GRID FRIENDLY™ APPLIANCES FOR DEMAND REDUCTION: THE TECHNOLOGICAL LEAP TO MARKET TRANSFORMATION OF DEMAND RESPONSE

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Abstract

Grid Friendly™ Appliance (GFA) control can be added to appliances so they can autonomously reduce their demand for electricity when the power grid gets into trouble. If deployed in vast numbers, they can create a highly effective "safety net" under the power grid by detecting and responding to abnormal frequency or voltage fluctuations. Then they respond by dropping their load for 2-3 minutes. By building in this capability at the factory it is possible to turn off loads *within* the appliance, which consumers would be less likely to notice than if the entire appliance was turned off.

This paper describes key aspects of GFA technology: why disturbances in the power grid frequency and voltage can indicate problems with the power grid, how the technology works, its potential and key issues surrounding its use and deployment, and the first demonstration project designed to confirm its performance in the field. The demonstration project will collect data to confirm the effective and reliable function of the GFA controller. It will also provide evidence on customer acceptance of the technology. We think this is the first step in preparing a new opportunity for collaboration between loads and the power grid—and between appliance manufacturers and the utilities or energy service companies that will deploy them in lieu of more expensive grid stability resources. We further suggest that GFA controllers may for a platform for deploying lower cost demand response that can add substantially to their basic value.

Introduction

Grid Friendly™ Appliance (GFA) technology allows household appliances to automatically detect and respond to frequency disturbances on the grid. Within a few seconds or less, the controls turn off the appliance for as long as a few minutes to allow the grid time to stabilize. This autonomous response can reduce the demand for electricity enough to prevent or arrest cascading blackouts during times of grid instability.

Consumers are not likely to be inconvenienced or even perceive that their appliances have momentarily assisted the power grid if the GFA technology has been integrated with appliance controls. For example, by working with appliance manufacturers the GFA controller could turn off the heating element in the clothes dryer, but leave the drum tumbling and the lights and controls enabled.

In addition to helping the grid when trouble arises, GFAs can help ease the tension as it recovers. GFAs randomly restart the full appliance load to prevent a sudden surge in demand and restore load diversity. If a blackout ever actually occurs, this same functionality would delay the restart of appliances. This delay would make it easier for utilities to restore service by preventing the surge in demand, known as cold-load pick-up, which comes from all the appliances whose operation was interrupted trying to resume operation at the same time.

This paper describes key aspects of GFA technology: why disturbances in the 60-Hz frequency of power (50-Hz in Europe) can indicate problems with the power grid, how the technology works, its potential and key issues surrounding its use and deployment, and the first demonstration project designed to confirm its performance in the field.

How a Grid Friendly Appliance Works

The current version of the GFA controller, the size of a credit-card (Figure 1), can be installed into air conditioners, electric heaters, heat pumps and "white-goods" appliances (washers, dryers, dishwashers, water heaters), in addition to equipment in commercial and industrial facilities. By monitoring frequency, they autonomously recognize a disturbance and turn off the appliance for short periods—as long as 2 to 5 minutes—to reduce the demand for electricity. While those appliances are down, grid operators have additional flexibility to react to the crisis and prevent it from cascading out of control. The appliances that are most suitable for GFA controllers cycle on and off or from one mode to another during normal operation. Consumers are not inconvenienced—and likely do not even notice—when the appliances turn off momentarily in response to trouble on the grid. On the other hand, it is not practical or desirable to use GFA controllers in lights, televisions, computers or other appliances and devices where these interruptions would be noticed.

By installing the controllers in the equipment while still at the factory, we can control selected processes to make GFA operation even less obtrusive. For example, in a refrigerator, the compressor could be turned off because that component uses almost all the power, but the light could stay on in case someone opens the door. Similarly, we can leave the clothes tumbling in the dryer but turn off the heating element. Depending on the appliance and its use, deployment time may also be limited. For example, food safety considerations might require curtailment of refrigerator loads to be limited to no more than, say, 5 minutes.

