Appliance Interface for Grid Responses

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Abstract

A successful, rapid integration of technologies from three different companies was achieved as part of the Grid Friendly™ Appliance Project. Therein, a simple but effective interface was defined between a vendor's commercial energy management system control module, an experimental electronic sensor and controller, and a smart appliance. The interface permitted each entity to use its preferred, proprietary communications up to the interface without divulging any protected or sensitive attributes of the entity's hardware, software, or communication protocols.

Those who participated in this integration effort recognize the potential value of the interface as an interoperability model, which could be expanded and extended with participation and buy-in from a larger community of stakeholders. The result could become a universal interface for the communication of demand response objectives to appliances and other small loads. We focus here on the business and marketing challenges.

1. SIMPLE, APPLIANCE CONTROL INTERFACE DEMONSTRATED

The authors began their collaboration during the Grid Friendly Appliance Project [1]. This project modified residential hot water heaters and clothes dryers to be responsive to the Grid Friendly appliance controller. Pacific Northwest National Laboratory (PNNL) designed the controller to reside in an appliance and monitor system frequency. During an underfrequency event the controller signaled the appliance to shed load. A fourth collaborator, Invensys Controls, won a competitive project solicitation to supply persistent monitoring of the controllers and appliances via components of their GoodWatts™ energy management system.

Practical limitations due to manufacturing constraints and safety issues forced the project to adopt a limited integration with the controller external to the appliance. However this change created the seed for the new approaches discussed in this paper.

With the controller external to the appliance, the next critical step was to meld the communications between the dryer, controller, and monitoring system. Understandably, both Whirlpool and Invensys use proprietary serial communications on their respective products. To also ease the testing and debugging phase, a decision was made to reduce communication at the interface down to only three Boolean signals that could be communicated on dedicated wires indicating the following messages:

GFA - An underfrequency event has been recognized by the Grid Friendly controller. Appliances should immediately reduce their power consumption.

En - This signal asks the appliances to respond to a traditional direct load control program. The water heater turns off. The dryer beeps, displays "En", and requires the consumer to acknowledge if they want to override this request and initiate a drying cycle.

Pr – This signal indicates that a high price condition is in effect. The appliance should advise its owner to defer energy consumption, or to respond in a way appropriate for the particular appliance receiving the signal. The project dryer will beep and display "Pr" on its panel.

While remarkably simplistic, these basic signals captured these authors' imaginations and demonstrated how a simple appliance interface can fulfill the basic needs for Demand Response (DR).

1.1. New Approach for Responsive Appliance Loads

Evaluation of the project with an eye towards commercialization led to the following potentially economical demand response opportunity. The basic solution would be a standard that defines a single physical socket to be located on all major appliances. The pins of the socket provide power to a communication device that the appliance owner would "plug in" at a later date. The pins relay basic Boolean logic signals between the appliance and device, which may then communicate externally via any chosen medium and protocol. Optionally, a serial protocol can be used to communicate not only basic command signals but also more advanced, richer information. The appliance interprets one or more of the defined command signals and then responds as designed by the manufacturer, and as has been configured by the customer at the appliance's user interface.

2. PROJECT BACKGROUND, GOALS, AND LIMITATIONS TO BE OVERCOME

What factors are motivating the furtherance of the concepts studied and demonstrated?

2.1. Smart Grid Developments

The Grid Friendly Appliance Project that initiated the authors' collaboration is a small part of a larger movement to modernize and create a smart electric power grid. One emphasis of this movement should be to overcome financial and technical barriers that have thus far limited the participation of responsive loads. Loads can accept responsibility for peak energy management, system stability, regulation, spinning reserve, and other ancillary services far beyond what is now practiced. Appliances and other small loads especially remain a largely untapped load resource.

2.2. Advantages and Opportunities

Where will the entities who adopt this approach find benefits and opportunities?

2.2.1. Interoperability between Complex and Proprietary Systems

The ideal appliance interface will be interoperable, meaning it will possess a defined, standard physical interconnection and will use a known, common language. There appears to be agreement up to this point. But most competing "interoperability" standards and protocols rely on increasingly complex serial communications and class structures residing on evolving media. Regrettably, numerous workable standards and protocols lie unused. Few standards and protocols are practiced by competitors without the evolution of proprietary, non-interoperable versions.

