SCE DRET Findings
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DR10.16: Demand Response Potential of Residential Appliances – Refrigerator test

REFRIGERATOR PERFORMANCE IN DEMAND RESPONSE EVENTS

In the residential sector, smart appliances are the key to realizing the full potential benefits of the smart grid. Such appliances achieve the highest levels of energy efficiency during normal operation and are also capable of responding to demand response (DR) events—periods when utilities need to drop electric load to manage pricing peaks or grid reliability events. Appliance manufacturers have embraced DR functionality and are just beginning to release their first DR-capable products.

Conceptually, DR allows the utility to send a signal to a customer's smart meter to alert it to high price conditions or in response to a critical adverse grid condition requiring a quick reduction in connected load to prevent widespread grid failure. The DR signal is then re-broadcast from the smart meter to the home area network (HAN) or to smart appliances, which react by reducing load as much as possible. Smart appliances have built-in algorithms that allow them to determine whether they can respond to the signal while maintaining an acceptable level of service to the consumer.

This report describes one part of a larger Southern California Edison (SCE) effort to evaluate the DR capabilities of various residential appliances in a laboratory environment. As noted above, several manufacturers have recently developed DR-capable appliances, but little is known about how DR capabilities will be implemented. This testing will give SCE a better understanding of how specific appliances will react to certain DR signals before these appliances are installed at customer sites. Future efforts may use this information to project grid impacts of large-scale adoption of this technology.

The overarching DR Appliance project is aimed at three types of residential appliances: refrigerators, dish washers, and clothes washers. This report is focused on refrigerator A, manufactured by a company referred to as manufacturer A.

INTRODUCTION

Why are residential appliances important to DR?

The 2009 California Residential Appliance Saturation Survey (RASS) 2 determined that annual refrigerator energy consumption ranged between 660–827 kilowatt-hours (kWh) for the first refrigerator in a residential unit. This population likely includes many older, less efficient units. For new homes (which most likely include new appliances), the average was 707 kWh versus 778 kWh for old homes. New refrigerators that qualify for ENERGY STAR® typically consume 500 kWh annually.

Power consuming components in a refrigerator typically include the compressor, evaporator fan(s), condenser fan, anti-sweat heater (ASH), lights, ice maker, ice dispenser, and defrost heater. The operation patterns and typical power demand of individual components or systems of components are detailed in Table 1.

Because all of these systems and components operate in response to different stimuli, predicting the operation of refrigerators can become extremely complex, even under controlled conditions.

Most manufacturers choose to add DR capability onto their already-efficient products, as the energy-aware consumer is the most likely to demand, and ultimately take advantage of, DR capability. These efficient units also have higher levels of sensing and control technology incorporated into their design, making it simpler to incorporate DR as an extra feature.

What was done?

The goal of this project is to observe the refrigerator's response to DR signals and quantify the demand reduction that can be expected during different segments of the operation cycle.

2 main series of tests were conducted:

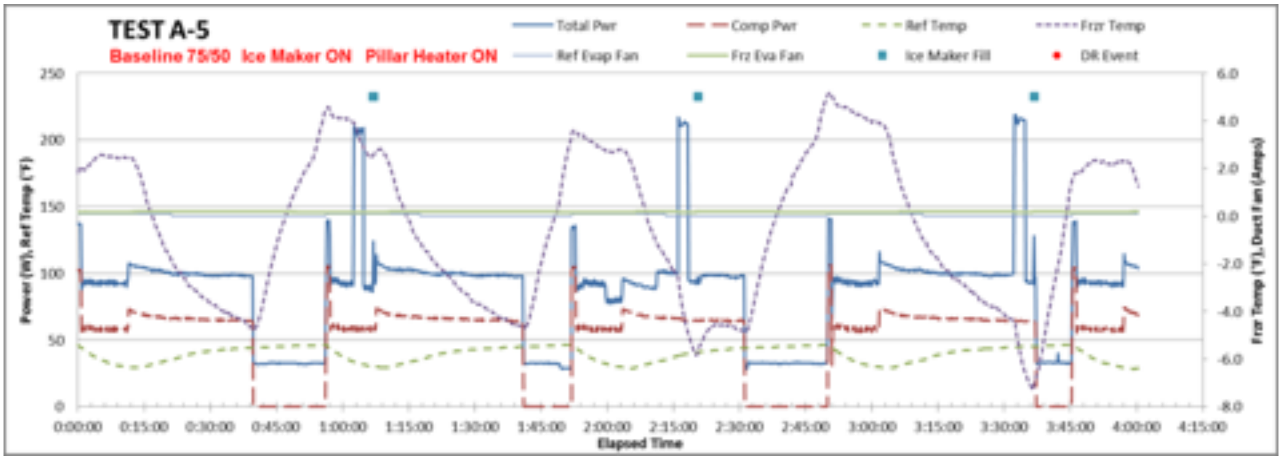
- **Baseline tests** to acquire typical power profile data for the refrigerator running under various normal conditions such as ambient temperature and humidity as well as various periods of operation such as compressor cycle, ice making, defrosting, and door opening.
- **DR tests** to observe and quantify the refrigerator's response during short DR High events (spinning reserve), defined as 8 minute durations and Critical events (Delay Load) defined as having an hour long duration. Tests would be conducted under the various baseline conditions evaluated: such as ambient temperature and humidity; as well as various periods of operation, such as compressor cycle, ice making, defrosting, and door opening.