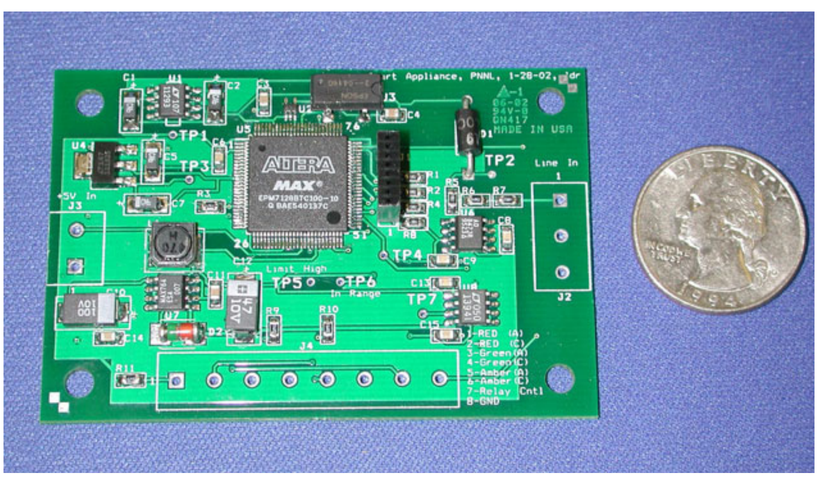


Figure 1. Grid Friendly Controller Produced for the Project

Why the Frequency of the Grid Indicates Trouble

Figure 2 is a plot of the fluctuations in the 60-Hz frequency of the power grid in various places in New York State during the August 14, 2003 blackout. You can see that the normal (U.S.) 60-Hz frequency, which is usually maintained by the grid operators within very strict limits (±0.03 Hz) began to oscillate wildly. Locations on Trajectory 1 were rapidly heading toward zero frequency – this is the area of the blackout, including New York City (the horizontal axis time scale here is seconds).

In general, when the grid's frequency deviates from normal, it is a sign of serious trouble. If a power plant suddenly drops off line unexpectedly, or a major transmission corridor goes out of service, suddenly there is not enough power available to meet demand. When this happens, the generators in the grid, whose controls keep their operation in synch with the grid frequency, collectively draw power out of their rotational momentum to make up the deficit, but slow down in the process [1]. This is just like your car slowing down as it starts up a hill, until you push down on the gas pedal to get more power to meet the increased demand. The grid operators must bring on more power to make up the difference, and it may take 30 seconds and sometimes up to 30 minutes to do this.

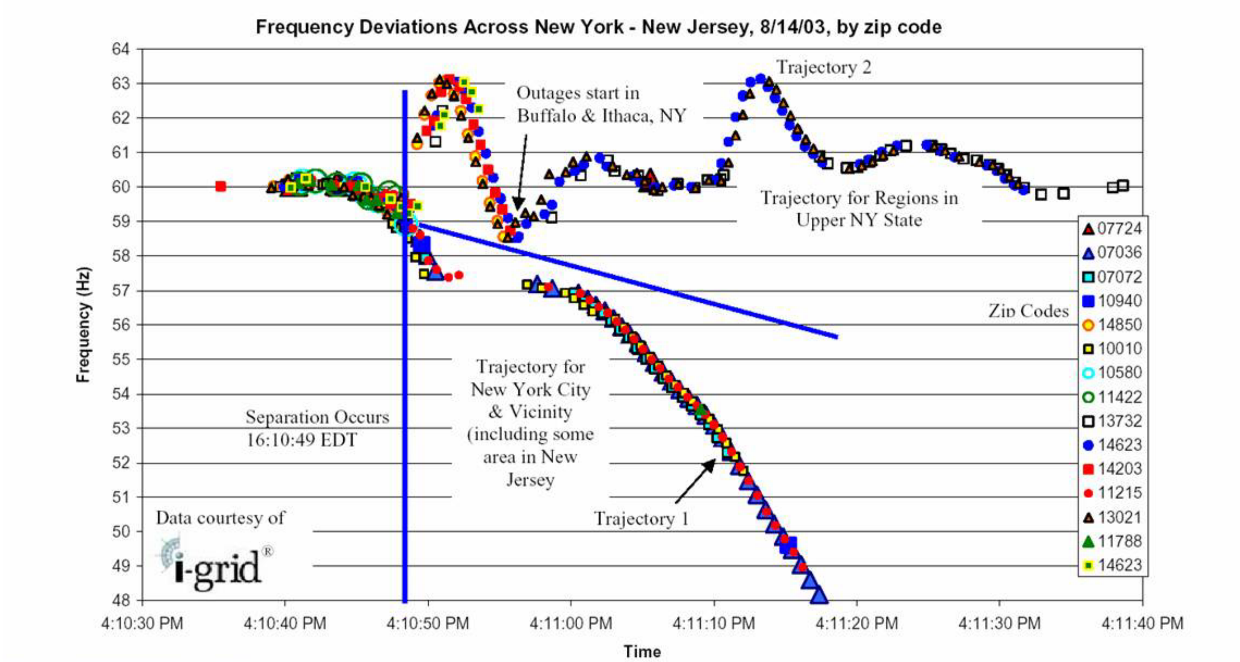


Figure 2. Power Grid Frequency Deviations During the August 2003 Blackout, by Zip Code

Figure 2 shows that after the 4:10:39 P.M. ETD, the locations on Trajectory 2 exhibited large positive and negative excursions from the normal 60-Hz frequency. The oscillations occurred because northern New York, which had actually been exporting power eastward toward Ohio when the blackout occurred, was suddenly cut off and had *too much* power. So, the grid there sped up, which caused some power plants there to trip off, quickly changing the surplus into a deficit and low frequency. This in turn caused whole cities to trip off, with the ensuing wild swings in frequency.

