# Performance Test Results: CTA-2045 Variable Speed Pool Pumps

*Testing Conducted at the National Renewable Energy Laboratory*

**3002011749**

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Technical Update, November 2017

EPRI Project Manager

C. Thomas

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# ABSTRACT

Utilities and manufacturers are assessing the CTA-2045 communication standard, published by the Consumer Technology Association (CTA) (previously Consumer Electronics Association (CEA)) to determine the degree to which it meets the needs of consumers, aggregators, and utilities. The Electric Power Research Institute (EPRI) is facilitating a collaborative project specifically studying the extent to which CTA-2045 provides compatibility and interoperability with the wide range of systems into which consumer loads might be connected. If a modular interface works as intended, achieving interoperability and being self-installable by consumers, it could significantly advance the state of demand response worldwide. One of these systems is a Variable Speed Pool Pump, and this report details laboratory evaluations of the system's capabilities.

## Keywords

CEA-2045
CTA-2045
Variable speed pool pump
Smart grid
Demand response
DR ready

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# 1

# INTRODUCTION

In 2013 the Consumer Electronics Association[1] (now called the Consumer Technology Association) released the ANSI/CEA-2045 standard. This standard defines a modular communication interface intended to be designed into end-use loads to enable demand response (DR). The CEA-2045 standard has been described in detail in EPRI report 3002004020, *Introduction to the CEA-2045 Standard*[2].

Utilities and manufacturers are assessing this new standard to determine the degree to which it meets the needs of consumers, aggregators, and utilities. Electric Power Research Institute (EPRI) is facilitating a collaborative project that is specifically studying the extent to which CEA-2045 provides compatibility and interoperability with the wide range of systems into which consumer loads might be connected. If a modular interface works as intended, achieving interoperability and being self-installable by consumers, it could significantly advance the state of demand response worldwide. A detailed description of the CEA-2045 Field Demonstration project, including its goals and plan, has been provided in EPRI report 3002004009, *ANSI/CEA-2045 Field Demonstration Project Description*[3].

In addition to the field demonstration described above, the EPRI and a team of partners were selected by the National Renewable Energy Laboratory (NREL) to carry out a project to develop and test how smart, connected consumer devices can act to enable the use of more clean energy technologies on the electric power grid. This project was a component of the NREL Integrated Network Test-bed for Energy Grid Research and Technology (INTEGRATE) initiative and was awarded under RFP Number RCS-4-42326, Topic 1, “Connected Devices”.

The project team includes the following end-use technologies and companies, each of which are market leaders in their fields. All of which were installed and tested at NREL’s Energy Systems Integration Facility (ESIF) in Golden Colorado.

- Electric Vehicle Service Equipment (Siemens)
- Thermostat (Emerson)
- Solar Inverter (Fronious)
- Pool Pump (Pentair)
- Water Heaters (AO Smith)

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[1] Now known as the Consumer Technology Association.

[2] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004020

[3] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004009

## Device-Type Specific Requirements for CTA-2045 Devices

The end-use devices (loads) tested in this project were all designed using device-type specific requirements.  These requirements and links to each document are listed in Table 1-1.  The requirements were created through a collaborative effort by which utilities and technology providers participated.  The intent of these requirements is to provide guidance by which manufacturers of end-use devices, communication hardware, and other service providers could use to help create a predictable, interoperable, data rich architecture.

**Table 1-1**
**Device-Type Specific Requirements**

| Document Name | EPRI Product ID |
|---|---|
| Demand Response-Ready Domestic Water Heater Specification, Preliminary Requirements for CEA-2045 Field Demonstration | 3002002710 |
| Demand Response-Ready Thermostat Specification, Preliminary Requirements for CEA-2045 Field Demonstration | 3002002711 |
| Demand Response-Ready Electric Vehicle Service Equipment Specification, Preliminary Requirements for CEA-2045 Field Demonstration | 3002002712 |
| Demand Response-Ready Heat Pump Water Heater Specification, Preliminary Requirements for CEA-2045 Field Demonstration | 3002002719 |
| Demand Response-Ready Variable-Speed Pool Pump Specification: Preliminary Requirements for CEA-2045 Field Demonstration | 3002008320 |

The tests conducted at NREL were done so to measure the performance characteristics of each end-use device so that their potential to support the integration of renewables can be evaluated.  This report includes the results from the Variable Speed Pool Pump tests.

# 2

# VARIABLE SPEED POOL PUMP

This document presents the test results from the Pentair IntelliFlo Swimming Pool Pump and Pentair and the CTA2045 Pentair demand response controller.

Development testing was performed at Pentair and EPRI and the final testing reflected in this document at the NREL ESIF Smart Power Laboratory (SPL) during a series of onsite visits by team members.

The test plan that guided this testing has been documented separately.

## Test Setup

Figure 2-1 shows the test setup used for the Pentair IntelliFlo pool pump testing at NREL. All testing was conducted using a normal grid connection feeding the AC circuit. The NREL laboratory SCADA system included the following sensors and controls that were used in this test:

- Real power consumption of the IntelliFlo pool pump

In addition, Pentair monitored the following directly from the Pentair Demand Response device using the CEA-2045 Simulator software:

- Present power consumption
- Cumulative energy consumption
- Present energy-take capability
- Present operating state
- Consumer override

Pentair provided the following monitoring equipment with the pump demonstration unit to supplement the laboratory data acquisition system:

- Flow meter to measure gallons per minute
- Power Monitor

The Pentair Demand Response Controller provides RPM and watt readings polled from the IntelliFlo pump.

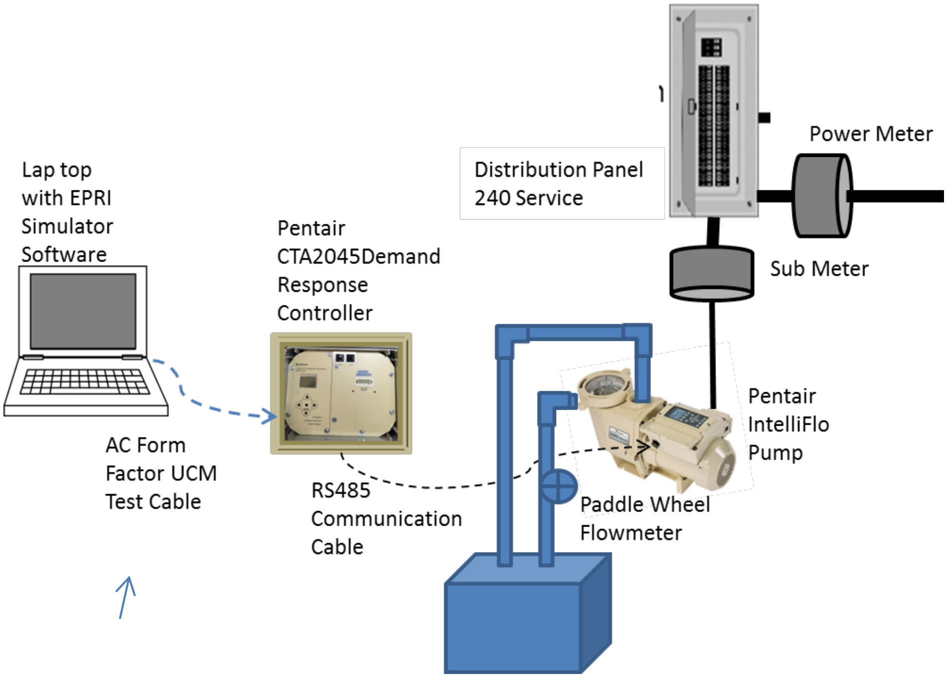


**Figure 2-1**
**Swimming Pool Pump Test Setup**

Figure 2-2 shows the installed Pool Pump Demonstration unit in the laboratory at NREL.

**PRI Simulator Software (Top Left), Pentair Demand Response Controller (Bottom Left) and the Pentair IntelliFlo Pool pump demo with computer monitor displaying Flow rate, watts and pressure.**

**Figure 2-2**
**Pentair Test Setup at NREL**

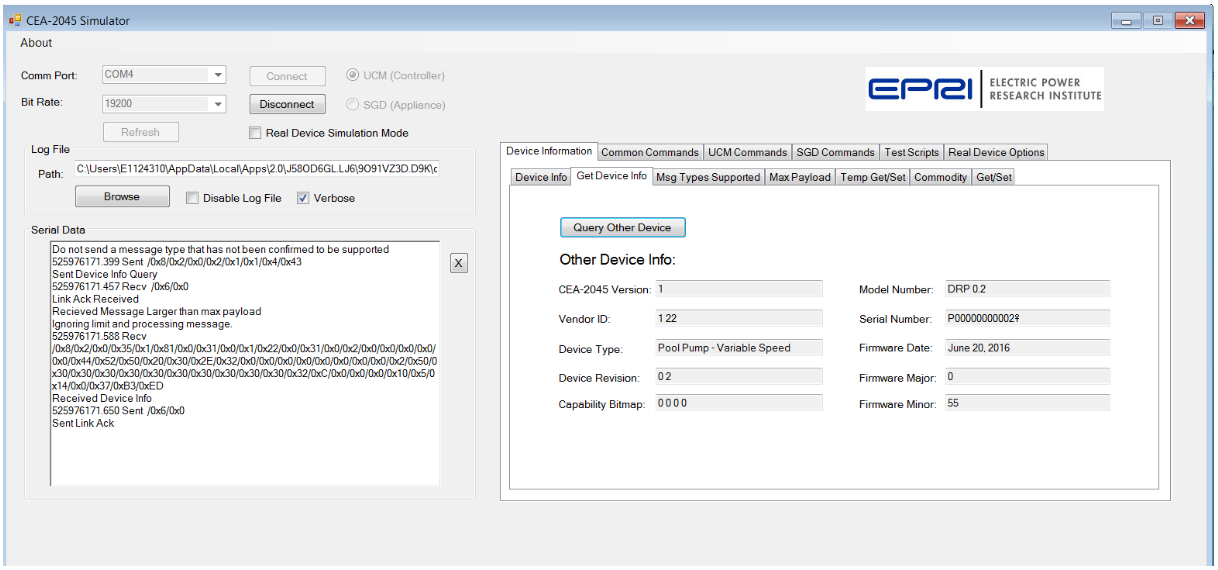
Figure 2-2 shows the EPRI simulator software (top left), Pentair demand response controller (bottom left), and the Pentair IntelliFlo pool pump. The arrangement included a computer monitor displaying flow rate, real power, and pressure also provided by Pentair and shown to the right. The paddle wheel flow meter is not visible.