The definition of a simple pin interface for the communication of energy needs, where the assertion of pins from the utility side is interpreted as a request for an appropriate appliance response, could break this cycle and could result in an enduring, functional, and truly interoperable interface. The adoption of this simple pin interface would not preclude also exchanging rich serial communications with those few appliances that will require it, although most will not.

2.2.2. Does not Attempt to Pick a Winning In-home Communication Method

The proposed interface permits fair competition. It does not preclude the advancement of propriety and non-proprietary means of communication and special product features that may be enabled by such advancements. For example, makers of building energy management systems could expand their product offerings by providing the utility-side communications to the appliance interfaces.

2.2.3. Less Susceptible to Obsolescence

Product obsolescence is a valid concern. Utilities have become accustomed to equipment amortization over 20 – 30 years, and appliances can also last decades. New appliance models may take several years to develop. There is a fundamental mismatch between the slow turnover of appliance products and the rapid obsolescence of digital products like those that might emerge to talk to these appliances. Annual appliance sales equal roughly 10% of the current installed base. If industry were to begin offering a viable interface today, it could take a decade to saturate the appliance load capacity, but that capacity may endure several more decades thereafter. In contrast, will your present laptop computer remain useful after 10 years?

2.2.4. Create a Global Solution

Until now, demand response programs have been offered regionally. This is a mismatch with appliance manufactures, which focus on a more global design. Even a region as large as a state is determined to be too small to warrant unique appliance model designs and the logistic management to direct these models to the appropriate region. This global approach may present a real opportunity and advantage for the practice of economical demand response for appliances and small loads.

2.2.5. Eliminate the Need for Professional Installation

The cost to install a single end-use point has been as high as $350, including professional licensed installation, permitting, and the necessary equipment. Few appliance types can justify this cost. Rather than having an installer drill holes, string wire, and install ugly boxes to gain a seasonal compensation of $10 per month, the customer should receive a small module to plug into a standard socket on their appliance. Its installation may be electronically verified by the utility.

3. THE BUSINESS CASE FOR UTILITIES

A number of factors are pressing utilities to

- seek green capacity and energy solutions
- improve the value proposition to end-use customers
- show responsiveness to Energy Policy Act of 2005
- find a cost effective version of the "smart grid."

3.1. Advanced Metering

Advanced Metering Infrastructure (AMI) is desirable, but it is not a necessary component for the implementation of demand response. Many utilities (such as PGE) expect to utilize AMI networks to send demand response price and control signals. However, cheaper communication paths might be feasible if demand response is the only or main benefit of the technology. Various home networks, Power Line Carrier (PLC), or wireless solutions are possible. But having a communications technology-neutral appliance end point enables a variety of utility-specific business cases to co-exist while utilizing the same DR-enabled appliances.

3.2. Verification of Demand Response Participation

The serial interface of an appliance interface standard should support acknowledgement of a demand response command, but verification needs in the utility industry are not yet well defined. Some demand response systems operate today without direct verification. Acknowledgement is useful, but may not be considered a requirement.

3.3. Available Load Resource from New Appliances

A Federal Energy Regulatory Commission (FERC) report indicates that the existing direct load control in the residential sector is 7,000 MW [3]. Direct load control has been available since the mid 1980s, but after 20 years we have less than 1% of the peak system load under control. As shown in Table 1, 32 million new appliances sold each year contribute 16 GW of new controllable capacity. Optimistically, in one year one could capture more than twice as much direct load control as exists today. To achieve results near this optimistic projection, a large fraction of new appliances must come to participate by market forces or by mandate. Furthermore, the projection has assumed that all of the participating appliances' load would be curtailed and never overridden, which may not be practicable for all shown appliance types. The appliance load resource could be earned over several years while utilities and appliance manufacturers learn and then design and use these new appliance resources.

3.4. Old Economics

In previous cases direct load control was not economic compared to building a generation plant to serve system peak load. A simple cycle combustion turbine installed for this purpose has a first cost of about $400/KW. After one amortizes the cost and pay for fixed labor and maintenance, the annual cost for this plant is about $70/KW. Using the total cost of $350 per control point (Section 2.2.5) and data from Table 1, one can see that the only appliance load resource that presently competes with generation on a cost per kW basis is central air conditioning.