The tests were conducted in SCE's Technology Test Center. Ambient conditions were controlled and set to simulate a typical kitchen situation with space conditions at 75oF and 50% Relative Humidity, RH , and a garage setting where conditions were set to 90oF and 30%RH, and 105oF and 19.5% RH.

TABLE 1. OPERATION PATTERN AND TYPICAL PATTERN OF REFRIGERATION COMPONENTS

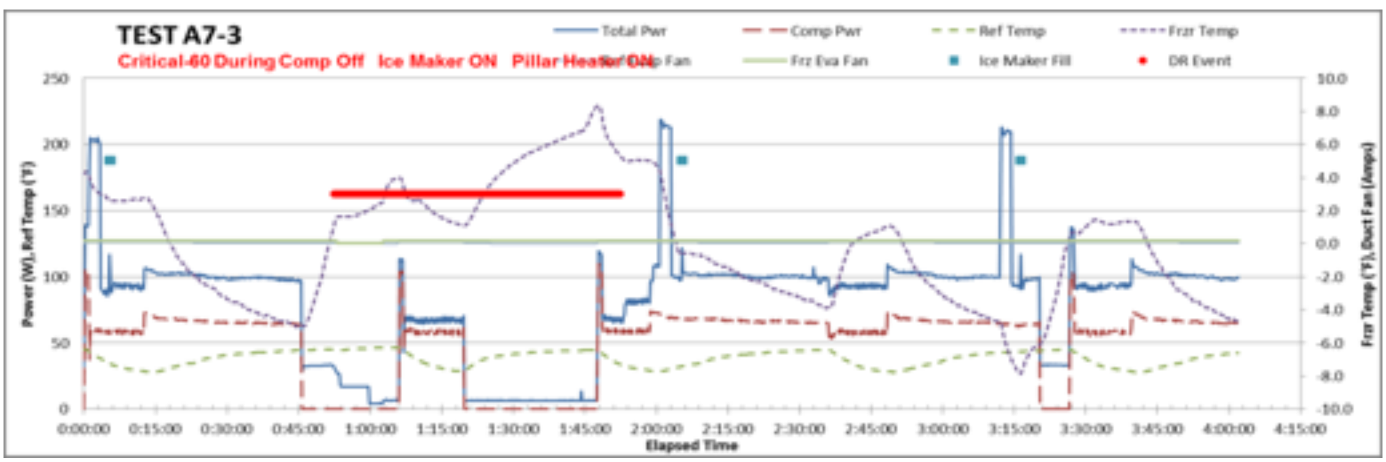
SYSTEM	PURPOSE	OPERATION PATTERN	COMPONENTS	TYPICAL POWER (WATT)
Refrigeration	Maintains refrigerator temperature and freezer cabinet temperature	Continuous according to thermostat	Compressor Condenser fan Evaporator fan(s)	100 5 5
Anti-Sweat Heat	Prevents moisture (dew) from forming on door/frame	Continuous with compressor cycling	Anti-sweat heater	10
Lights	Illuminates cold cabinet for user	With door opening	Lights and drivers/ballasts	10
Ice Making	Supplies batches of ice cubes to the ice bin	Based on ice bin fill sensor	Compressor Fan Heaters	100 5 20
Ice Dispensing	Dispenses ice in cube or crushed form	With user activation	Auger Crusher	20 100
Defrost	Removes ice and frost from evaporator coil	Periodic based on proprietary algorithms	Defrost heater	350

BASELINE PROFILES Baseline operational profiles were established for power and refrigerator and freezer temperatures. The profile below, Test A-5 is the refrigerator operating in a manner consistent with normal consumer actions in a kitchen, with the ice maker and pillar heater (anti-sweat heater) turned ON.