## Device Identification

As indicated in Figure 2-1, the EPRI CEA-2045 Simulator software was used to communicate with the demand response control box via the standard ANSI/CEA-2045 interface and associated test cable. The Control box shown in Figure 2-3 monitors the status of the pump, indicates system status and manages the pumps behavior throughout the test. This software is designed to plug-in directly to the CEA-2045 port interface at which communication modules would normally be connected.

**Figure 2-3**
**Demand Response Controller with ANSI/CEA-2045 AC Test Cable**

The unit's identification was queried and reported as indicated in Figure 2-4. This includes a device-type code indicating "Pool Pump", as well as a unique vendor ID, serial and model numbers.



Comm Port: COM4

Bit Rate: 19200

● UCM (Controller)

○ SGD (Appliance)

☐ Real Device Simulation Mode

Log File

Path: C:\Users\E1124310\AppData\Local\Apps\2.0\J58OD6GL.LJ6\9O91VZ3D.D9K\c

☐ Disable Log File ☑ Verbose

Serial Data

```
Do not send a message type that has not been confirmed to be supported
525976171.399 Sent  /0x8/0x2/0x0/0x2/0x1/0x1/0x4/0x43
Sent Device Info Query
525976171.457 Recv  /0x6/0x0
Link Ack Received
Recieved Message Larger than max payload
Ignoring limit and processing message.
525976171.588 Recv
/0x8/0x2/0x0/0x35/0x1/0x81/0x0/0x31/0x0/0x1/0x22/0x0/0x31/0x0/0x2/0x0/0x0/0x0/0x0/
0x0/0x44/0x52/0x50/0x20/0x30/0x2E/0x32/0x0/0x0/0x0/0x0/0x0/0x0/0x0/0x0/0x2/0x50/0
x30/0x30/0x30/0x30/0x30/0x30/0x30/0x30/0x30/0x30/0x32/0xC/0x0/0x0/0x0/0x10/0x5/0
x14/0x0/0x37/0xB3/0xED
Received Device Info
525976171.650 Sent  /0x6/0x0
Sent Link Ack
```

Other Device Info:

CEA-2045 Version: 1

Vendor ID: 1 22

Device Type: Pool Pump - Variable Speed

Device Revision: 0 2

Capability Bitmap: 0 0 0 0

Model Number: DRP 0.2

Serial Number: P00000000002♀

Firmware Date: June 20, 2016

Firmware Major: 0

Firmware Minor: 55

**Figure 2-4**
**Communication Interface Showing Device Identification**

## Baseline Behavior

The CEA-2045 standard identifies four monitorable parameters that are of particular relevance to pool pumps and are supported by the Pentair Demand Response control product.

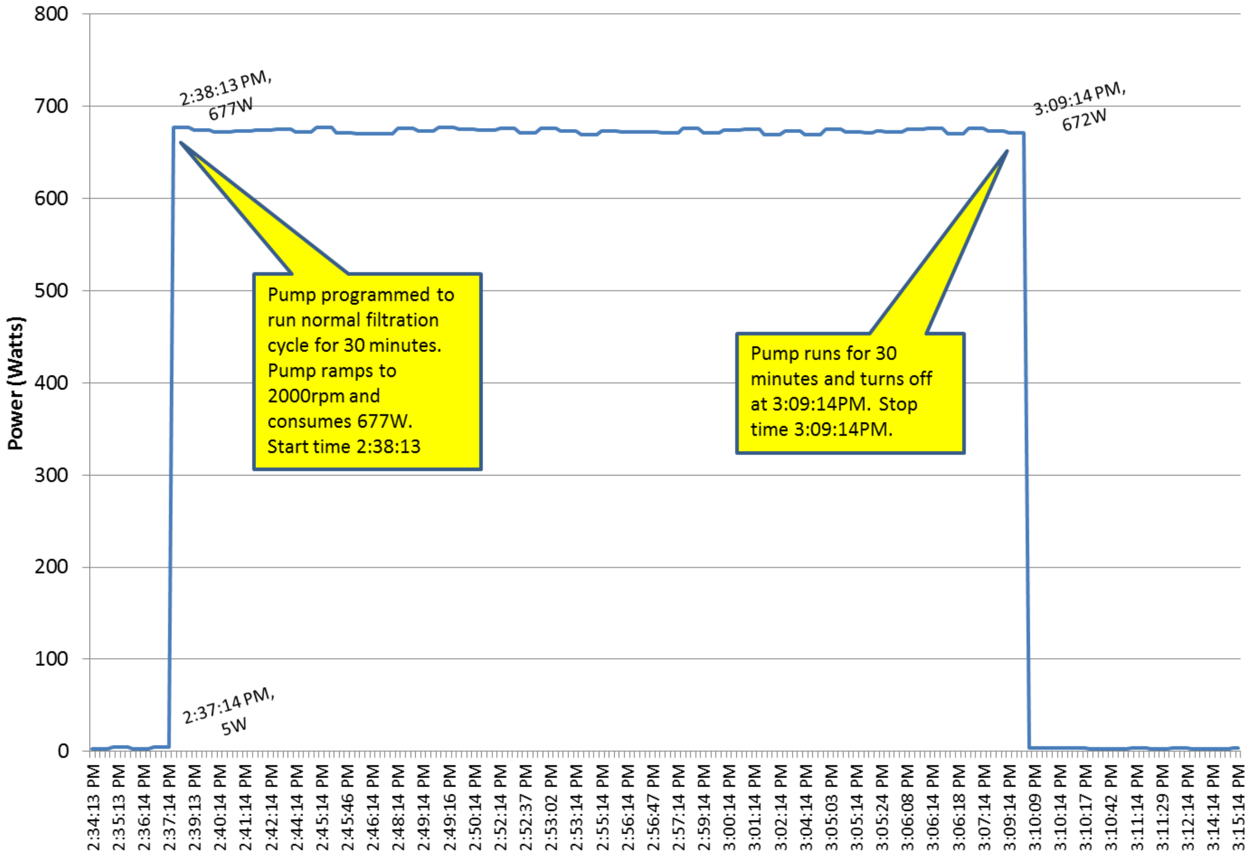
- Present power consumption (an estimated value)
- Cumulative energy consumption (based on the estimated power values)
- Total energy-take (energy storage) capability – computed based on the pool pumps filtration schedule and speed ([RPM]).
- Present energy-take (energy storage) capability – a calculated value in Wh indicating how much energy the pool pump can take at the present time.

Variable speed pumps offer a high degree of flexibility.  Unlike some other device types that directly impact consumer comfort, variations in pool pump speed/power can often go unnoticed by the homeowner.  In addition, with smart responses, variations can be achieved with no compromise in daily circulation or water quality.

As will be seen in the test data that follows, the Pentair Connected demand response controller calculates lost flow as it responds during curtailment events and compensates at other times so that the intended daily circulation is achieved.  Conversely, if a load-up event occurs (asking the pump to operate sooner or faster), the extra circulation is subtracted from the pumps schedule so that no unneeded circulation occurs and energy is not wasted.

Installation of variable speed pumps has greatly increased over the years in part due to the immediate energy savings realized by the homeowner and the reduction in noise since the pump is running at a fraction of the speed of the single speed pump that it replaced.

Figure 2-5 provides a view of the baseline settings for the pool pump as configured for the testing at NREL. As indicated, the pump began its filtration cycle at 2:38pm. The filter time was set for a 30 minute run time at a speed of 2000[[RPM]]. Typical pool pump daily run-time would be longer (e.g. 8-12 hours) in order to meet filtration needs, but was set to only 30 minutes to simplify laboratory testing.



Pump programmed to run normal filtration cycle for 30 minutes. Pump ramps to 2000rpm and consumes 677W. Start time 2:38:13

Pump runs for 30 minutes and turns off at 3:09:14PM. Stop time 3:09:14PM.

**Figure 2-5**
**Baseline Behavior**

At the programmed speed of 2000[[RPM]] in the closed-loop demonstration system, the pump consumed 675[W]. This level is slightly higher than would be seen on a typical swimming pool application at the same speed. For example, using the California Energy Commission's system curve "C" for the average pool, the pump would consume 600[W] with flow at approximately 56[gpm]. This speed would create ample filtration for most swimming pools while also providing the correct flow to operate auxiliary devices like cleaners, heaters, etc. As indicated in the baseline data, the pump turned on at 2:37PM and off at 3:09PM for an approximate run time of 30 minutes.

