Integrating Renewable Energy onto the Electric Grid with Automated Demand Response Resources

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Abstract

This paper reviews a pilot program implemented by the Hawaiian Electric Company (Hawaiian Electric), testing whether demand response (DR) can serve as a "quick-start" bridge resource to manage variable renewable generation. The paper addresses Hawaiian Electric's operational experience, and in particular employs econometric modeling of customer loads to characterize the speed, magnitude, and persistence of load curtailment impacts. This load estimation technique was optimized to minimize differences between the actual load and the predicted load during hours prior to the load curtailment impacts.

The Fast DR pilot has demonstrated relatively reliable, automated load curtailments in response to Hawaiian Electric's initiation of Fast DR events. However, pilot participants achieved on average only two-thirds of their contracted load reductions. More importantly, participants are not achieving full load curtailments within ten minutes, and the magnitude of reductions begins to degrade beyond about 30 minutes.

The authors conclude that Fast DR does, in fact, exhibit the characteristics required to support renewables integration, but the operational experience to date is not yet sufficient to designate Fast DR as a principal resource to help mitigate the challenges posed by higher penetrations of renewables.

Introduction

Over the past decade, European Union goals and national policies have dramatically increased the share of electric power coming from renewable energy sources. In Germany in particular, there is so much renewable energy on the grid (more than half of all production at times) that wholesale market prices periodically go negative, forcing generators to pay grid operators to take their electricity. Furthermore, European utilities "worry that the growth of solar and wind power is destabilizing the grid, and may lead to blackouts or brownouts" (*The Economist* 2013).

The rise of renewables, along with the inherent intermittency of these resources, has made it harder for system operators to maintain the stability of the electricity grid with existing generation resources. The industry is increasingly looking to demand response (DR) resources to help integrate the growing amount of intermittent renewables by bridging the gap between the sudden loss of renewable power and the start of combustion turbines or other supply-side resources.

In 2008, the State of Hawaii launched the Clean Energy Initiative to decrease the state's dependence on imported oil with the goal of energy independence. One of the primary objectives of the initiative is to increase the use of renewable energy sources for electricity generation, achieving 40% by 2030. At present, the state's primary electric utility, Hawaiian Electric Company (Hawaiian Electric), which serves the island of Oahu, obtains 12% of its energy from renewable sources, including roughly 100 megawatts (MW) of wind power and more than 200 MW of customer-sited solar (Hawaiian Electric 2014). Hawaii's island setting presents Hawaiian Electric with unique operational challenges in accommodating this increase in renewable energy. Hawaiian Electric cannot rely on other utilities or power generators for back-up generation, but must independently manage reliability and the intermittency of renewable energy sources. This need for independence has catapulted Hawaiian Electric to the forefront of U.S. utility efforts to employ demand response (DR) with automated load response technologies to accommodate the growth of renewables.

The resulting Fast DR pilot program, which began in January 2012, was designed to enable rapid, automated curtailment of commercial customer loads to serve as a “quick-start” bridge resource when intermittent renewable energy declines until additional generating units can be brought online. As stated in Hawaiian Electric’s Fast DR Pilot Program application (Endo-Omoto 2010), the objectives of the Fast DR Pilot Program include:

1. Conduct a **market assessment** of Fast DR by identifying participation barriers through the recruitment process, and testing key program attributes such as event duration, event frequency, event pre-notification, incentive levels, and load control methods.
2. Assess the **technical readiness** of Fast DR technologies (e.g., Semi-Automated and Automated DR, including customer barriers to adoption and cost-effectiveness).
3. Evaluate the company’s **operational experience** in using Fast DR as a grid management tool, including characterizing the speed, magnitude, and persistence of load curtailment impacts.
4. Estimate the **cost-effectiveness** of a full-scale Fast DR program by comparing the anticipated utility system benefits to the expected program costs.

The authors’ subsequent evaluation of the pilot program assessed the viability of Fast DR in meeting these objectives. This paper presents findings specifically from the evaluation of operational experience (Objective #3 above).[1] After describing the design and status of the Fast DR Pilot Program, the paper discusses the impacts on participant loads during DR events, assessing the magnitude, speed, and consistency of the load curtailments. The paper concludes with an outlook for Fast DR as a possible resource to help mitigate the challenges posed by increasing penetrations of intermittent renewable energy.

Design and Status of the Fast DR Pilot Program

A major challenge in the design and rollout of a Fast DR program is to develop an attractive value proposition for participants without compromising the operational objective to serve as a bridge resource for the increasing penetration of intermittent renewable energy sources. As a result, the program rules must allow for effective grid management at a lower cost than the alternatives while limiting the disruption to business operations and tenant/customer comfort. This means that requirements for DR events should be rigorous enough to serve the needs of the company’s grid operations, yet flexible enough not to discourage customer participation. And customer benefits from participation in Fast DR, such as financial incentives, should be significant enough to attract customers without rendering the resource too expensive to justify its development.