3.4.1. New Economics

Adding a socket on every appliance is not as simple as it sounds. The good news is that marginal cost per appliance is probably $2 to $5. But the one-time recurring engineering cost for mechanical, electrical, control, tooling, and safety considerations is probably $100K to $500K for each

Table 1 New Appliances Placed Annually in Occupied US Households

Appliance	Replacement in Existing Homes % Electric	Avg Life	Units Sold in millions	Penetration in New Homes % Electric	Units Sold in millions	Coincident Peak kW contribution per Appliance btwn 4p & 8p (summer) Avg Day	Pk Day	New Appliance Load Contribution in GW Avg Day	Pk Day
Water Heater	38%	15	2.8	40%	0.4	0.60	0.60	1.9	1.9
Window AC	22%	13	1.8	25%	0.2	0.50	0.90	1.0	1.9
Central AC	54%	25	2.4	60%	0.5	1.00	3.00	2.9	8.7
Stove	59%	16	4.0	60%	0.5	0.48	0.46	2.2	2.1
Refrigerator	110%	18	6.7	100%	0.9	0.10	0.11	0.8	0.8
Dryer	57%	15	4.2	60%	0.5	0.15	0.14	0.7	0.7
Freezer	32%	20	1.7	30%	0.3	0.10	0.10	0.2	0.2
Dishwasher	53%	13	4.5	60%	0.5	0.05	0.04	0.2	0.2
			28.0		**3.9**			**9.9**	**16.4**
					Average Benefit per Appliance=>			0.3 KW	0.5 KW

Assumptions

Market Saturation from Table 963 Statistical Abstracts 2006		
Number of US Households 2007	109.3	million
Number of New Households	0.9	per yr.

For reference in 2007
US Peak Summer Load
Forecast is 790 GW

appliance line. Collectively across multiple OEMs, the one time cost is probably $100 to $200 million investment. However, amortizing this cost across 32 million appliances per year over 5 years adds only another $1 per appliance.

For a medium sized utility like PGE (700,000 residential customers) this means about 200,000 new appliances are added each year. After 5 years, a program might control 1 million appliances with a potential benefit of about 500 MW. This is a serious resource, and PGE could afford to spend $200 million to capture it. If it reserves $20 million of this for one-time development and program startup costs, PGE could afford to spend $180 per home.

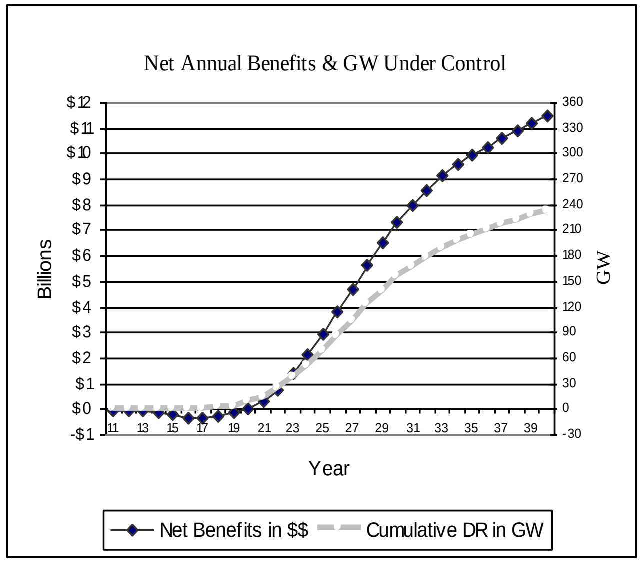
Under the new proposed approach, PGE would more likely spend about a fifth of this. The initial cost for the communications interface might be $50, but with up to 32 million additional appliances appearing each year, and as the product matures, there is no reason not to expect that the product couldn't eventually be stocked at supermarkets for perhaps $10 each.

After an initial education campaign, marketing costs should be small. Since the cost of trying the program would be so low and the communication device might be installed and uninstalled by the appliance owner, there would be no risk to the consumer, and recruitment will occur by word of mouth experience from their friends. There would be no new control system to master; there would be only the appliance controls that the customer has already mastered. If a customer were to sign up for a utility program and didn't like the consequent lifestyle or comfort impact, then undoing their enrollment would be totally transparent and 100% under their control. This solves the problematic poor customer experience that has hampered some previous demand response programs..