## Visual Indicators

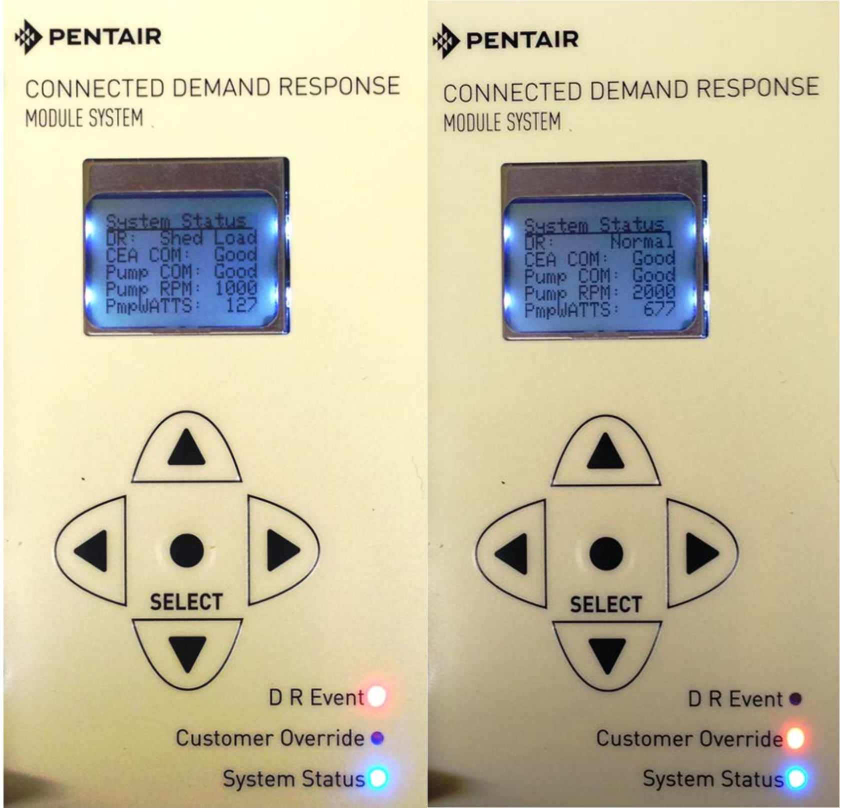
The Pentair Connected Demand Response Module includes an LCD display and LED visual indicators as shown in Figure 2-6 and with the following display capabilities:

- LCD Screen: Read out indicates Normal when there is no DR event and reads out the name of the DR event when one is active.
- Status of CEA module. Good or Bad
- Status of communication to the pump. Good or Bad
- Pump RPM
- Pump Watts

**DR Event LED:** This indicator illuminate's red indicating there is an active demand response event in effect. Unlit, indicates normal pump operation with no demand response event.

**Customer Override LED:** Illuminates orange indicating a customer override is in effect.

**System Status LED**: Illuminates solid blue indicating the system is operating normally. A blinking blue system status indicates a problem with the system. This can be triggered by pump alarms or lost communication with the pump or the CEA-2045 control module. The LED will also blink if the user disengages the pump by entering "Change pump parameters" or "Service Mode" in the menu.



```
System Status
DR:   Shed Load
CEA COM:   Good
Pump COM:  Good
Pump RPM:  1000
PmpWATTS:   127
```

```
System Status
DR:      Normal
CEA COM:   Good
Pump COM:  Good
Pump RPM:  2000
PmpWATTS:   677
```

**Figure 2-6**
**Visual indicators with DR Event in progress (left) and Customer Override (right)**

### Shed Event

The results from the testing of the pool pump's basic "Shed" function are summarized in Figure 2-7. This test was conducted on August 17, 2016 at NREL. The pump was programmed to run a 30 minute filtration cycle at 2000[RPM] and consumed 675 [Watts] at this speed. The start time of scheduled operation was 4:21.

About 5 minutes into the scheduled operation, a Shed event was sent with 10 minute duration. The pump system responded to this event by reducing its speed in half (to around 1000[RPM]) and as indicated in Figure 2-7, consumed 132[Watts] at this speed.

The programmed 30 minute filtration cycle would have ended at 4:51 if there had not been a curtailment event. But because the shed event caused the pump to run at a reduced flow rate, the pump ran an additional 4 minutes and 15 seconds to make up for the loss in flow and complete the required circulation for the day.

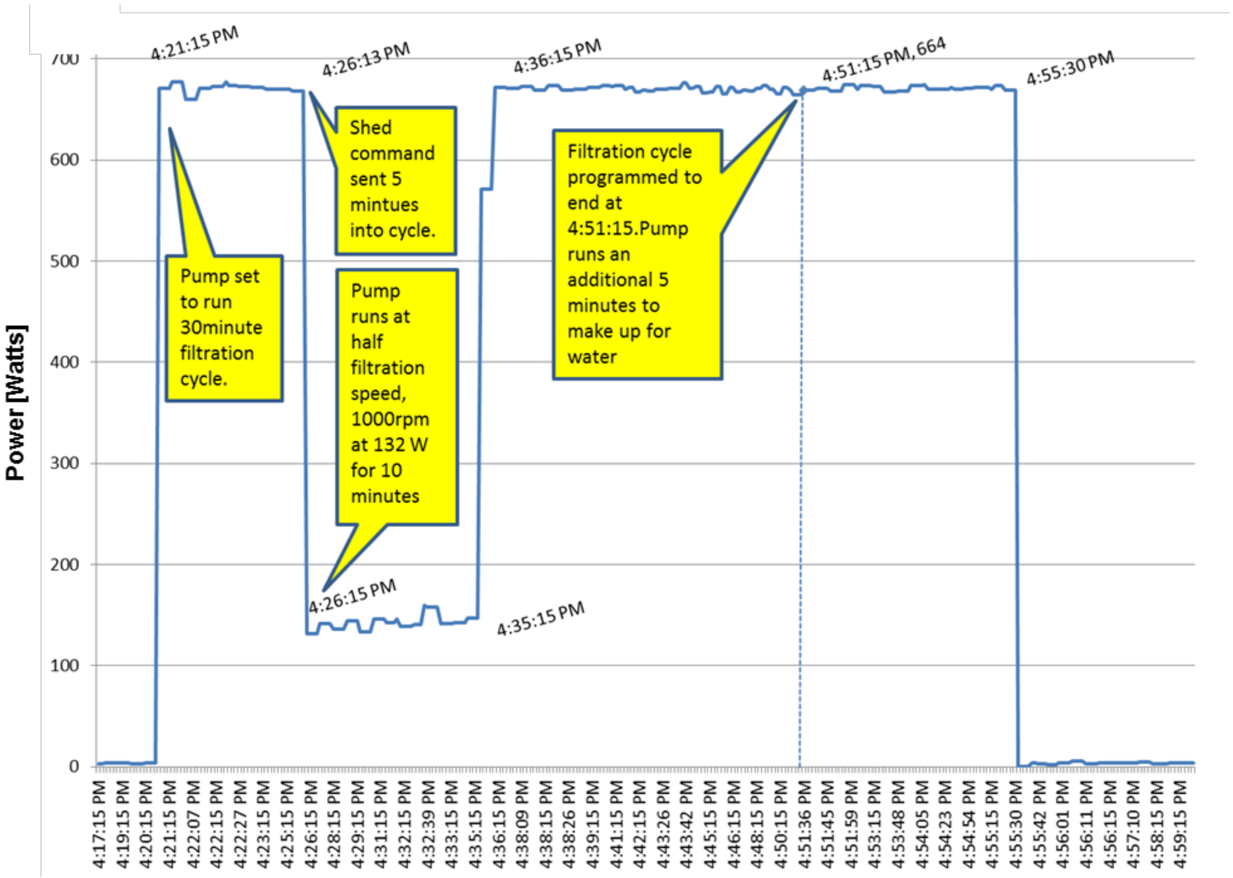


**Figure 2-7**
**Shed Event Results**

#### *Shed Event at 2800 [RPM]*

According to Pentair's design, when the filtration speed is 2800[RPM] or greater, a shed command will cause the pump to run at 1/3 of the filtration speed. In this test step, the filtration speed was set at 2800 [RPM] and, as indicated in Figure 2-8, the shed command caused the pump to run at 930[RPM]. The filtration time was set for 30 minutes and the shed command lasted approximately 10 minutes. The pump was scheduled to stop at 11:23:12 but ran and extra 6 minutes and 42 seconds to make up for the lost flow during the shed event. Because speed is directly proportional to flow it is straightforward to calculate the missed flow:

Subtract the curtailed filtration speed from the normal speed: 2800-930=1870.

Multiply the missed RPM by the shed time in minutes: 9 minutes and 48 seconds or 9.8 minutes. 9.8 X 1870 = 18,326 (rotations that were missed during the curtailment period).

Divide by the filtration speed (in this case 2800[RPM]) to get the extra run time in minutes. This equals 6.545 minutes or roughly 6 minutes and 33 seconds.