Pilot Program Requirements and Incentives

In striking a balance between operational needs and the marketability of the program, Hawaiian Electric designed the pilot to require commercial customers to provide at least 50 kilowatts (kW) of interruptible load, available for ten consecutive hours between 7 a.m. and 9 p.m. on weekdays. A maximum of 40 DR events may be called per year (with the option of 80), with each event lasting a maximum of one hour in duration. Unlike traditional capacity DR programs with several hours of advanced notification, Fast DR events can be dispatched immediately, with customer response time depending on their level of automation.[2]

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[1] Assessment of the other three objectives is ongoing and is not expected to be publicly available until fall 2014.
[2] The operational characteristics of the Fast DR pilot were based on experience from the mainland U.S., which suggested that the Fast DR resource would be needed between 20 and 200 times per year, and would need to be available within a few minutes of the identified need for the resource (Perlstein et al. 2012). Hawaiian Electric’s preliminary internal assessment suggests that Fast DR events may be needed for up to 40 minutes in duration.

In response to a load shed signal issued by Hawaiian Electric, participating customers either reduce load automatically (Automated DR) or within ten minutes of when a DR event is initiated (Semi-Automated or Manual DR). *Automated DR* is the most common and the company's preferred method of load curtailment; it requires no manual intervention after an initial configuration, using pre-programmed shed strategies via a building's energy management system (EMS). S*emi-Automated DR* requires the customer to manually initiate a pre-programmed shed strategy, and *Manual DR* requires the customer to manually turn off/down equipment following a load shed request.

The program provides a Technical Audit and Technology Incentive (TA/TI) of $2,500 per audit and up to $300 or $600 per kW, depending on the level of automation, to enable commercial customers to reduce load. In addition, participating customers receive monthly financial incentives, including both demand incentives ($5/kW per month, or $10/kW per month for customers choosing to be available for up to 80 events per year) and energy reduction incentives ($0.50/kWh reduced during events). Participants also receive less tangible benefits including access to a web portal presenting usage summary reports and real-time consumption data at intervals as short as five minutes, public relations opportunities, and the opportunity to support grid stability and Hawaii's energy independence.

Pilot Status

The Fast DR pilot program originally targeted for 7 MW to be available for load curtailment by the end of 2012. However, delays in the recruitment and enablement process resulted in the first customer not signing a contract until August of 2012 and the first Fast DR event being called in December of that year. It was not until March 2013 that the first MW was available for load curtailment (**Figure 1**). Due to these delays, Hawaiian Electric requested an extension of the pilot program through December 2014; this request was approved by the Public Utilities Commission in October 2013.