Even though the grid in New York had "broken up" into two parts, note that the frequencies in each of the two parts are very uniform after the initial shock. This is key to the functionality of GFAs – within each of three vast interconnected areas of the North American power grid (the East, West and Texas), a disturbance of the 60-Hz frequency is a universal indicator of serious imbalance between supply and demand *seen at every location in the interconnection*. This means that any piece of equipment equipped with a Grid Friendly controller in the entire interconnection can sense the disturbance and respond, without the need for communication or central control system.

Pacific Northwest National Laboratory (PNNL) has been monitoring grid frequency in the Western U.S. for 3 years. There, frequency excursions outside normal tolerance are an almost daily occurrence, with a more serious event occurring weekly [2]. It is a tribute to the resiliency of the grid and the skill of our utility operators that these almost never result in a significant blackout. But, as in Ohio in 2003, every once in a while such an event cascades out of control, with obviously devastating consequences.

The Basic Value Proposition – A Safety Net for the Grid

GFAs can represent a better and less expensive emergency resource than the current approach to managing crises on the grid. In the U.S., some power plants are paid to run at less than their full capacity so they can increase output in response to a crisis. These *spinning reserves* ensure that some fraction of extra capacity, typically around 5%, is available at all times. The power plants that provide spinning reserves have been paid for by ratepayers (in a regulated utility) or are not available to bid into the wholesale market and mitigate prices through competition (in a competitive wholesale market). In either case, consumers' electric rates cover the costs of idle capacity, which is there "just in case." When these spinning reserves are needed, it takes anywhere from 30 seconds to 30 minutes to bring the power plants up to speed, depending on the type of plant. In contrast, GFAs can turn off demand from equipment and appliances in a half-second or less.

The fact that GFA controllers can respond autonomously and nearly instantaneously, without the need for any communication or central control system, is key to their functionality. They can act fast, without the cost and lag time of a central communication system. Further, because the power disturbance itself may disrupt communications, technology not dependent on communications can respond more reliably.

GFAs create a powerful "safety net" under the grid with a response that is proportional to the seriousness of a crisis [3]. We actually don't want *all* the appliances to respond instantly – that may be more than are needed. Instead, appliances can be turned off based on how much and how quickly the frequency on the grid is changing. With each appliance programmed to respond at a randomly assigned deviation from normal frequency over some range, more and more appliances would shed load as a crisis deepens. Once the situation stabilizes, albeit at a lower-than-normal frequency, the GFA controllers slow or stop turning off more appliances. As the frequency returns to normal, the GFAs automatically and gradually return appliances to service to avoid shocking the power grid with a suddenly renewed surge of demand.

The GFA controllers also are programmed to randomly delay restart for a period of time after the crisis has passed. This is an important function that restores much of the natural diversity of appliance loads. It also serves a very valuable second purpose – it eases power restoration after a blackout. Today, when all the appliances are trying to turn on immediately once power is restored, the surge in demand often causes the power grid to re-collapse.

GFAs will allow customers to become an integral part of power grid operations and could even reward consumers for their participation in helping prevent a widespread outage. So, even without any formal communications capability, ordinary appliances are transformed from being part of the problem to part of the solution. GFAs act as assets that form a much quicker and better safety net under the power grid.

With this new safety net in place, power plants typically on standby duty could be freed up to increase competition, lower prices and meet future load growth.

Adding to the Value Proposition – Under-Voltage Load Shedding to Prevent Voltage Collapse

The same Grid Friendly controller can be used to host an under-voltage load shedding capability with relatively minor hardware modifications. This addresses a cause of grid instability that results from stalled electric motors, especially in areas with long distribution lines and heavy air conditioner (or heat pump) loadings. Unlike frequency, which is a relatively universal indicator of grid conditions with an interconnection, voltage is observed and controlled at the feeder level. A local voltage instability begins when heavy loads along a loaded feeder begin to accelerate the natural voltage drop that occurs down the length of the circuit because of line losses. If a loaded compressor motor cannot start and reach full speed at the available voltage, it continues to draw a high startup current. The high currents on several struggling loads further load the feeder line and further reduce the voltage, making it even harder for motor loads to function. As the voltage continues to drop, the current drawn by the motors continues to rise until the protective relays trip. Re-closing the relays may not restore power as usual because all the air conditioning units that caused the problem initially are now all still trying to restart and the over-current again trips the relays.