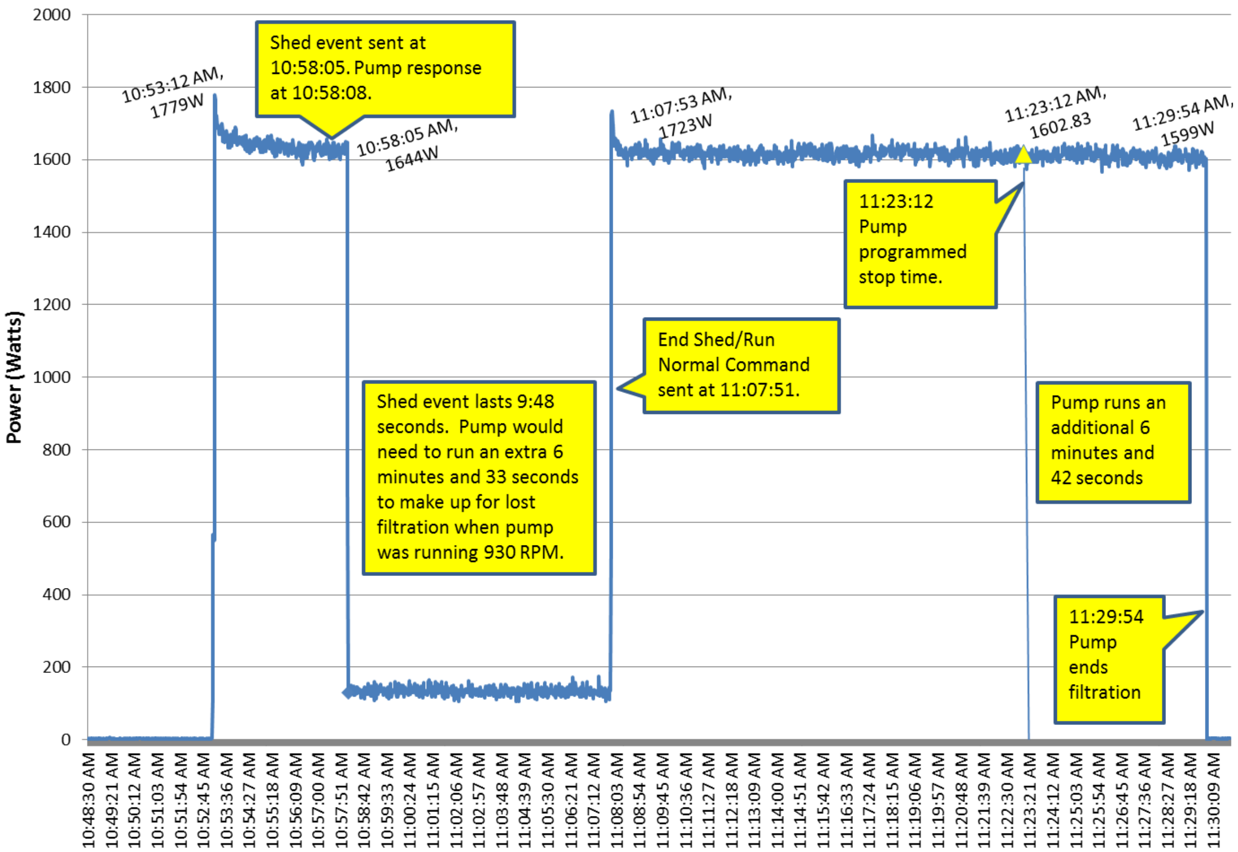


**Figure 2-8**
**Basic Shed at 2800[RPM]**

### *Basic Shed Function – with Early End-Shed Event*

This test uses the same control message (Shed) as in the previous test, but terminates it prematurely with an End Shed command. The results are shown in Figure 2-9. The pump reduced speed to 1000 [RPM] during the shed event which resulted in the power consumption dropping to around 142[W]. The shed event, which was originally sent with a 10 minute duration, was terminated early by way of an end-shed message. The pump responded by running past the programmed filtration stop time to make up for the shed event's actual time.

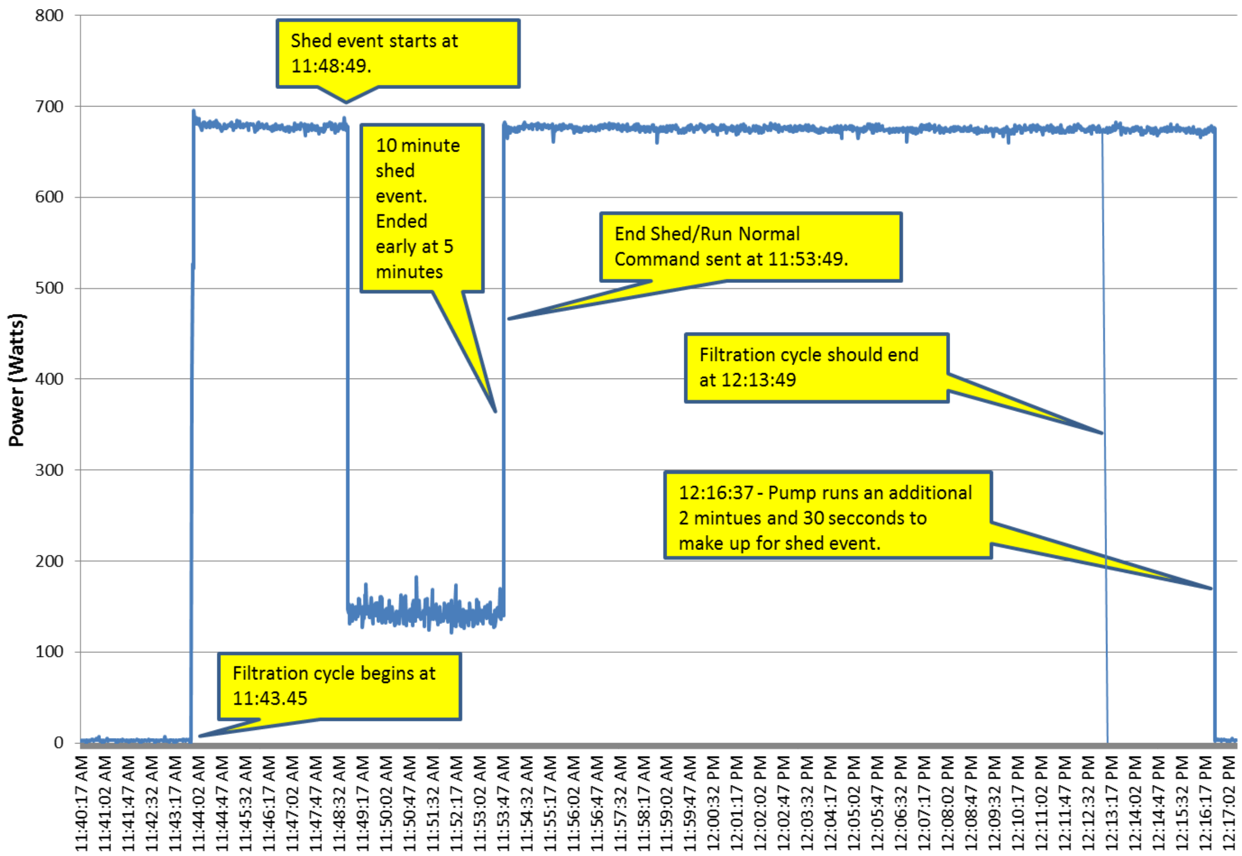
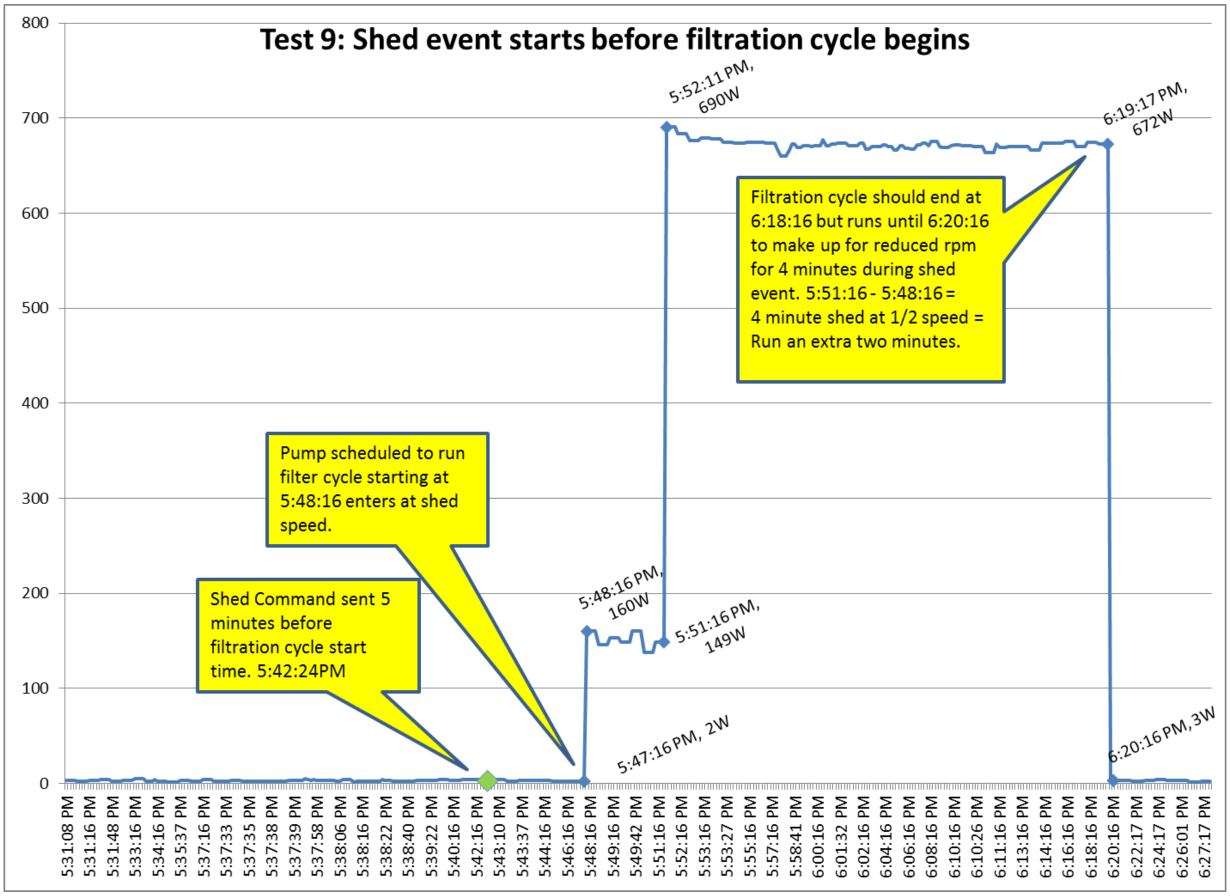


**Figure 2-9**
**Basic Shed Function with Early End-Shed**

### *Shed Event Before Filtration Cycle Begins*

This test was run to see if the pump would run when it was sent a shed command at a time when the pump was not operating. The pump was programmed with a 30 filtration time and a 9 minute and 38 second shed command was sent 5 minutes before the filtration cycle began. The pump started the filtration cycle at the programmed time of 5:48:16. The shed event lasted for four minutes from 5:48:16 to 5:51:16. The programmed stop time would be 6:18:16. The pump ran an extra two minutes stopping at 6:20:16. Perfect!