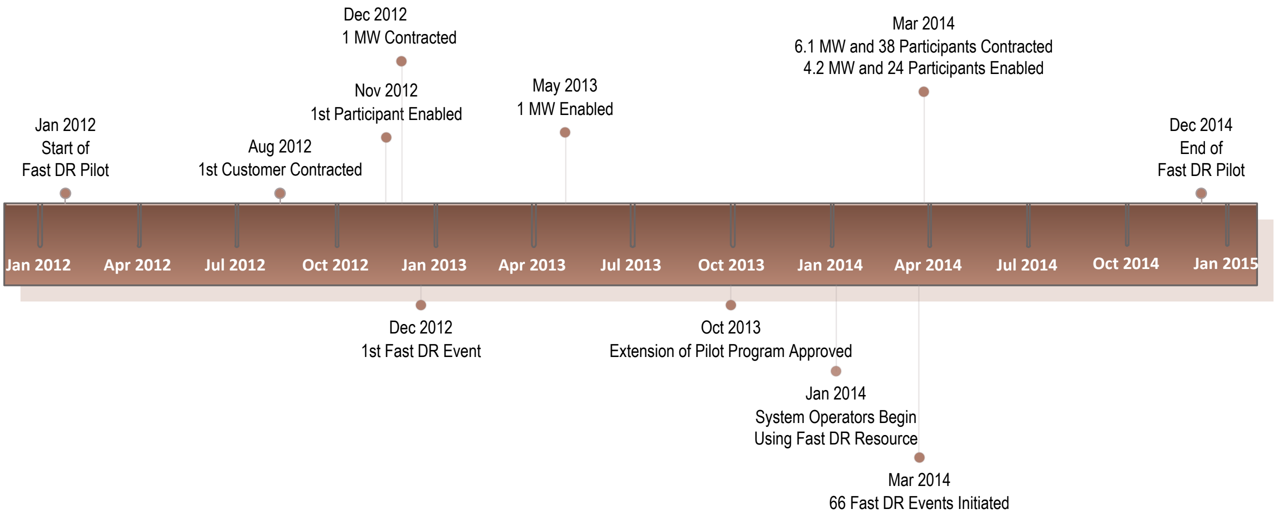

Figure 1. Timeline of the Fast DR Pilot Program

As of March 2014, 24 customers had contracted with Hawaiian Electric for a total of 4.2 MW of available load curtailment, for an average load curtailment nomination of 180 kW. Another 14 customers were contracted but not yet enabled for curtailment, accounting for another 1.9 MW. In total, 38 participants had signed contracts representing a variety of market sectors including office buildings, condominiums, hospitals, educational facilities, retail, entertainment, and more. Sixty-six Fast DR events have been called since the start of the pilot of various durations (15 minutes, 30 minutes, 45 minutes, and one hour) and across all program hours.

Hawaiian Electric intends to file a final pilot evaluation report in fall 2014. The pilot will remain active through the end of the year, however, to enable a smooth transition for participants should Hawaiian Electric choose to operate a full-scale program in 2015 or to transition customers to an alternative DR program offering.

System Operations with Fast DR

Beginning in 2014, Hawaiian Electric implemented a testing protocol for system operators to manually initiate events and test Fast DR as an operational resource. A key objective of the pilot program was to develop operational experience with the resource, informing the effectiveness of Fast DR to effectively serve as a bridge resource for renewables integration, as well as the viability of a full-scale Fast DR program. The testing protocol followed a three-phase approach that gradually encouraged system operators to gain operational experience with the Fast DR resource.

Phase I - Prescribed Event Schedule

During the initial phase, the Fast DR Program staff trained members of the Generation Planning and System Operations teams on the characteristics of the resources and how to manually dispatch the resource (i.e., initiate a Fast DR event). Once trained, system operators began initiating events following a prescribed schedule developed by the planning team.

Phase II - Day-Ahead Scheduled Events

During the second phase, Hawaiian Electric staff periodically scheduled the Fast DR resource in the day-ahead plan based on weather forecasts or other internal considerations. Once in the resources stack, system operators could utilize Fast DR at their discretion.

Phase III – System Operations Real-Time DR Dispatch

During the final phase, which is ongoing, system operators are given full discretion to initiate Fast DR events as part of their regular operational duties. Whether or not Fast DR appears in the resource stack for a given day, system operators were instructed to deploy the resource on an “as-needed” basis. The objective of this phase is to give system operations experience in utilizing the Fast DR resource to respond to system conditions—even if the size of the resource is currently too small to significantly alter the supply-demand balance. In the near term, this phase provides an opportunity to assess the operational adoption of Fast DR to offset a downturn in the production from Hawaiian Electric’s utility-scale photovoltaic (PV) resources; the expected 5 MW of Fast DR can be used as a one-for-one replacement of the 5 MW of utility-scale PV.

To date, Hawaiian Electric has deployed the Fast DR resource as part of Phase III testing, though almost exclusively as a capacity resource during the evening peak—and not yet as a bridge resource for renewables integration. This is driven by the fact that the operators have become accustomed to deploying other DR resources during the evening peak, and there is not yet any protocol in place for near-term DR deployment specifically in response to fluctuations in renewable energy output.

Load Impacts – Magnitude, Speed, and Consistency

A key component of evaluating the ability of Fast DR to serve as a grid management tool is understanding the load curtailment impacts. In particular, to effectively serve as a bridge resource for renewables integration, the Fast DR resource requires maximum curtailment within ten minutes and must provide consistent load curtailment throughout the daytime and evening hours over dozens of events.

Estimation Methodology

As an assessment of operational reliability, the authors estimated load curtailment impacts using five-minute interval meter data for 25 customers who participated in some or all of the events called between April 1, 2013, and March 31, 2014. The impact estimation employed an econometric regression model that predicted customer loads according to the time of day, day of week, month, and temperature. Load impacts from Fast DR were then determined by comparing metered loads during event hours with the predicted "baseline" loads during those same hours.