1. Total Power, solid blue line. The ice maker produces a batch of ice cubes approximately every hour and fifteen minutes. The spike on the total power correlates to the ice ejection heater, which allows it to dump the cubes out of the tray.
2. Compressor power, dashed red line, cycles on/off based on freezer temperature.
3. Freezer temperature, dashed purple line.
4. Refrigerator temperature, dashed green line.

DR PROFILES DR operational profiles were established for power and refrigerator and freezer temperatures. The profile below, Test A7-3, is the refrigerator operating in a kitchen setting under a Critical event showing the reduction in power from elimination of ice maker and anti-sweat heaters.



1. Solid Red line, is the DR Event, Duration of 60 minutes.
2. Dashed Red line, shows the compressor is off at the start of the event.
3. Shows the freezer temperature, dashed purple line, increases over the duration of the event and the compressor is allowed to cycle on after the temperature reaches a critical value.
4. Freezer temperature decreases to acceptable levels and the compressor cycles off.
5. Freezer temperature increases over the duration of the event and the compressor is allowed to cycle on after the temperature reaches a critical value.

CONCLUSIONS

What We Concluded?

Overall, the refrigerator was able to achieve power reductions in response to DR events in most instances. Under normal residential kitchen operating conditions, the refrigerator generated demand reduction of approximately 90 watts (W) for longer-duration DR event signals. This amount of demand reduced depended on a number of factors, including the operational status of various components, ambient conditions, and the type of signal received. For High level events, small reductions were observed immediately and larger compressor reductions resulting from increased set points occurred after some delay. Because of the delays, the reductions did not necessarily fall within the event duration for very short (8-minute) events tested here. For Critical events, mandatory compressor and fan OFF cycles, combined with increased temperature set point, provided predictable long-lasting power reductions. However, based on observations from the tests, it is unlikely that savings would persist more than an hour, as temperatures would begin to creep up and compressors would start to cool the space back down. Longer DR event durations that might have tested savings persistence were not included in this test scope.

These Findings are based on the report "Demand Response Potential of Residential Appliances – Refrigerator A" which is available from the ETCC program website, https://www.etcc-ca.com/reports.

Lessons Learned

Consistent operational profiles were developed for Refrigerator A which can lead to reliable baseline references. Repeatable profiles for power and temperature were also established for the refrigerator under DR conditions for the various operational situations. The results show that for Critical events, mandatory compressor and fan OFF cycles, combined with increased temperature set point, provided predictable long-lasting power reductions. However, based on observations from the tests, it is unlikely that savings would persist more than an hour, as temperatures would begin to creep up and compressors would start to cool the space back down. Longer DR event durations that might have tested savings persistence were not included in this test scope.

DR events can take several different forms; some may last an entire afternoon due to increased stress on the grid from a heat wave while others may be in response to an isolated catastrophic event on the grid. In the case of an immediate response, the duration of the event may be unknown. It is highly unlikely that a utility would call an event with duration shorter than 10 minutes. Thus, the only way to take advantage of the spinning reserve capability would be as part of an aggregating program where multiple communicating refrigerators are successively cycled through spinning reserve events.

For the longer duration events, individual units would be able to respond with smaller power reductions for longer periods of time. But, for very long events (such as an event lasting the 12:00–6:00 summertime peak on SCE's system), a single event with a 4-hour maximum duration limit could not take care of the entire time period. Thus, the participating units would again need to be broken into aggregated response groups to attain benefit through the entire period.

TECHNOLOGY IMPROVEMENTS

At a higher level, there appears to be a disconnect between utility needs during DR events, the AHAM definitions of spinning reserve and delay load, and the prescribed refrigerator response to each type of signal. Future interaction with AHAM and standards-setting agencies will attempt to address these issues. Furthermore, understanding of the response of other smart appliances and computer simulation of grid-wide DR events that account for account usage diversity and duty cycles are necessary to fully understand the achievable impact of adoption.