Test 9: Shed event starts before filtration cycle begins

Filtration cycle should end at 6:18:16 but runs until 6:20:16 to make up for reduced rpm for 4 minutes during shed event. 5:51:16 - 5:48:16 = 4 minute shed at 1/2 speed = Run an extra two minutes.

Pump scheduled to run filter cycle starting at 5:48:16 enters at shed speed.

Shed Command sent 5 minutes before filtration cycle start time. 5:42:24PM

**Figure 2-10**
**Shed Event Starts before filtration cycle begins**

## Critical Peak Event

The results from the test of the pool pumps “Critical Peak” function are summarized in Figure 2-11. This test was conducted on August 18, 2016 at NREL. The Critical Peak event was sent with a 5 minute time duration.

The pump began its regularly scheduled 30 minute filtration cycle at 12:40:15. The critical peak event was sent 5 minutes into the filtration cycle with a duration of 5 minutes. The pump dropped speed to 600[RPM] which is the default minimum speed set in the Pentair Connected Demand Response Module.

*Note: This minimum speed is adjustable in the setup menu (MinRPM) as there may be auxiliary items on the system which require a minimum flow rate. The relay built into the Demand response control module opened so if there are items that were operating on the system which require flows above the MinRLY default speed of 1000 [RPM] they would be turned off.*

The pump filtration cycle would have ended 30 minutes later at 1:10:15 but ran an extra 3 minutes and 51 seconds to make up for the lost flow during the critical peak event.

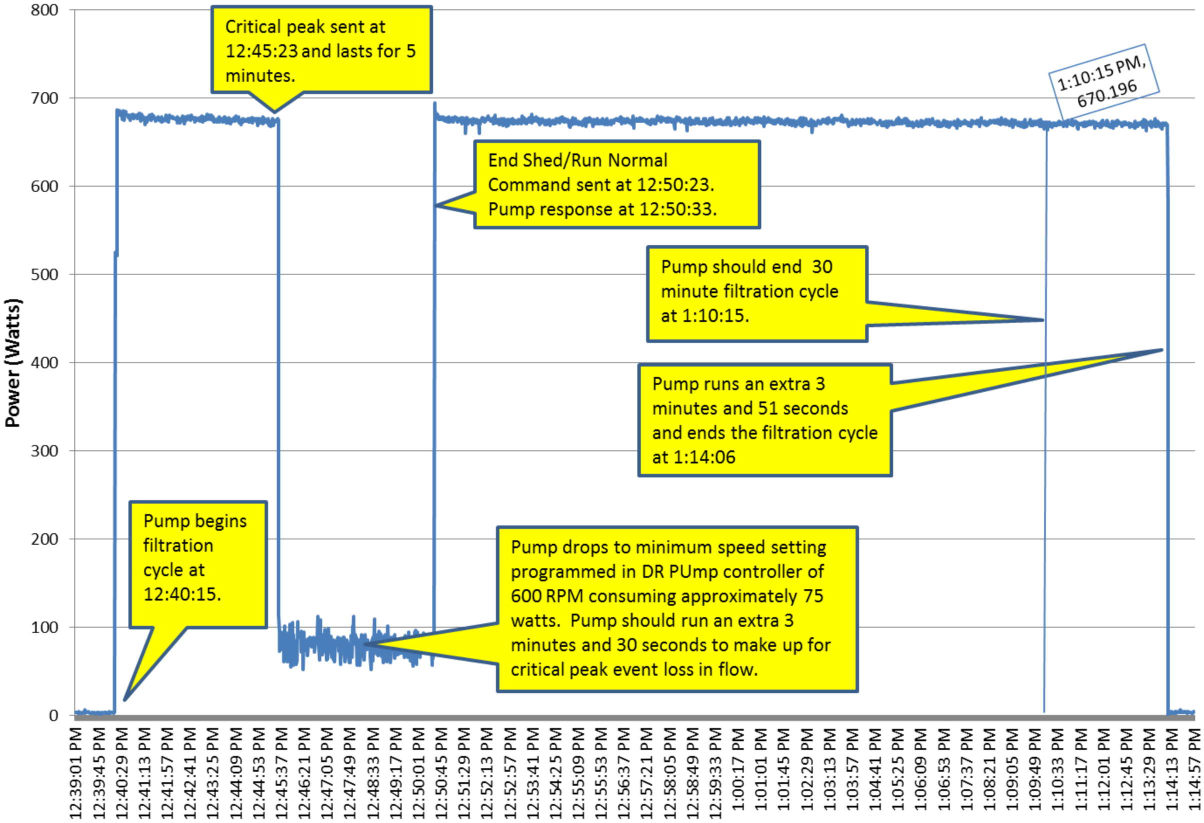
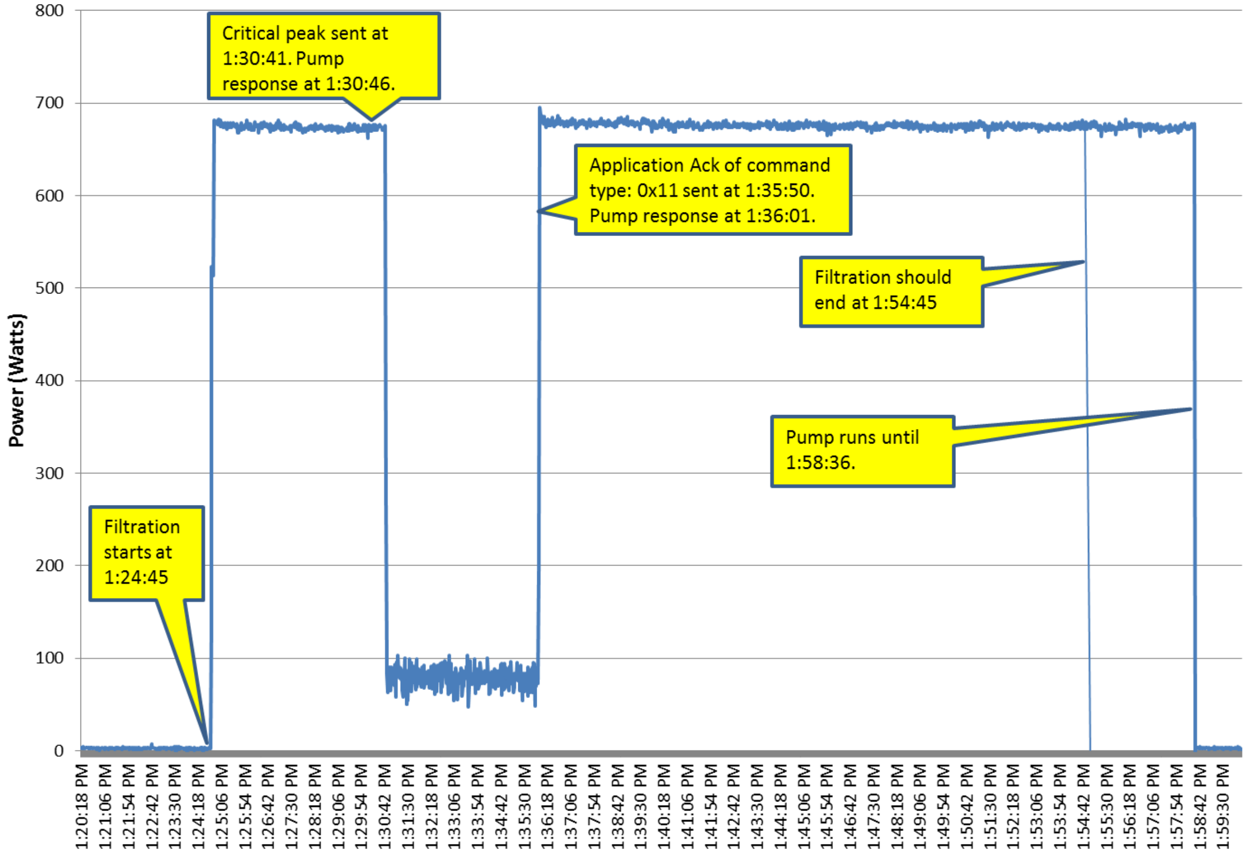


**Figure 2-11**
**Critical Peak Event**

## Consumer Override

Although not a functional requirement in terms of enabling more solar generation on the grid, consumer override is considered a required feature in order to ensure that the consumer is in control and to encourage program participation.

For this test the pump was set up to run a 30 minute filtration cycle starting at 1:24:45. As indicated in Figure 2-12, a Critical peak event was started at 1:30:41, 5 minutes after the start of the filtration cycle. A customer override was then initiated at 1:35:01 and the pump responded immediately. The critical peak remained in effect for approximately 5 minutes before being interrupted by the customer. The extra run time to make up for the critical peak event would be 3:30 seconds. The pump's programmed filtration cycle end time was 1:54:45 and it ran an extra 3:51 seconds to make up for the loss in flow from the critical peak event prior to the override.



Critical peak sent at 1:30:41. Pump response at 1:30:46.

Application Ack of command type: 0x11 sent at 1:35:50. Pump response at 1:36:01.

Filtration should end at 1:54:45

Pump runs until 1:58:36.