An important aspect of the load estimation technique was the adjustment for differences in the event-day load and the predicted load during pre-event hours. This is typically referred to as a "day-of adjustment" and is a simple percentage adjustment to the predicted load during every interval of the event period, based on the ratio of event-day loads to predicted loads (EnerNOC 2014). For example, if loads during pre-event hours were 20% above the level estimated by the model, then the baseline used for purposes of load impact estimation was adjusted upwards 20%.[3]

While the hour, day, and season may be necessary predictors of load, there can be significant variation in an individual customer's load on a daily basis. It follows that a strong predictor of the counter-factual usage during event hours is the load in the period leading up to the event. The question is what period of time is optimal to use in maximizing the accuracy of the baseline load estimation: Too short a period (e.g., a single five-minute interval immediately prior to an event)[4] could introduce inconsistency caused by normal fluctuations in load, such as due to large air conditioning units cycling on or off concurrently; however, too long a period (e.g., the three hours prior to an event) could prove to be a less accurate predictor of loads during event hours (ISO New England 2009, 58).[5]

There is relatively little research on appropriate baselines for Fast DR since the most common DR programs offer 30 minutes or more of advanced notification, thus requiring that load data be utilized from an hour or more prior to the event period.[6] Given that the Fast DR Pilot Program provides no advanced notification, pre-event load data for baseline estimation can be used from a period much closer to the time of the event. The authors tested the accuracy of alternative pre-event periods, as well as alternative caps to the day-of adjustment (e.g., a maximum of a +/- 20% adjustment), by evaluating the model's "goodness of fit" (i.e., how closely the predicted baseline matched actual demand on non-event days) for each participant. Specifically, the estimated baseline for each of 324 unique models was compared with the actual participants' consumption during Fast DR-eligible hours (7 a.m. through 9 p.m.) on all non-event Fast DR-eligible days (e.g., excluding holidays and weekends) between April 1, 2013, and March 31, 2014. The difference between the predicted baseline and actual demand in each five-minute interval was then squared, and summed up for every non-event day. This sum of squared differences was averaged across days, events, and participants. The relative success of each model was determined by this score, with a lower score implying a more accurate baseline estimation technique.

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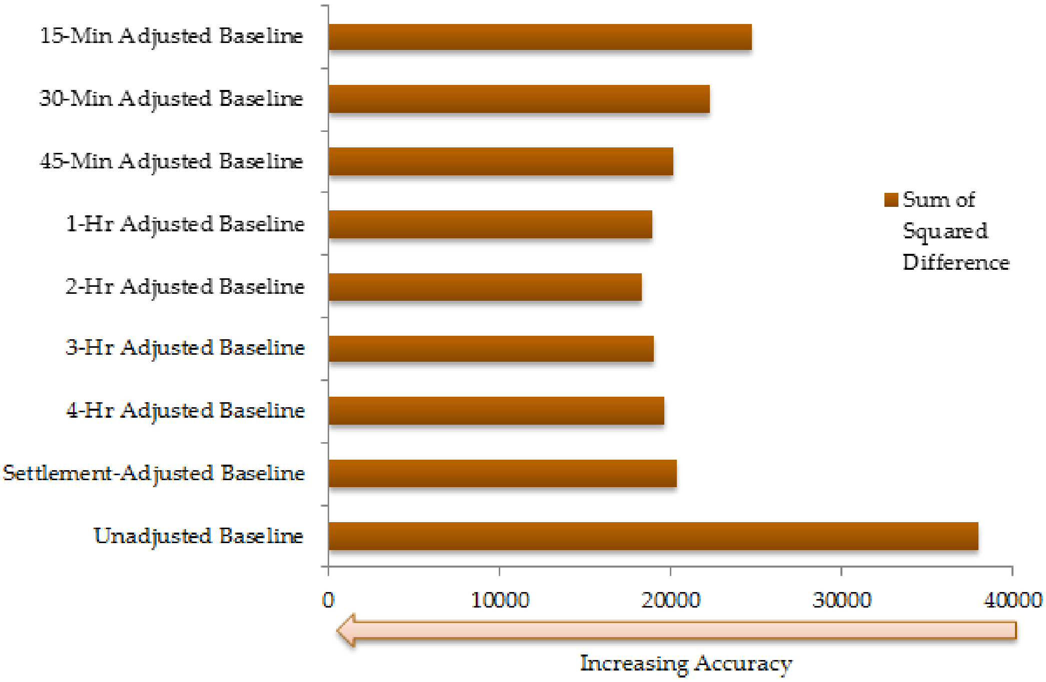
[3] As explained below, the period used for the day-of adjustment was the two hours immediately prior to the beginning of a given event.

[4] Because Hawaiian Electric's MV 90 system provides average demand values every five minutes, a meter read concurrent with event start will reflect average demand over the previous five minutes.

[5] ISO New England studied alternative baseline methodologies for its Demand Response Reserves Pilot (which provides ten-minute response) and concluded that "the present baseline with a positive and negative adjustment (*based on the two hours preceding the interruption event*) is the most appropriate of those analyzed."