We propose that a Grid Friendly voltage response could recognize and respond to this incipient voltage instability and could protect important motor loads and the feeder thereafter by randomly delaying motor restarts after an incident. Research is required to target the important loads. Research is also needed to design the triggering algorithm to assure that the incipient voltage collapse can be quickly differentiated from normal grid transients and motor startup transients on circuits within the customer premise.

A Cost-Effective Solution Accessing a Large Resource

In the U.S., "white-goods" appliances represent about 20% of electric demand most any time of day or year. This is because during moderate weather, when neither heating nor cooling are needed, the other appliances remain in use. Even though they represent a much smaller resource per controller than heating or air conditioning, they are important in maintaining an emergency resource that is always available. The nation's appliance stock "turns over" (that is, the average appliance is replaced) every 17 years. To further mass deployment, grid operators and utilities may eventually pay appliance manufacturers to install the GFA technology in every appliance sold, or regulators may establish GFA as an integral part of appliance performance standards. If GFA controls were built into every new appliance, we would be acquiring the equivalent of about a 1% reserve resource each year.

Because white goods have relatively low average consumption, GFA costs must be low for it to be a cost-effective solution in these appliances. PNNL has had the controllers commercially built in quantities of 100-200 for $50 each. In mass production, shrunk to a microchip, they might be as inexpensive as $2 or $3 each at the retail level. Installation at the factory would take advantage of mass production and factory labor to keep costs low. As another option, it is possible to develop a retrofit device in the form of a plug-in module or circuit breaker containing a GFA controller. The plug-in module would plug into the wall, between the receptacle and the appliance. This approach could be used where it is acceptable to turn off the whole appliance. Water heaters and space conditioning equipment would require a circuit breaker or junction box version and require the services of an electrician and the attendant labor costs. While these installations would be more expensive, the cost is counterbalanced by the larger resource obtained, and the fact that integration with the appliance is not required. For space conditioning, a GFA control might be supplied in a thermostat requiring only low voltage wiring skills.

While eliminating the need for communication is an important way to keep deployed costs low, it may make sense to incorporate communications that could be used to support demand response during times of peak demand from appliances with large loads and heavy usage, like space conditioning equipment and water heaters. For appliances with smaller loads or those with intermittent usage patterns, the number of average watts shed per GFA deployed may not support the cost of adding communications. Further, it is not clear that *automating* demand response for these appliances makes sense. Because these appliances require that someone be home to start them, it would be possible to turn them off automatically as a default response to periods of critical peak demand and provide an override button to support customer choice. While this option requires communications, it is not very different from simply displaying a warning light or other indicator of high prices and letting the customer decide whether to start the appliance.

Adding to the Value Proposition – Providing Other Grid Services

By extending the range of frequencies over which they respond, GFA controllers can provide other valuable services to the power grid, as well. The discussion so far proposes that GFAs begin to react to frequencies in the range below about 59.95 Hz, well in advance of 59.92 Hz, when Northwest utilities begin to react to a deepening crisis by shedding entire substations (see Figure 3). Before substation shedding begins, it may prove desirable to lock out some appliances, equipment, and circuits in favor of others. Having <u>some</u> power for <u>everybody,</u> at least for <u>some end uses,</u> is obviously preferable to having no power for anyone for anything. In a truly severe crisis of longer duration, streetlights, and working water, sewage, and gasoline pumps are obvious priorities, perhaps followed by communications, lights, and refrigeration.

Also of interest are more subtle types of response at frequencies above the proposed GFA trigger frequency of 59.95 Hz and also above 60.05 Hz. In the Western (North America) Interconnection, power plants are throttled up and down when the grid ranges from 59.95 Hz to 60.05 Hz to restore grid frequency to near the desired 60.00 Hz. This small-signal control function wastes fuel and causes wear and tear on power plants that, in the end, tie up some generator capacity and cost the consumer money. If the thermostats for devices such as air conditioners, space heaters, water heaters, refrigerators, and freezers could be programmed to shift their set points up or down a small amount in response to frequency extremes, perhaps only 1°F either way from normal, then some fraction of them would be activated (or satisfied). As a result, the system-wide load would tend to adjust slightly to provide this regulating function, and power plants would be kept operating near their optimal efficiency point until sufficient change in the system load occurred and an entire plant could be brought on (or off) line. This creates a kind of symbiotic partnership between loads and the grid serving them.