Filtration starts at 1:24:45

**Figure 2-12**
**Customer Override Test Results**

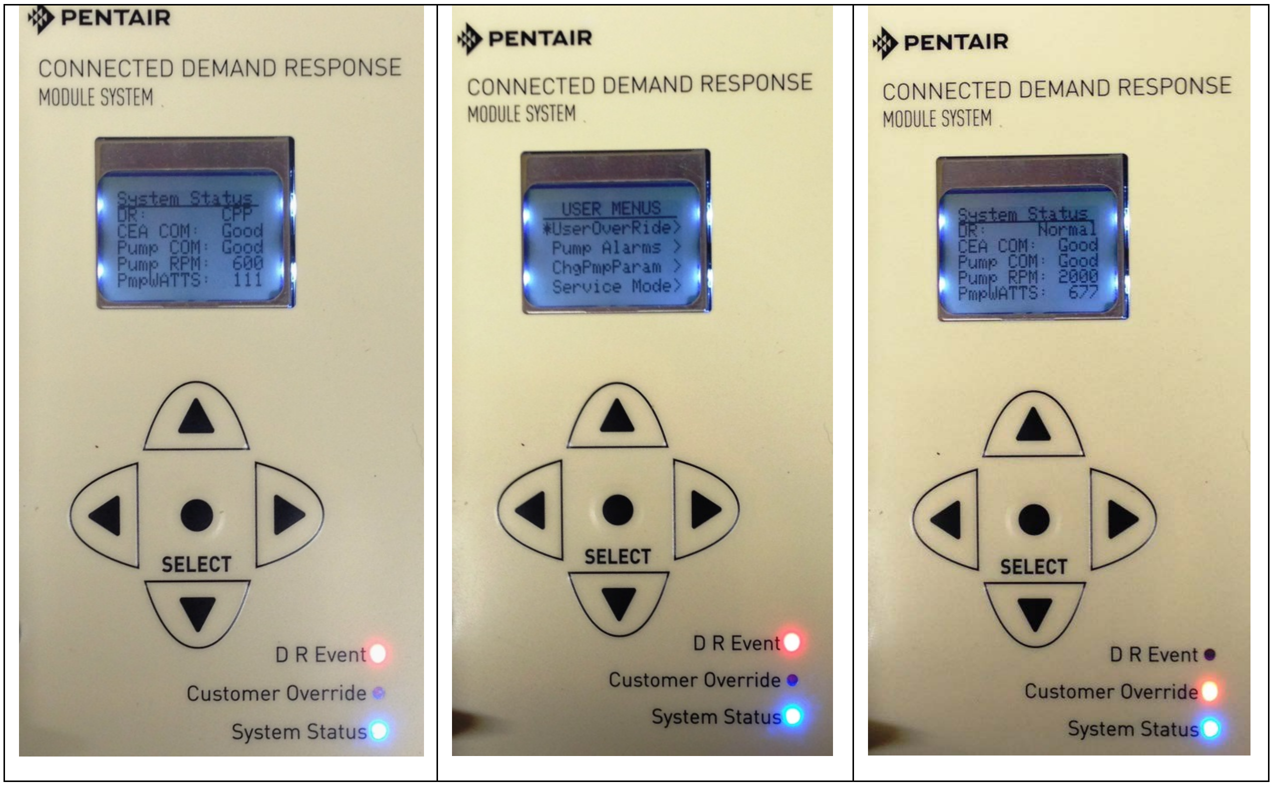


**Figure 2-13**
**User Interface Features for Customer Override**

The consumer override function is executed from the Pentair Connected Demand Response module. The home owner can press the select button to access the menu as seen in Figure 2-13. When in override mode, the Customer override LED is lit as indicated in the figure on the side.

## Load Up Function

For this test the pump was programmed to run a 30 minute filtration cycle at 2000[RPM] starting at 5:06:15. As indicated in Figure 2-14, the pump received a load up command 5 minutes into the filtration cycle. The load up lasted for 9 minutes and 38 seconds during which the pump ran at the maximum default speed of 3000[RPM]. Note: this maximum speed can be adjusted in the Pentair connected demand response module. The power consumption increased during the event to 1794[W]. The maximum speed can be set as high as 3450[RPM]. The pump was initially programmed to run until 5:36:15. Because of the extra filtration that occurred during the load up event, the pump shut off earlier at 5:30:16. This is another smart-response characteristic, ensuring that the pump doesn’t perform additional, unnecessary work as a result of control messages received.

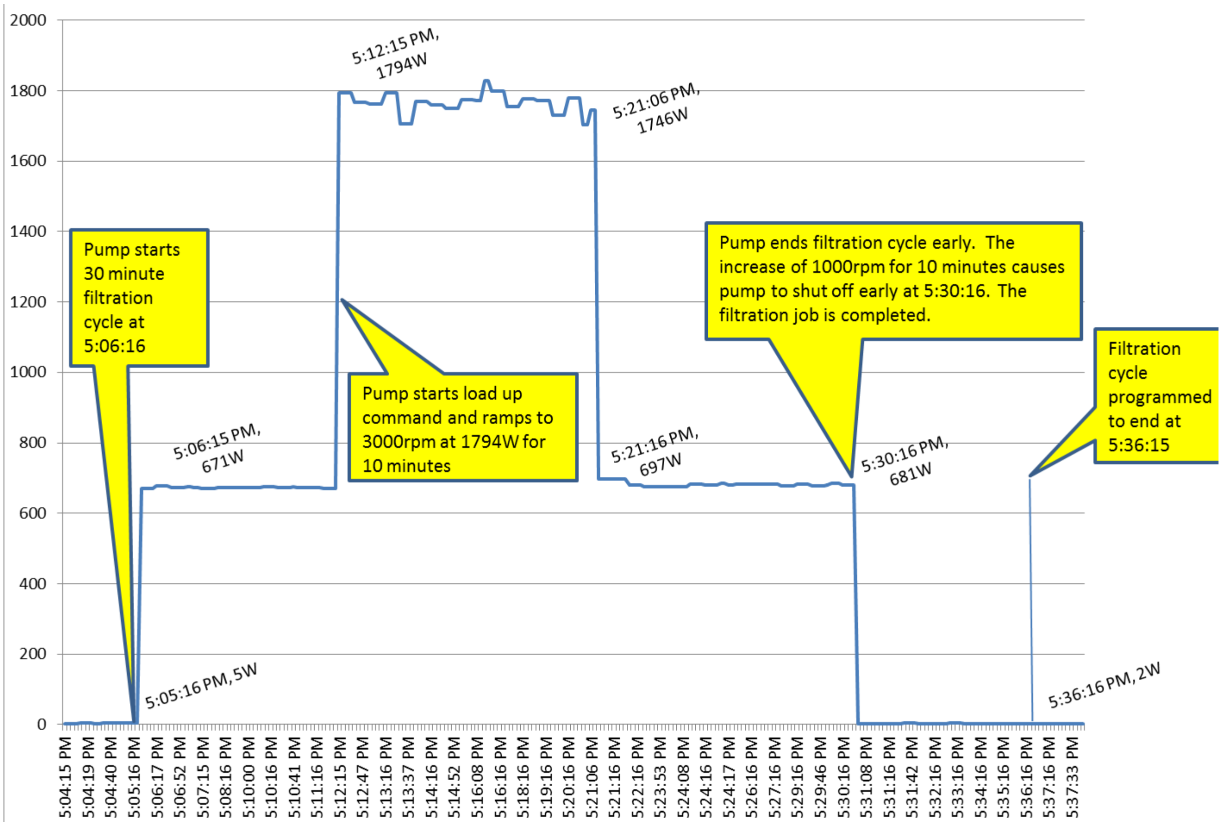


**Figure 2-14**
**Load-Up Event**

Figure 2-15 demonstrates the response time to the load up command.