[6] Customer load data for baseline estimation must be taken from time intervals prior to event notification. Otherwise, customers could "game" the system by purposefully increasing load after event notification in order to raise their calculated baseline load—and thus increase their measured load reduction during the event. Alternatively, customers may begin to reduce load after receiving notification, but prior to the start of an event, thus lowering their baseline from what their load would have been in the absence of an event.

The "best" predictor of participant loads was determined to be a baseline using interval data from a two-hour period immediately prior to the events. Interestingly, as the adjustment period becomes shorter than one hour in duration, the goodness-of-fit decreases. (See the relative accuracy of alternative "adjusted baselines" in Figure 2.) This is likely due to the variation in the demand values between one meter read and the next, such that too few data points creates imprecision in the estimates.[7]



Note: "Adjusted Baseline" refers to the period of time prior events that was used in the regression equation to help estimate counter-factual customer loads during event hours. A shorter bar indicates that a particular baseline method is a better predictor of customer loads than are other methods with longer bars.

Source: Navigant analysis from a comparative baseline assessment conducted using Fast DR participant data as of fall 2013.

Figure 2. Relative Accuracy of Alternative Baseline Methods

Fast DR Load Impacts

A first step in evaluating the ability of Fast DR to serve as a grid management tool is a determination of the degree to which Fast DR participants achieved their contracted load reductions for the program. In particular, the evaluation assessed whether customers reached their curtailment goals within the ten minutes desired by Hawaiian Electric, and whether these achievements varied by time of day, were sustained over the course of each event, and persisted over the course of dozens of events.

Using the estimation methodology described above, the authors estimated that the average *realization rate* (actual load reductions averaged over the course of all events as a share of the customers' contracted loads) was 67%.[8] In other words, for any given event, participants delivered two-thirds of the load curtailment that they had contracted with Hawaiian Electric to provide. There is considerable variation in the participant-specific and event-specific realization rates. In other

[7] While the two-hour adjustment performed best *on average* in the initial testing of baselines in fall 2013, the accuracy of a one-hour adjustment was nearly identical and performed best for the majority of participants. Furthermore, subsequent testing in spring 2014 found that the one-hour adjustment provided the most accurate baseline load forecasts. As a result, Navigant estimates load curtailment impacts using the one-hour day-of adjustment.

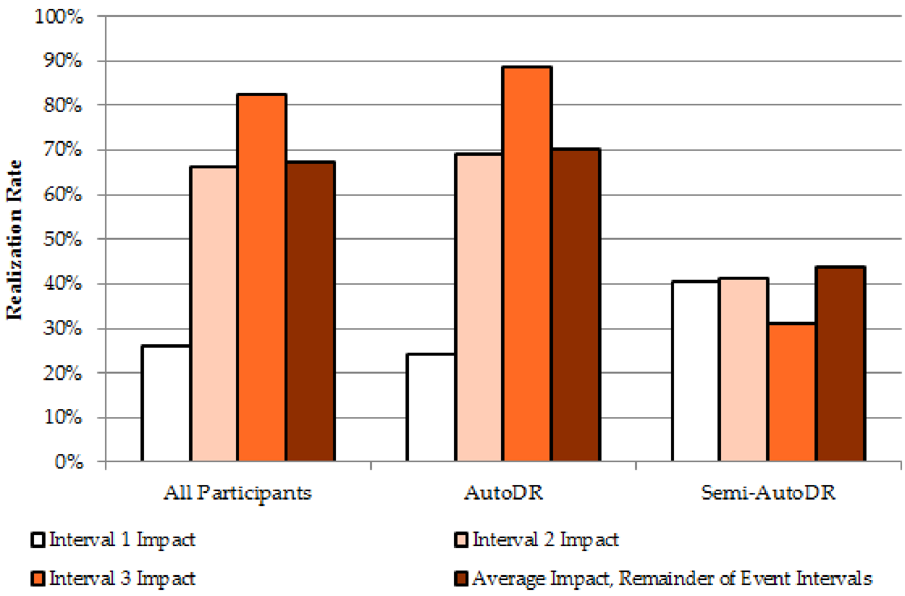
[8] Negative impacts, where actual load exceeds the predicted baseline, are included in this estimate. In these cases, participants did not curtail load during the event, but did not officially opt out of the event. When excluding negative impacts, the average realization rate increases to 79%.

words, the average realization rate is 67%; however, it is not that most participants are delivering two-thirds of their nominated load, but rather some participants are delivering well, and others are delivering poorly. Only half of the event-specific realization rates were within 15 percentage points of the average impact per event (67%). In addition to understanding the magnitude of the DR impacts, it is important to understand the characteristics of the impacts. In particular, to effectively serve as a bridge resource for renewables integration, the Fast DR resource must provide maximum curtailment *within ten minutes* and must *persist for the duration of the event*. In addition, the resource must provide consistent load curtailment throughout the daytime and evening hours over dozens of events.