At the margins of the range above 60.05 Hz, short fluctuations in output from intermittent sources like wind farms could be absorbed. Much higher frequencies are indicative of the oscillations associated with system breakup (like that shown in Figure 2). These frequency excursions are of very short duration, up to a few seconds. Appliances and equipment could actually be programmed to *absorb* the momentary excess power they represent and help stabilize the grid. Resistive elements in things like heat pumps, water heaters, defrosters in refrigerators and freezers could be safely activated for a few seconds without disrupting the operation of the appliance or inconveniencing the user. For example, this kind of active grid stabilization has been estimated to dampen North-South oscillations and permit another 450 MW of import capacity on a critical transmission path into southern California [4].

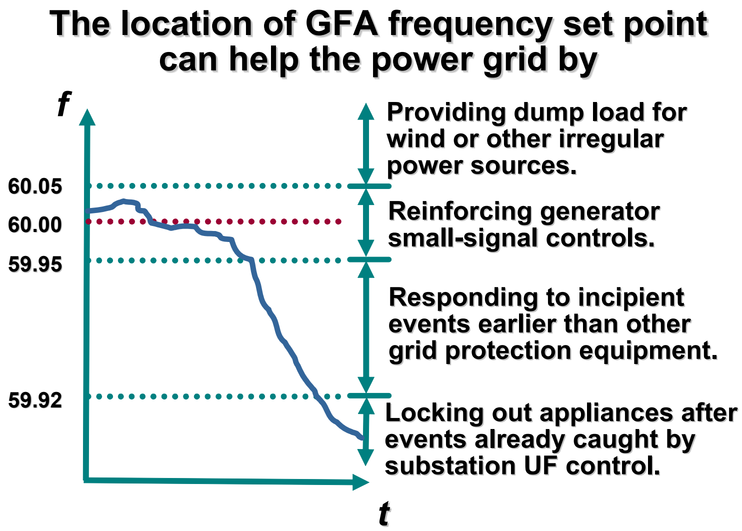


Figure 3. Frequency Ranges for Other Grid Services

What Else Can a Grid Friendly Appliance Do?

GFAs can take appliances that were previously "dumb" and made them "smart." The GFA microchip has plenty of processing power, and putting this brain on board can be the first step of a broader smart appliance transformation that could support things like:

- **Demand response** with more sophisticated negotiation and control of energy use based on price or curtailment signals can be added.
- **Load shifting** can accomplish simple things like preventing refrigerators from going into the energy-intense defrost mode during times of peak demand.
- **Emergency management schemes** would allow prioritization among what stays online during rolling outages, such as selectively keeping traffic lights, water and sewer service, lights and communications operational while curtailing lower-priority end uses.
- **Energy efficiency** can be improved by warning consumers of equipment or control malfunctions that waste energy, or supporting more sophisticated control algorithms.
- **Consumer amenities can be increased** by exploiting the processing power in the GFA controller to provide additional convenience and service to the consumer, such as a refrigerator that could keep an inventory of food and automatically draft shopping lists.

Demonstration Project

Planning for the GFA demonstration project has been underway for a number of months among the Bonneville Power Administration, Portland General Electric, Pacificorp, Whirlpool, and the U.S. Department of Energy (DOE) and its Pacific Northwest National Laboratory. About half the funding for the project was provided by DOE through its GridWise™ program, and each of the utilities offered to host the demonstration in their service territories, and provided the remainder of the funding and in-kind participation related to recruiting and project planning. Bonneville engaged Public Utility Districts in Mason and Clallam counties, and the municipal utility in Port Angeles (all on the Olympic Peninsula in Washington) to participate. Whirlpool has constructed a GFA-interface for a new model Sears Kenmore dryer, is supplying the first production models from the assembly line at cost, and will conduct a consumer acceptance survey at the end of the project. The project's field activity is just getting underway with the installation of measurement gear, water heater retrofits, and newly produced clothes dryers in January.

The demonstration involves two end-uses (50 electric water heaters and 150 electric clothes dryers) in 150 homes in three areas served by three participating utilities in the Pacific Northwest. The project is designed to prove that GFA controls function in the field as well as they have in a laboratory setting. In particular, it is imperative to show that the sensor hardware and algorithm used to detect frequency excursions on the grid is robust to various forms of noise present in a diverse set of locations in regional distribution systems. It is equally imperative to show that, by working directly with white goods appliance manufacturers to embed GFA control functionally within appliances at the factory, brief interruptions of service in appliances are unobtrusive and not noticeable by the consumer. By testing these propositions, the project serves as the first step in transforming the marketplace for this new technology.