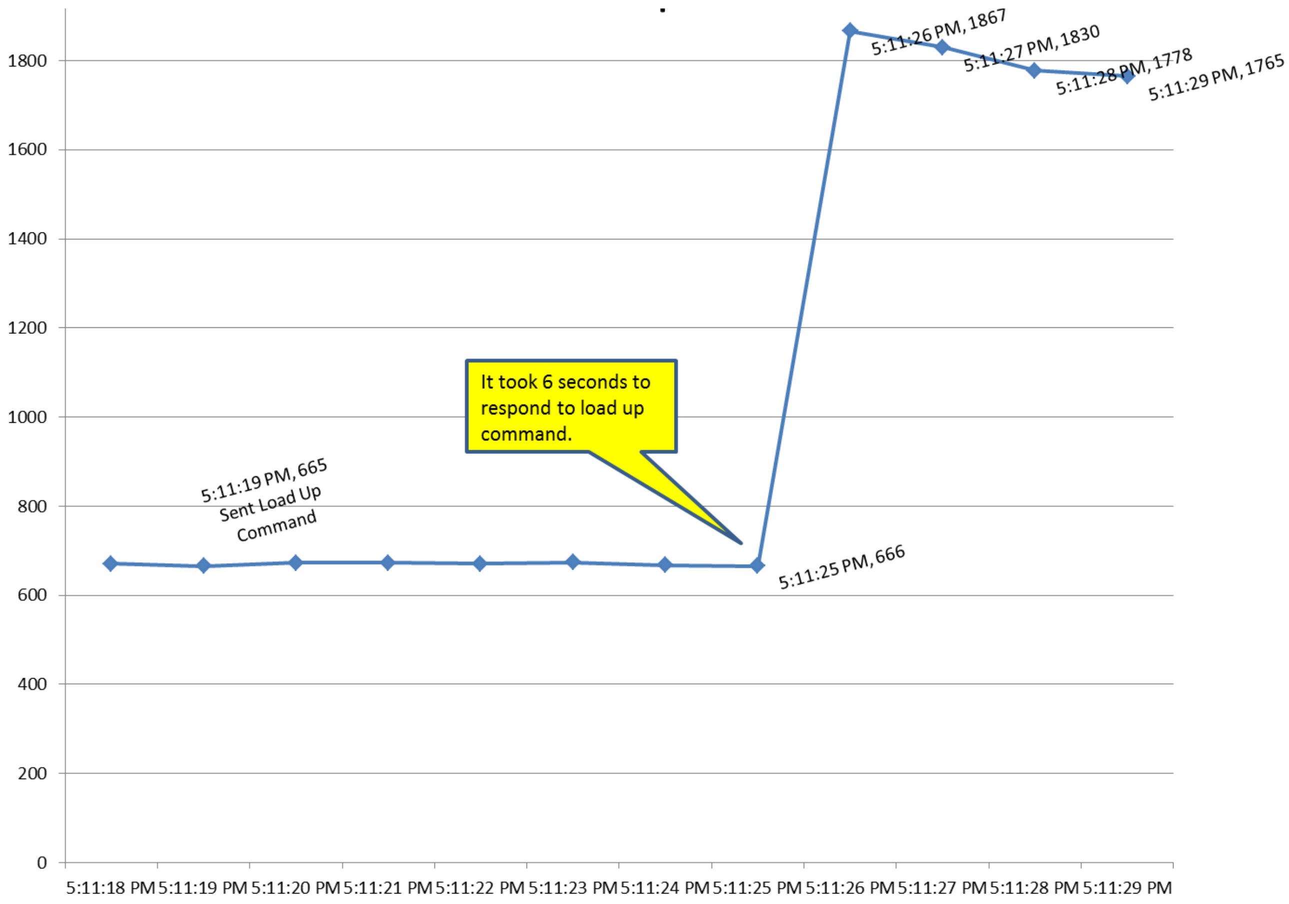
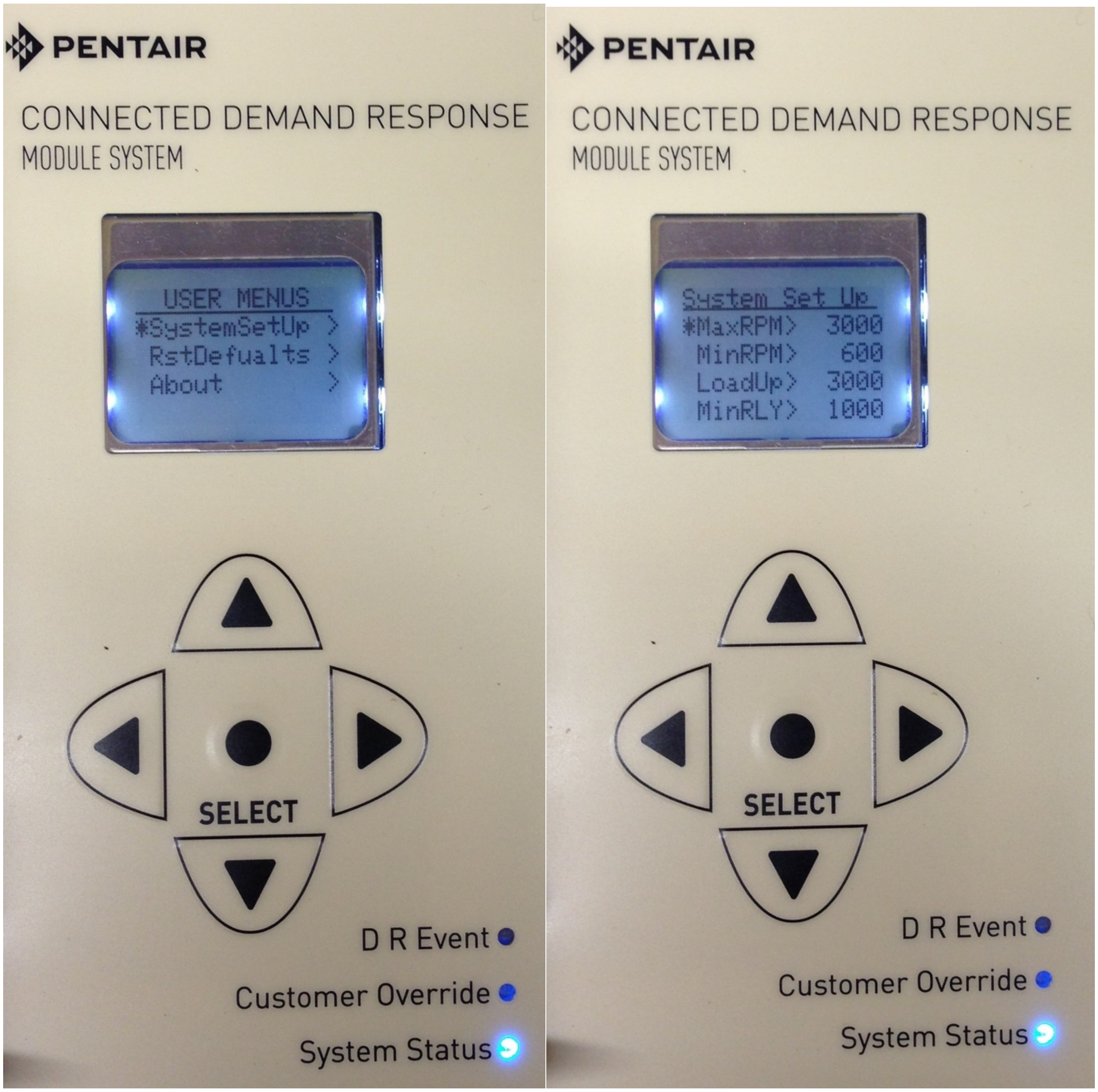


**Figure 2-15**
**Load-Up Event Response Time**

## Maximum and Minimum Speed Settings

As noted previously, the user interface provided a means for the consumer to configure the maximum and minimum operating speeds for their system. Figure 2-16 shows the menu through which a consumer can setup the parameters for their system. The MaxRPM setting is the maximum speed that the DR module will send to the pump. It is adjustable up to 3450[RPM]. The MinRPM setting default is 600[RPM] and is also adjustable. The Load Up speed default is 3000[RPM].

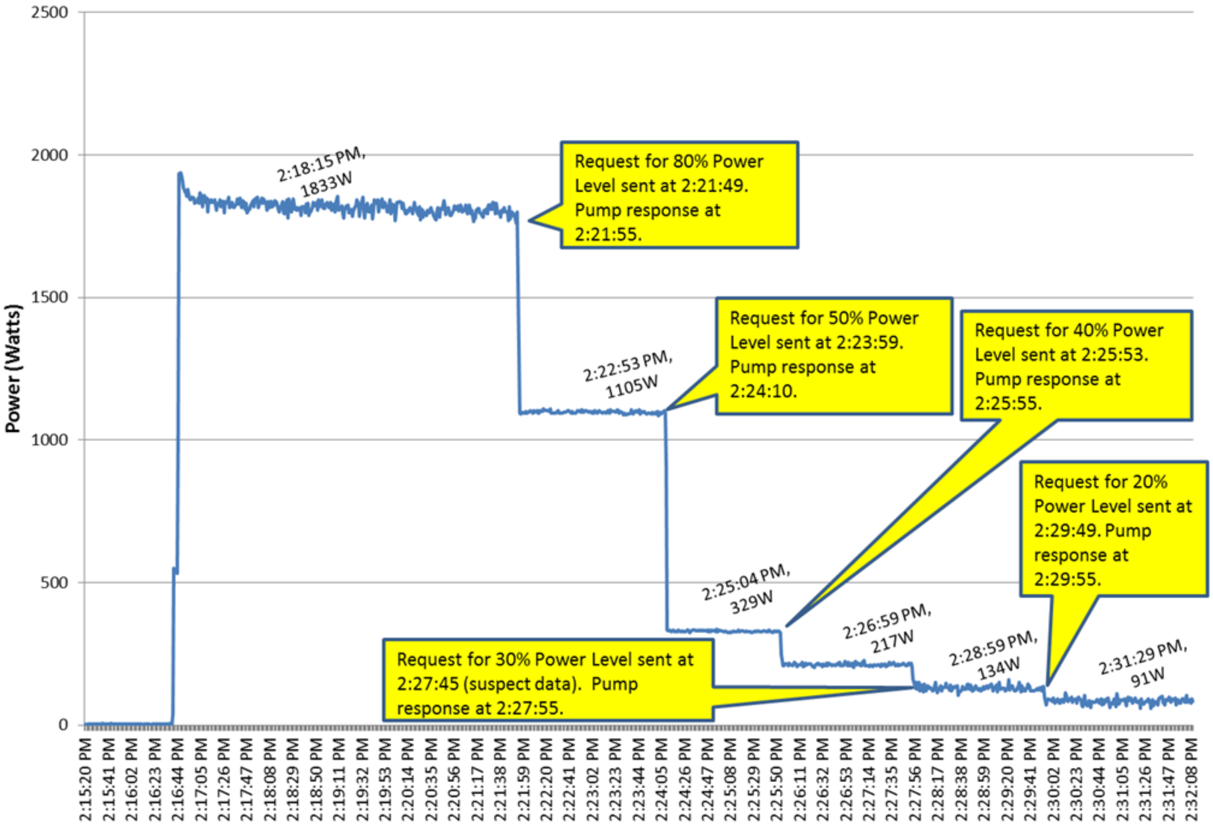


*MaxRPM> 3000
MinRPM> 600
LoadUp> 3000
MinRLY> 1000

**Figure 2-16**
**User Menu-System Set Up**

## Power Level Function –Variable

Figure 2-17 and Figure 2-18 provide the results of the variable power level testing. In the as-tested implementation, the pool pump controller did not directly control percent power level but rather the pump speed as a percent of the MaxRPM setting. In this test case, the MaxRPM was set to 3000[RPM] which is the default maximum setting in the DR control module.



Request for 80% Power Level sent at 2:21:49. Pump response at 2:21:55.

