion, incentivize the use of renewable energy such as wind power, reducing peak-load, reducing phase imbalance on a transformer, avoiding distribution grid congestion and line overload. The basic functional block diagram of a transactive control node is shown in Figure 1.

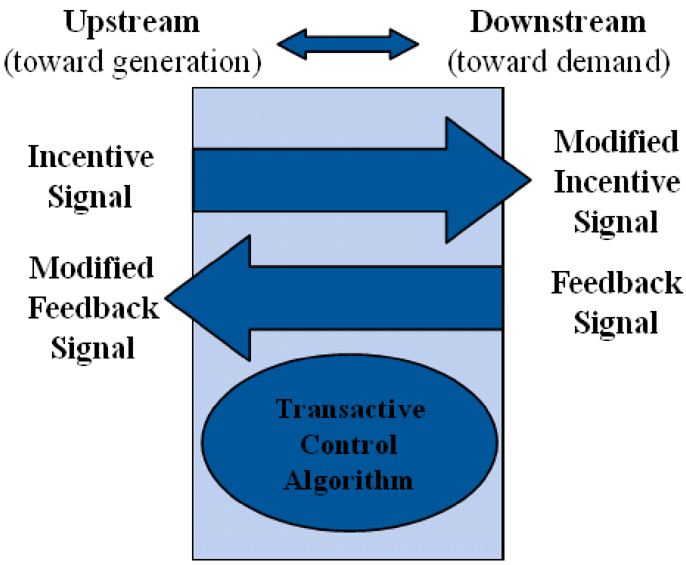

Figure 1. Simplified functional block diagram of a transactive node. [1]

Because the project is ongoing at the time of this report the details behind the transactive control algorithm shown in Figure 1 are not available. However, specifications of the signals have been defined and both the value signal and the demand signal are forecasts, typically over several days. This is one of the changes made from the preceding OP project. The resolution of these signals can be higher for periods closer in time than periods far in the future. The concept of forecasted value and demand signals is shown in Figure 2.

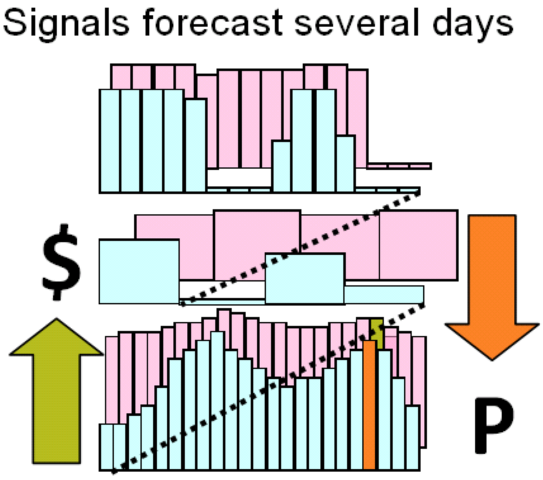

Figure 2. Forecasted value/incentive ($) signal and demand signal (P) at a node.

The assets at the bottom of the hierarchy use the value signal to make decisions about the future consumption. These assets can be distributed energy resources that respond to value signals by changing their current demand and the current demand signal forecast.

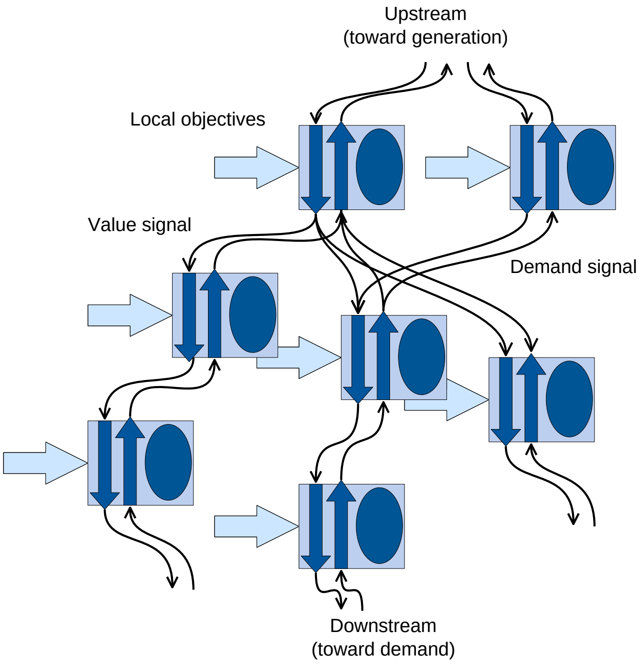

Figure 3. Example hierarchy of transactive control nodes. A node can have multiple parents because at the higher voltage levels the grid is usually not radial.

The transactive control hierarchy does not necessarily have to be a tree in graph theoretic terms. It is important to note that at the higher voltage levels the electricity grid is in general a mesh and that the hierarchical transactive control must be able to reflect this. Figure 3 shows an example of such a hierarchy where a single transactive control node can have multiple parent nodes and multiple children nodes.