A secondary goal of the project is to confirm the resource potential of GFA technology for these end uses. Resource potentials for a number of residential appliances have been estimated on the basis of metering-based end-use load profiles collected by past load research projects.

The project will involve two modes of deployment and testing:

1. **Deploy GFA controllers that provide autonomous, under-frequency load shedding for water heaters**. Water heaters were selected because they are simple devices to manage and because they are a large load coincident with regional peak loads for the Pacific Northwest.
2. **Deploy GFA controllers for clothes dryers.** Clothes dryers were selected because Whirlpool development efforts for appliance load control are most advanced for this appliance type. They will provide a new, advanced dryer with built-in curtailment operating modes and an application programming interface (API) allowing external access to those modes. Dryers also allow important investigation of the extent to which load shedding schemes may interfere with consumer use of appliances. Receiving a new clothes dryer will be the primary incentive for customer participation.

Research Objectives

The primary research objectives for the project are to determine how the GFA technology performs in the field:

1. Do the appliances all respond to the same, global frequency events or does local "noise" in the grid affect them?
2. What are the rates of false positives and negatives regarding local noise and frequency excursions?
3. What is the "performance factor" of the GFAs, i.e., combining the effects of reliability and local frequency noise? What fraction of the deployed number can be counted on to respond appropriately?

Determining the size of the potential resource is not the primary focus of the project. We are only focusing on two of the potential end uses, and in a limited sample of homes that is not representative of the population or a subpopulation. Estimating the resource potential is best done by applying the performance factor to measured end-use load shapes from other data collection efforts.[5] However, the project will:

- Compare the measured loads for the water heaters and clothes dryers with measured data from other projects
- Project the potential resource (and costs per kW) to other end uses based on the field performance and standard, regional load shape assumptions so that the reduction per appliance can be used in a preliminary business case and for further research.

We hope to establish the basis for a business case for GFA deployment by conducting an analysis of:

- What is the stability value proposition from the grid operator's standpoint?
- How does this compare functionally with spinning reserves?
- How much is this worth in the Pacific Northwest power grid today?
- How might changes in the grid's market/financial system be crafted to appropriately reward the GFA resource in the future?

Whirlpool will evaluate the results of the project and conduct a customer acceptance survey at the conclusion of the project to determine:

- Is the GFA response noticeable by consumers and if so, is it acceptable?
- Will GFA technology be acceptable to appliance manufacturers?

Participant Recruiting

Working with PNNL, the utilities designated a representative to develop joint recruiting materials. These includes flyers, solicitation scripts, web sites, sign up and permission forms, access lists, participant lists, and maintenance of participant lists and information, and an information hot line.

Each utility worked with PNNL to offer the project to homeowners within its service territory: Portland General Electric (in Gresham, Oregon), PacifiCorp (in Yakima, Washington), and the Bonneville Power Administration (thorough the public and municipal utility districts on the Olympic Peninsula, Washington) will each host 50 homes with 50 dryers. Pacificorp and Bonneville agreed to host 25 water heaters each, co-located in a subset of the participating homes.

During recruitment, each resident participant must agree to:

- Accept and use a new Sears Kenmore brand clothes dryer manufactured by Whirlpool.
- Permit experimentation on the new clothes dryer within their residence (and the water heater, for the 50 homes where it will be involved).
- Allow and provide for reasonable access to project representatives for the installation, maintenance, and removal of project hardware.
- Facilitate remote communications of project appliance control equipment, which might include access to a broadband network via their cable modem, fiber network, or high speed DSL.
- Answer questionnaires or otherwise participate in data collection efforts at the end of the project that will help us evaluate the residents' attitudes toward their project participation.

The residents' incentive for their participation in this demonstration is the opportunity to keep the clothes dryer (worth $800) in exchange for continued project participation for a year. All other project equipment will be removed at the conclusion of the demonstration. The project will pay the cost to deliver and install the dryers, and, at the homeowners' discretion, haul away their old dryers.

Control and Measurement Systems

The performance of the GFA-controlled appliances will be analyzed by correlating the frequency curtailments of each appliance with each other. In principle, each GFA-controller should detect and respond to the same events at nearly the same time. Isolated responses by a single appliance suggest false positive signals, perhaps produced by electrical noise in the distribution system. Appliances that fail to detect and respond to events seen by others suggest hardware failures or detection errors. In each instance, events will be correlated with independent measurements of grid frequency in the Western Interconnection at PNNL and elsewhere.