3.5. Societal Benefit/Cost Analysis

In the early years, since the marginal societal cost per appliance is likely to be about $50, there is justification to target only the appliances in Table 1 with the largest kW impact. After experience is gained and the marginal cost drops, even control of appliances like refrigerators, freezers, and dishwashers can be captured cost effectively compared to generation.

To account for all of the incurred costs, one must assume a timeline for development and for utility and customer adoption. Figure 2 shows the cumulative GW of demand response from the electric appliances added each year in accordance with the adoption rates in Figure 1. For simplicity, an average capacity benefit of 0.5 kW per appliance (Table 1) is assumed in Figure 2. To compute the annual net benefit from the new appliance capacity, $50 per KW is assumed for the cost of avoided generation. This is a conservative estimate compared to the current cost for peaking capacity (Section 3.4). The conservative benefits were chosen because control of demand resources tends to eliminate some use and shift the rest to a time when the fuel cost per kWh is less. None of the energy cost savings is included in this analysis. Assuming a real, societal discount factor of 3.5%, the net present value of the nation-wide effort in today's dollars is $60 billion.



3.6. Additional Benefits

With 100's of millions of appliances to target, the original concept of autonomous Grid Friendly controller and similar grid-responsive tools could be implemented through the same interface. A discussion of direct demand response addresses but one of several value propositions. There are billions more to be saved in improved transmission utilization and avoided outages. The interface could also further enable other innovations such as a central home controller, demand-side regulation services, automated energy price responses, whole-house battery back up systems, and off-grid products to cost-effectively manage outages.

4. BUSINESS CASE FOR MANUFACTURERS OF RESIDENTIAL DEVICES

Prior to the GridWise Testbed Project [1], Whirlpool Corporation conducted an independent study on special appliance designs to help the consumer interact with time-based pricing such as time-of-use (TOU) and real-time pricing (RTP). The Whirlpool Woodridge Project and Energy Monitoring Pilot [2] when combined with the GridWise demonstration indicate several items of note:

- Consumers must alter their lifestyle to some degree to react to time-based energy pricing structures.
- Consumers are willing to change their use times for certain process-oriented appliance products.

- Appliance design can enhance consumer acceptance of time-based pricing and underfrequency grid response.

4.1. Customer and Appliance Interaction

To design proper modifications, manufacturers need to understand how, when and why appliances consume energy and match this data up with the most likely times of grid stresses. Each consumer may have unique interactions with the appliance and the consumer products involved in the process. We need to understand how much of the appliance power can realistically be affected, during what phase of the process, and at what development and manufacturing cost.

Manufacturers need to understand the consequent impact each energy response might have on users of the appliance. For example, the Grid Friendly Appliance Project [1] demonstrated that turning off the dryer's heating element during a grid underfrequency excursion while leaving the dryer drum tumbling was unnoticed by 97% of the consumers. These are important research findings that shape the design process.

4.2. Business Issues for Device Manufacturers

Consumers make the decision on what, when, where, and whether to purchase appliances. A mass production product in the free unregulated market necessitates further study of the marketability and profitability of a new feature. Questions may include "What will induce a consumer to want a product with this feature?", or "Will there be government and utility incentives to encourage market transformation?"

Due to previously mentioned customization and logistical issues, the logic of our discussion will focus on an economic model that cost effectively enables grid-ready features in mass without customization and without adding logistical expenses.

For illustration purposes, assume a manufacturer makes 5 million dryers a year. Now assume the addition of a grid-responsive interface adds $2 to the cost of the product. This added cost will be taking $10-million of profit directly off of the bottom line. There may not be any guarantee that the $10 million will be recovered because the consumer is not necessarily forced to fund it by purchase of this product.

The manufacturer's challenge is to provide such features that will save them far more than the product cost increment, or to keep the cost down or below standard pricing via incentives to the manufacturer. Various potential cost recovery models have been discussed. See the Pacific Northwest GridWise Testbed Demonstration Project reports [1] for further discussion.