Essentially, the hierarchy is being mapped onto the existing physical network, i.e. the electricity grid. Figure 4 shows a generalized mapping between the information network, e.g. the transactive control hierarchy, and the electricity grid.

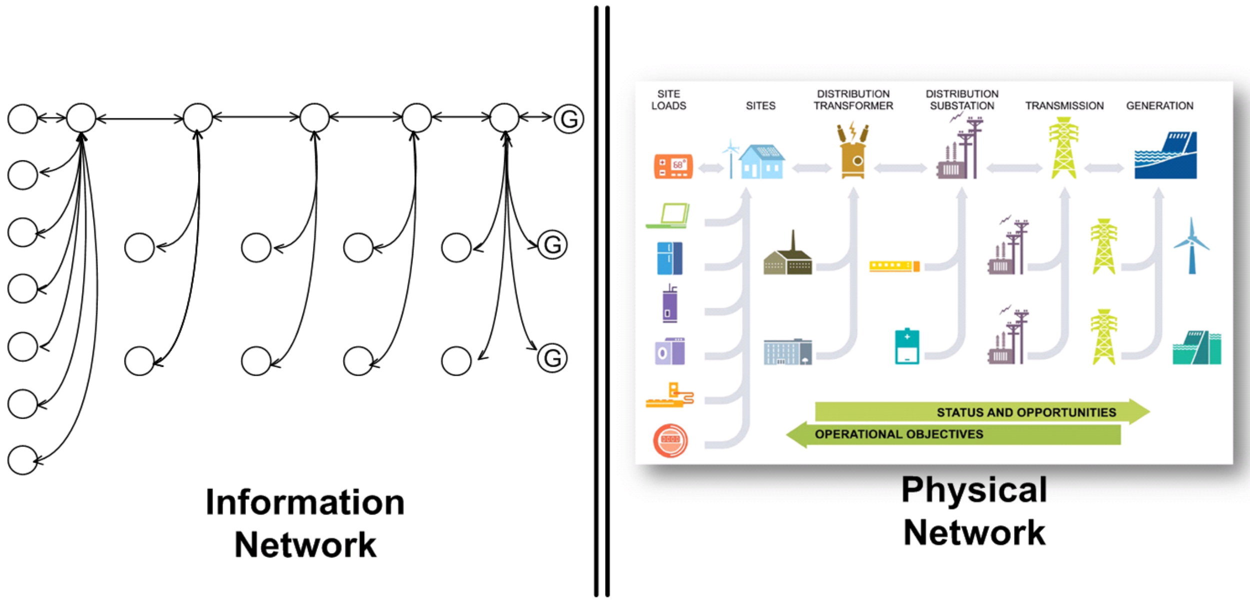

Figure 4. An examplified mapping between the physical network with grid entities and the information network with transactive control nodes.

2.3 Previous Experiences

Because the PNW-SGDP is ongoing the previous experiences are only focused on the PNW-GWTDP and in particular on the OP project. However, during the project duration it is important to learn from the experiences from the PNW-SGDP as they are acquired.

The experiences from the OP project can be summarized in the following list:

- Shadow market: the creation of the shadow market where each customer received an account which was filled in the beginning of each month and later depending on the price responsivity spent or earned money. This was a creative concept that allowed the project to avoid rigorous regulation frameworks for billing and settlements.
- One of the conclusions of the project was that the consistent response from the participants played a key role. The consistent response was attributed to the automatic controllers in each home. The decisions that the participants could make was in general only regarding comfort levels. The automatic response was then generated based on these levels.
- Distribution grid congestion was avoided in a virtual feeder. The virtual feeder was created because all participants did not reside on the same real feeder. The shadow market managed to successfully reduce the feeder load at all three constraint levels that were imposed.
- Peak load reduction was demonstrated in the virtual feeders. The aggregated load curves were reduced by between 5 and 20% during the experiments with constrained feeders.
- One hurdle for the OP project was that the participants had to supply their own broadband internet connection. This limited the group of potential participants. Also, the availability of the internet connections was somewhat poor. However, the distributed energy resources managed to perform successful local control until the internet connection was available again.

3. References

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[2] D. Hammerstrom, T. Oliver, R. Melton, R. Ambrosio, “Standardization of a Hierarchical Transactive Control System”, In Grid Interop 2009 Conference, November 17-19, 2009, Denver, CO. GridWise Architecture Council, Richland, WA

[3] D. J. Hammerstrom et al., “Pacific Northwest Gridwise Testbed Demonstration Projects: Part 1. Olympic Peninsula Project”, Pacific Northwest National Laboratory, Richland, WA, Tech. Report PNNL-17167, October 2007

[4] D. J. Hammerstrom et al. “Pacific Northwest Gridwise Testbed Demonstration Projects: Part 2. Grid-Friendly Appliances project”, Pacific Northwest National Laboratory, Richland, WA, Technical Report PNNL-17079, October 2007.