The system collects both load current for all on/off events (GFA-induced or not) and the curtailment request data, in the form of a time-stamped event log. The initiation and release of each GFA curtailment request is recorded. GFA frequency set points are set to incur GFA events at least weekly, and not more often than daily, on average, based on 3 years of grid frequency measurements [**Error! Bookmark not defined.**]. Because we also seek to monitor normal appliance usage and whether the appliance was on or off at the start of each event, we also need to monitor power consumption. The events include changes in load that indicate changes in appliance cycle or state.

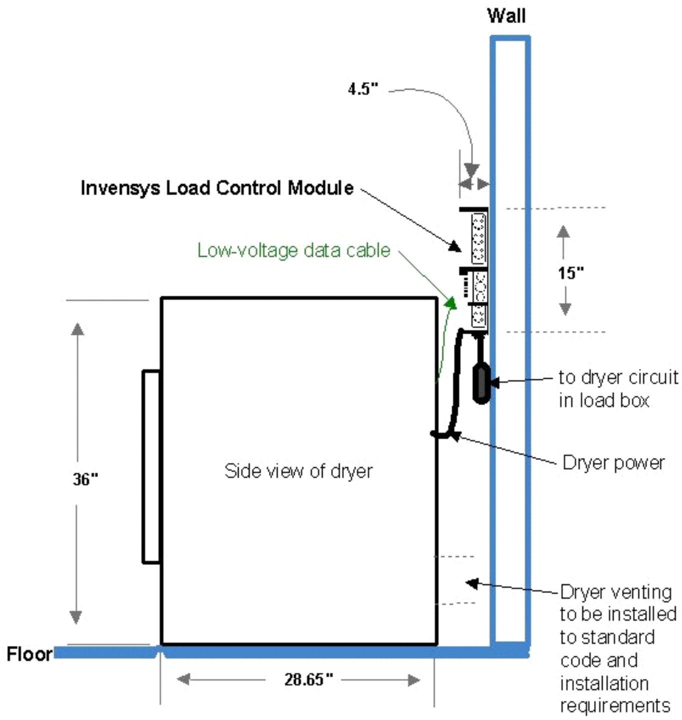
Thus, even though GFAs do not require a communications system, one is required to collect and monitor their performance data. Further, the GFA controller used in the project (Figure 1) does not itself contain a line voltage electrical switch controlling the appliance.

In the case of the water heater, a switch must be added. A commercial load control module (LCM) is used for this purpose, and the GFA controller is connected directly to the LCM. This, combined with the desire to 1) have near real-time access to performance data and 2) portray the potential to combine GFA functionality in tandem with peak load demand response, led us to solicit commercial vendors of load control systems to modify their hardware for use in the project. Invensys Controls won the contract in a competitive procurement for hardware and installation of the system. The Invensys system utilizes wireless communications within the home to a gateway residing on a home's Internet broadband connection. The Internet is used to collect the data from each appliance. Thus, only homes with broadband Internet were eligible to participate.

In the case of the dryer, the GFA curtailment signal is generated and transferred to the appliance through the measurement system that monitors both the curtailment events and the appliance consumption. The dryer control circuitry designed by Whirlpool disables the heating element for a maximum of 10 minutes when a GFA event is detected. Communications to the dryer are via a low voltage wire connected to a control interface on the dryer, which is otherwise used by the manufacturer for quality control and diagnostic testing. In this case, the Invensys LCM is used only for measurement and communications. A diagram of the system is shown in Figure 4. All equipment is UL-listed and suitable for permanent installation.

The under-frequency signal will be provided by a finger board produced by a local manufacturer based on a 2002 design by PNNL. This board allows modification of the frequency set point in firmware, but does not provide for changes to that set point in the field. The commercial load controller accepts this 5-

V signal and responds by breaking the load current. This functionality was tested in controlled laboratory tests of the equipment, including the communication of data back to researchers at PNNL.



Side view of dryer with Invensys Control Module

Figure 4. Configuration of Dryer, Load Control Module and GFA Controller

Acceptance Survey of Residential Participants

Interviews or questionnaires will be used to find out whether residents were noticeably inconvenienced by the GFA responses. Whirlpool has offered to lead this effort because of their commercial interest in this topic and because of their experience in conducting similar customer surveys. Such surveys will also assess perceptions toward other system components besides the dryer and water heater, and toward the conduct of the project itself.

Grid Friendly Function and the Appliance Manufacturer – Opportunities for Market Transformation

Working with an appliance manufacturer (Whirlpool) over the course of a couple years leading up to this project has provided us some important insights into how to engage appliance and equipment vendors on issues of demand response and GFAs.