The following discussion presents findings on the speed, persistence, and consistency of customer load reductions. The common metric used to assess performance—and to normalize across participants with different levels of contracted load curtailments—is the realization rate, defined above as achieved load reductions as a share of the reductions committed under contract with Hawaiian Electric.

Speed and Persistence of Load Curtailment

The authors analyzed both the speed and persistence of load curtailments to inform whether the Fast DR resource could effectively serve as a "quick-start" bridge resource. Figure 3 shows average realization rates during each of the first three five-minute intervals of each event, as well as the average realization rate for the remainder of the events subsequent to the first 15 minutes. It is apparent that, on average, *customers do not reach their contracted load curtailment levels within the desired ten-minute window*. In fact, the average participant has been able to reach just over 80% of the contracted amount, and this level of load curtailment has required between 10 and 15 minutes to achieve.[9]

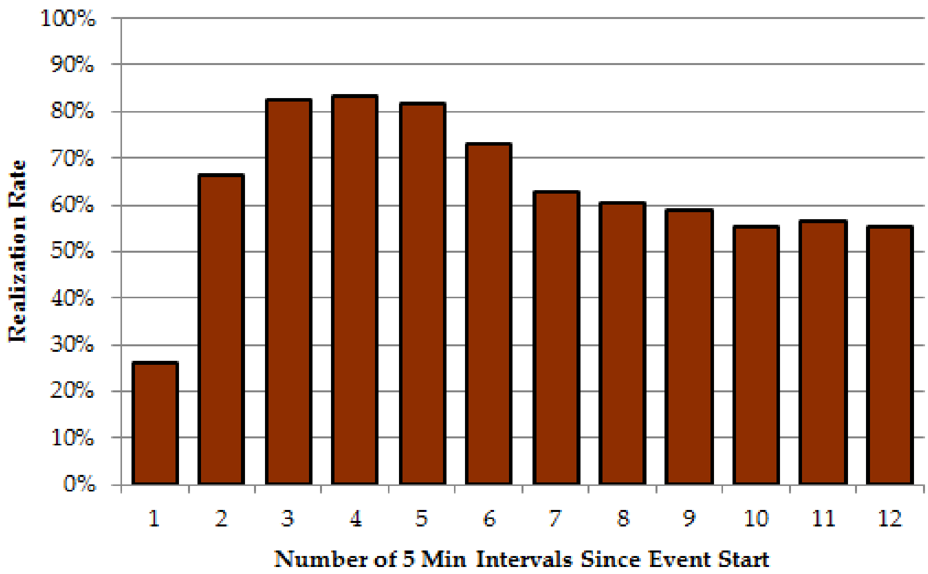


Note: A 100% realization rate implies that the participant achieved the contracted level of load curtailment.
Intervals represent metered demand average over a five-minute period.
Source: Navigant analysis using interval meter data provided by Hawaiian Electric

Figure 3. Speed of Load Curtailment

[9] Hawaiian Electric's five-minute meter data is an average load over a given five-minute interval. Therefore, the first five-minute interval after the start of an event represents the average load over the first five minutes—and *not* the instantaneous load *after* five minutes. As such, the data allow only for an estimate of the load reduction during a five-minute window. In order to assess whether customers were able to curtail a given amount of load within 10 minutes of an event, one must review the average load curtailment for both the second and third intervals, which represent the average curtailment between 5 minutes and 10 minutes, and between 10 minutes and 15 minutes, respectively.

Figure 3 above suggests that there is some decrease in load curtailment during the intervals following the first 15 minutes (i.e., that impacts do not persist). The authors analyzed the average realization rate by 5-minute interval across all customers and all events (including events of 30-minute, 45-minute, and one-hour durations). Figure 4 suggests that impacts seem to persist reasonably well for short periods, but begin to degrade somewhat after the first 25 to 30 minutes. This may present some limitations in using Fast DR as a bridge resource if 30 minutes proves insufficient to bring online an alternate generating unit.