From the business perspective, the cost of development, higher product cost, and communication technologies need to be justified. The amount of energy that can be managed by making appliances responsive to a grid management system appears to be reasonable under the proposed approach.

4.3. Engaging the Residential Consumer via Product Design

There are several basic realizations that have been uncovered in various residential demand response pilots and focus groups. The first is that demand response will affect consumer lifestyles, perhaps some more than others. This could be related to comfort levels or the time of day certain household devices are operated. A second item is that if consumers don't understand and accept the demand response program, they can and will thwart the program, reducing its intended impact. Consumers have voiced concern that they don't want to have to think about energy. They desire a way to automate whatever it is they have to do.

The *persistent* residential devices that operate with virtually no interactions with the consumer (e.g. water heater, HVAC, spa/pool pumps) can be automated to a large degree. *Process oriented* devices (e.g. dishwasher, stove, oven, and laundry) interact with the consumer every time they are used, requiring a different type of automation which must involve the process logic within the appliance's electronic control module.

As new appliance features are added, new sensors and interfaces are introduced, and manufactures of these products continue perfecting their consumer interfaces. Any new grid interfaces need to be melded into the product via these familiar tried-and-true methods. New appliances have "smart" controls that are able to handle some new functions with microprocessor logic. This logic knows the status of the process involving consumables (such as detergent), times, temperatures, and the effect of any changes to the state of the operation. The appliance control already has mechanisms to activate or deactivate the energy consuming components. Therefore expensive external switches should not be necessary.

5. PRINCIPLES FOR THE NEW APPLIANCE INTERFACE

The critical steps in the definition of the simple appliance interface are to

- Define the grid problems that can occur and communicate these conditions and needs to appliance design engineers.
- Define a simple standard protocol used to communicate these unusual events to the appliance using a small number of Boolean signals.

Through these steps, the process leverages the expertise of appliance design engineers to manage appliance grid responses in ways that could not otherwise be addressed. Through the resulting hardware integration, the cost of external control mechanisms (*e.g.* 240-V water heater disconnect) might be reduced. When a grid signal is issued, the appliance manufacturers have designed the device to respond in the best way it can with minimal overhead, cost, and consumer lifestyle disruption.

The remainder of this section lists some of the guiding principals that should guide development of the simple appliance interface.

5.1. Define a Standard that Could be Implemented on Every Major Appliance.

The standard must be independent of any specific communication protocol. Whether a particular region or utility utilizes PLC, Broadband, Zigbee™, HomeNet™, a pager network or any other approach, the message definitions should remain the same. These protocols, if used, should be easily interpreted near or at the appliance.

5.2. Open and Published Protocol

The protocol must be able to be implemented by any device manufacturer on any model of product. Implementation of the interface must be reasonably accomplished using published information only.

5.3. Responses are Described by Objective

Requested responses should be described by objective, not by specific action. For example, an interface request could be defined by the need to shed load immediately. A signal should not specify the turning off of a dryer's heating element. Implicit in this principle is that appliance makers design the responses and should be encouraged to differentiate their products by the superior ways they respond.

5.4. Provide Incentives for Rapid Adoption

Incentives need to be in place that account for the perspective of consumers, manufacturers, utilities, grid operations, government, regulatory, and technology providers.

5.5. Grid-Ready Appliances When Purchased

These appliances are ready to respond to a variety of utility or state energy programs at the time they are purchased and installed. Additional external components, if needed, are installed safely by the consumer.

5.6. Existing Vendors Welcomed

The vendors of advanced metering, communicating thermostats, and premise energy management systems are encouraged to use the interface. These vendors may be instrumental to the interface development as they provide the external communication components. These vendors profit by helping control still more responsive load.

6. THE NEXT THREE STEPS

Three years ago, the authors asked themselves, "What steps can be taken today to have a great demand-side appliance resource installed and ready to participate in various electrical energy programs within several years?" The simplified, low-bandwidth interface described in this paper may be the answer. The approach can be advanced, proven, and implemented by these next steps:

- Define the simple low-bandwidth communication protocol according to the outlined principles.
- Demonstrate the approach alone and in conjunction with a variety of communication infrastructure such as AMI.
- Further engage both appliance manufactures and utilities to help prove their business cases.

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Biographies

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