First, no one knows or cares as much about how the customer uses a piece of equipment than the manufacturer. They take it very seriously because their business depends on it, and they are adamant about protecting the convenience, amenity, and safety of the end user. For example, they would never allow the whole dryer function to be interrupted and then restored automatically, because stopping the drum can allow a child to crawl into the machine while it was stopped. That is why you must push a button (not just shut the door) of a dryer to get it to restart. So, any automatic curtailment that also stops the drum from turning would require a *manual* restart. Similarly, they are not going to curtail a clothes washer that is in a bleach cycle because it might damage the clothes.

They are also keenly aware that, because of their different use patterns, there are two categories of appliances: process-oriented appliances like clothes washers and dryers, and persistent-use appliances like air conditioners, water heaters, and refrigerators where intermittent cycles are used to maintain a desired condition such as temperature. They understand that the mode of human interaction, and the appropriate degree of automation, needed to successfully implement demand response and GFA-functionality are different for each category.

In process-oriented appliances like dryers, a GFA curtailment request must be weighed against the need to follow a prescribed sequence, the violation of which could be detrimental to the process. In the case of the dryer involved in the project, the manufacturer implemented a simple interface that supports two types of *requests* from the power grid: an emergency curtailment (for example, a GFA request), and a price-based or voluntary request for curtailment (such as during time of peak loads). In the emergency request, they allow up to 10-minutes of interruption, and the dryer extends the drying time as needed automatically.

If a high price or critical peak demand signal is received, the process typically cannot be interrupted, because these grid conditions typically last for an hour or more rather than a few minutes. So, there is little value in automating the appliance's response, since the user should retain the ability to override the request. For an appliance that is about to be started under such conditions, the user can simply be made aware of the request, and they can choose to start the process or not. Instead, the manufacturer added an LED display on the controls indicating a "Pr" warning to the user, and the user must push the start button *twice* to start the machine. In the cases of the dryer, they will not interrupt a cycle that is already running, because that could leave clothes wet and wrinkled.

The manufacturer is prepared to build dryers and a whole suite of other appliances with the GFA capability fully embedded if field tests prove it is not an inconvenience, and with demand response capability as well. Their willingness to do so requires the adoption of federal or state requirements like an efficiency standard, an industry-wide marketing campaign like the Environmental Protection Agency's Energy Star Appliances, or a power grid entity willing to pay them the marginal production cost and a reasonable profit. It is not currently fashionable to pursue such standards at the federal level, and leaving the choice to customers may have an uncertain outcome. We think an approach that unequivocally confirms the benefits and cost effectiveness of GFA technology to utilities and regulators should lead to a willingness to pay manufacturers to implement GFA-capable and demand-response-ready appliances is the best of these options to achieve prompt widespread deployment. In fact, it can be asserted that the National Electric Reliability Council's operating policy [6] already grid reliability standards already allows regions to count active load control as part pf their portfolio of frequency response resources [3].

Next Steps

Other desirable research objectives remain outside the current scope of the project. These include:

- Is GFA a cost effective resource? The project will shed light on this subject, but is not designed to project costs for manufacturing and deployment in any of several possible deployment modes. Rough cost estimates will result from this project.

- Finding areas of cost reduction, efficiencies in the design, manufacture, and cost effective implementation beneficial to all sponsoring parties and customers will be indirect results or recommendations of the project rather than direct, tested conclusions.
- With respect to providing an avenue for accelerating adoption of peak load demand response technology—
  - Does GFA technology have the potential to transform the demand response market?
  - Can we deploy GFA and then leverage it to get demand response later?
  - Can we deploy GFA in homes that already have automated meter reading/demand response?
- The grid simulation based research focused on the optimal set points and "ramp rate" at which we turn off the appliances. This is a critical line of research focused on building consensus that the proposed triggering and restoration algorithms are reasonably optimal to provide the grid stabilizing effects in widespread deployment.

Conclusion

The Grid Friendly Appliance technology is about to undergo its first test in the field, integrated with residential appliances. The demonstration project will collect data to confirm the effective and reliable function of the GFA controller. It will also provide evidence on customer acceptance of the technology. We think this is the first step in preparing a new opportunity for collaboration between loads and the power grid – and between appliance manufacturers and the utilities or energy service companies that will deploy them in lieu of more expensive resources to provide grid stability. We further suggest that other values, such as preventing voltage collapse, providing a degree of grid frequency regulation, and most importantly a platform for lower cost demand response may add substantially to their basic value.

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