Note: A 100% realization rate implies that the participant achieved the contracted level of load curtailment. Intervals represent metered demand average over a five-minute period.
Source: Navigant analysis using interval meter data provided by Hawaiian Electric

Figure 4. Persistence of Load Impacts over the Event

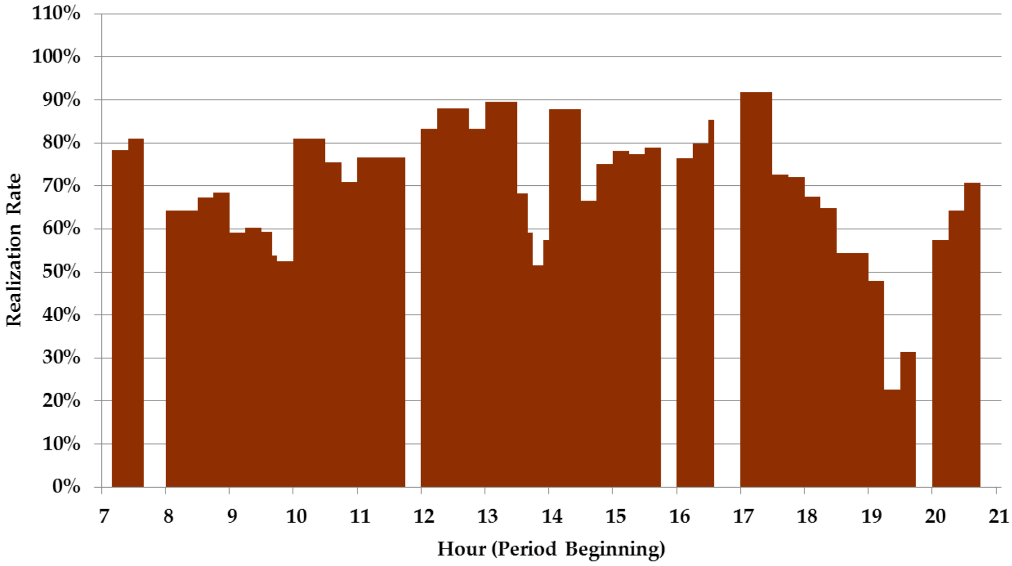
Consistency of Load Curtailment

For the final component of the evaluation of load impacts, the authors analyzed the consistency of the impacts at different times of day and across events. Figure 5 shows a smoothed realization rate by time-of-day. On average, realization rates tend to increase slightly throughout the morning, peak around mid-afternoon, and decline in the evening.[10]

To assess the ongoing reliability of DR capacity, the authors conducted an analysis of the degradation of impacts across events. When the realization rates for a given participant (or on average across participants) are consistently lower in each subsequent event, then the DR capability of the program may be said to be degrading. Figure 6 shows the average realization rate for all customers during the first event for which each customer was called, the second event each customer was called, etc. While there is significant inconsistency in the realization rates over the course of the pilot, there is no apparent trend of growing or declining curtailment, and the authors found no statistically significant change in realization rate as customers participated in more events.[11]

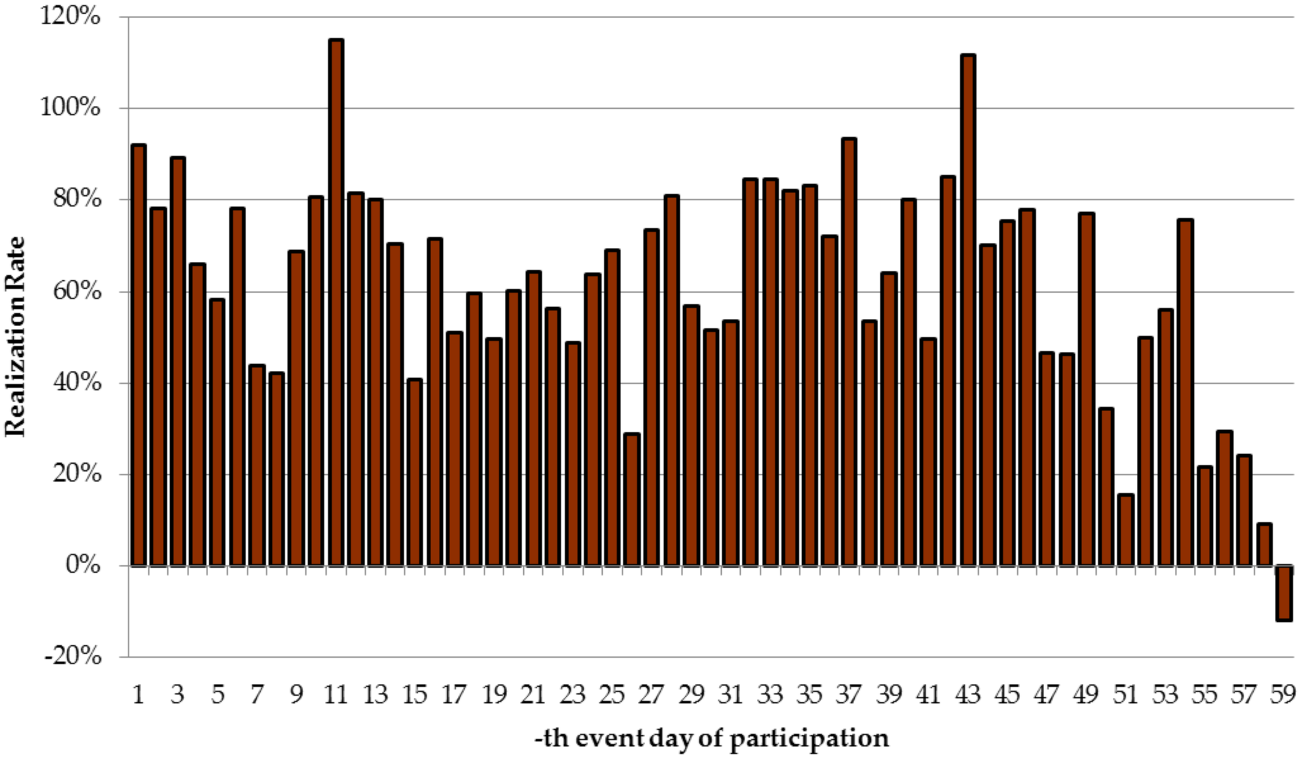
[10] The smoothed realization rate is derived simply by taking the average realization rate for each event, applying that average to each of the intervals on that event, and then taking the average of those numbers across all events by interval. On average, for any of the given intervals presented in the figure, there are only three events. There may be as many as seven events for some intervals (e.g., the intervals immediately following 9 a.m.) or as few as one or two events (e.g., the intervals between 7 p.m. and 8 p.m.).

[11] The statistical significance analysis was conducted on just the 37 events with five or more participants (represented by the values 1 through 37 on the x-axis). Since customers enrolled at different times over the course of the pilot, only four customers experienced more than 37 events; the 22 events that one or more of these customers participated in are represented by the values 38 through 59 on the x-axis.



Note: A 100% realization rate implies that the participant achieved the contracted level of load curtailment.
Source: Navigant analysis using interval meter data provided by Hawaiian Electric

Figure 5. Load Impacts by Time-of-Day



Note: A 100% realization rate implies that the participant achieved the contracted level of load curtailment.
Source: Navigant analysis using interval meter data provided by Hawaiian Electric

Figure 6. Degradation of Load Impacts Across Events

Conclusion

As more utilities in Europe increase their reliance on variable renewable energy sources, it will become harder to maintain the stability of the electric grid without additional resources to provide ancillary grid services. Hawaiian Electric's Fast DR pilot is providing much needed insight into whether, how, and what types of DR resources can be used to help maintain system stability. With the recent changes in the European regulatory environment that are removing barriers to demand response (Navigant Research 2013), Fast DR may warrant consideration among Europe's utilities with growing penetrations of renewables.

The Fast DR pilot has demonstrated relatively reliable, automated load curtailments in response to Hawaiian Electric's initiation of Fast DR events. However, pilot participants achieved on average only two-thirds of their contracted load reductions. More importantly, participants are not achieving full load curtailments within 10 minutes, and the magnitude of reductions begins to degrade beyond about 30 minutes.

The authors' evaluation indicates Fast DR to be an effective resource, but one which may need improvements in ramp-up speed and consistency before it could be relied upon as a replacement for generation in supporting grid functions.[12] Additional operational experience and evaluation of impacts would be valuable in attaining a more robust characterization of a Fast DR resource. Furthermore, utilities considering Fast DR for renewables integration should ensure system operators are adequately equipped to use the resource as intended. For example, a weather sensor network could provide system operators with 10-minute photovoltaic or wind generation capacity forecasts, allowing operators to match short-term needs with the available Fast DR resource, mitigating the risk of contingencies on their network. For its part, even as the Fast DR pilot winds down, Hawaiian Electric is already embarking on a path toward newer program concepts and technologies, such as grid-interactive water heating, that the company intends to utilize for a variety of grid services (Viola 2014).

This paper presented findings regarding the evaluation of the operational experience of Fast DR, one of the four objectives of the pilot program. Based on the operational experience to date, Fast DR shows promise, but there is not yet enough evidence to conclude how significant of a resource it can be in mitigating the problems of increasing penetrations of intermittent renewables on the grid. As part of the assessment of the viability of Fast DR, the authors are also conducting a market assessment, an assessment of technical readiness, and an analysis of the cost-effectiveness of a full-scale Fast DR program. As findings from this broader assessment are finalized, a clearer picture will emerge regarding the future role of Fast DR in addressing potential grid instability from renewable energy.

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[12] In any future DR programs used for ancillary services, Hawaiian Electric anticipates calculating performance metrics according to the PJM Interconnection's Performance Score Calculation, described in *PJM Manual 12: Balancing Operations, Revision 30*, Effective Date, December 1, 2013, p. 52.

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