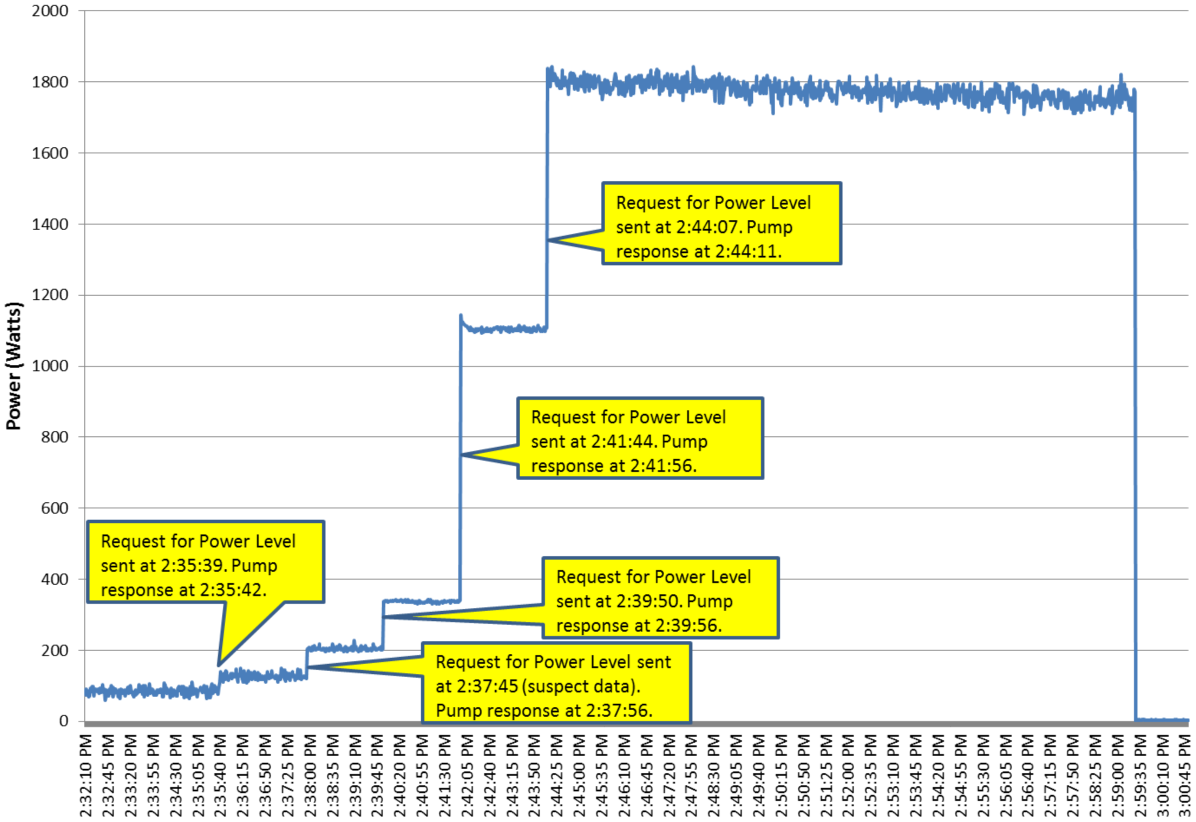
Request for 50% Power Level sent at 2:23:59. Pump response at 2:24:10.

Request for 40% Power Level sent at 2:25:53. Pump response at 2:25:55.

Request for 20% Power Level sent at 2:29:49. Pump response at 2:29:55.

Request for 30% Power Level sent at 2:27:45 (suspect data). Pump response at 2:27:55.

**Figure 2-17**
**Power Level Function, Decreasing Settings**



Request for Power Level sent at 2:44:07. Pump response at 2:44:11.

Request for Power Level sent at 2:41:44. Pump response at 2:41:56.

Request for Power Level sent at 2:35:39. Pump response at 2:35:42.

Request for Power Level sent at 2:39:50. Pump response at 2:39:56.

Request for Power Level sent at 2:37:45 (suspect data). Pump response at 2:37:56.

**Figure 2-18**
**Power Level Function, Increasing Settings**

At 2:21:49 a variable command was sent to the pump to run at 80%.   In response, the pump ramped down to 2400[RPM] which resulted in a power consumption of 1144[Watts].  A sequence of such variable control settings were sent, with the results as summarized in Table 2-1.

**Table 2-1**
**Pentair Power Level Chart**

| Power Level | Pump Speed [RPM] | Power Consumption [Watts] |
|---|---|---|
| 80% | 2400 | 1105 |
| 50% | 1500 | 329 |
| 40% | 1230 | 217 |
| 30% | 900 | 134 |
| 20% | 600 | 91 |
| 10% | 600 (reached minimum RPM) | 91 |

The intention of the CTA-2045 variable “Power Level” function is to directly manage an end-device’s power level (as a percentage of its maximum power).  Pentair notes that the present design could be improved in a future implementation to more directly manage power rather than speed.  The relationship between the two is a cubic function that depends on the operating pressure of the particular installation. The results for the closed-loop recirculating test system as characterized in the NREL test data and summarized in Figure 2-19.

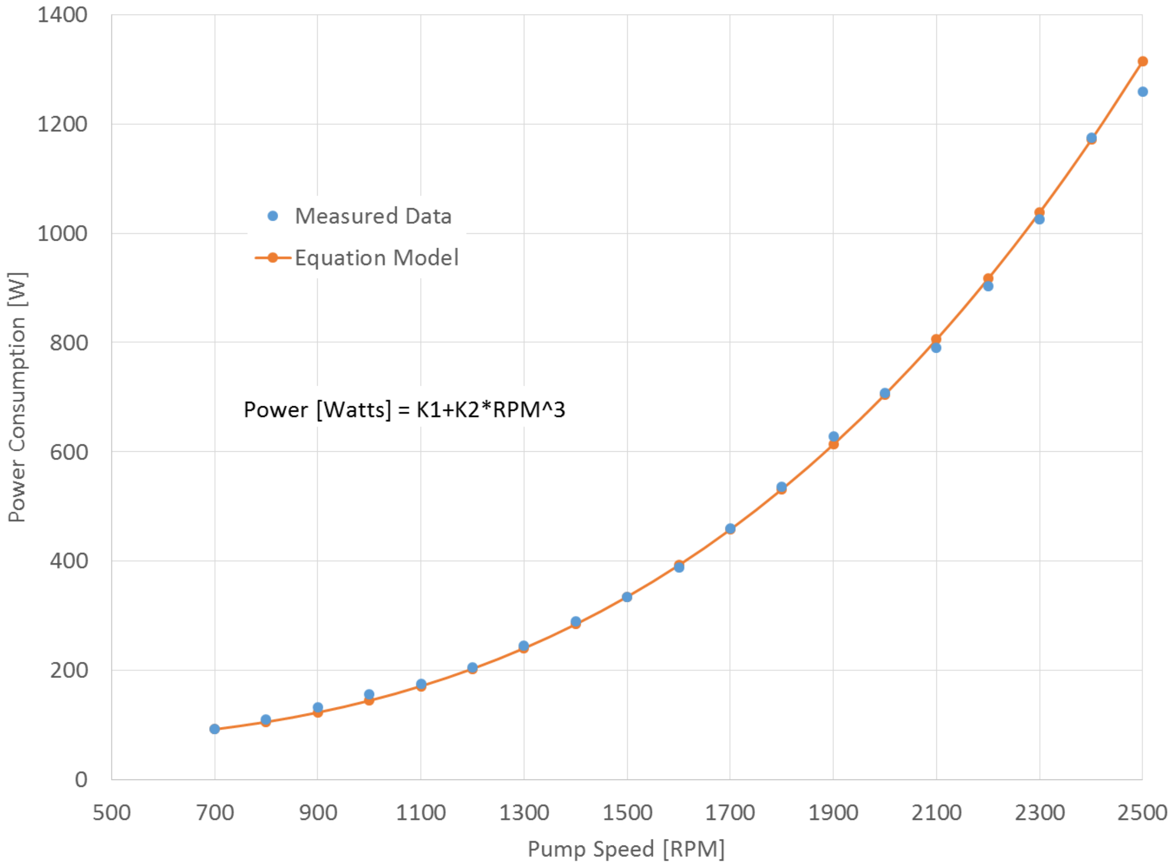


**Figure 2-19**
**Speed-Power Relationship, Pentair Closed Loop Pool Pump Test System**

*Note: The design is scaled with the MaxRPM setting. For example, if the DR control module MaxRPM parameter were set to 2800, a variable command of 50% would result in the pump running at 1400[RPM].*

## System Event Response Speed

The EPRI simulator used for most of the laboratory testing is a local connection and does not simulate the additional time delays that might exist when remote communication systems are utilized. A separate test was conducted on August 31, 2016 to evaluate the response time of the Pentair IntelliFlo pump connected to the Pentair Connected Demand Response Module receiving commands via internet from a remote headend system. The results are shown in Table 2-2. The time at which the Demand Response box received the command through the internet was recorded and the time it took for the pump to respond to an event was recorded as shown in the Table.

**Table 2-2**
**Response Time to Remote Shed and Load-Up Events**

| Event type | DR Box response time in seconds | Pump response time in seconds | Event type | DR Box response time in seconds | Pump response time in seconds |
|---|---|---|---|---|---|
| Shed | 0.8 | 5.1 | Load Up | 0.9 | 2.8 |
| End Shed | 0.9 | 12.4 | End Load up | 0.8 | 1.9 |
| Shed | 0.9 | 3.0 | Load UP | 0.8 | 8.3 |
| End Shed | 0.9 | 5.4 | End Load up | 0.7 | 5.6 |
| Shed | 0.8 | 11.0 | Load UP | 0.8 | 6.8 |
| End Shed | 1.1 | 7.9 | End Load up | 1.0 | 2.2 |
| Shed | 0.8 | 12.5 | Load Up | 0.7 | 5.8 |
| End Shed | 0.8 | 11.1 | End Load up | 0.8 | 2.4 |
| Shed | 0.8 | 14.2 | Load UP | 0.8 | 7.2 |
| End Shed | 0.8 | 11.1 | End Load up | 0.8 | 3.1 |
| Shed | 0.9 | 2.1 | Load Up | 0.8 | 7.2 |
| End Shed | 1.1 | 11.8 | End Load up | 0.8 | 3.8 |
| Shed | 0.8 | 9.2 | Load Up | 0.8 | 3.7 |
| End Shed | 3.2 | 7.3 | End Load Up | 0.7 | 2.0 |
| Shed | 0.9 | 15.4 | Load up | 1.1 | 5.0 |
| End Shed | 1.3 | 2.9 | End Load up | 0.8 | 14.4 |
| Shed | 0.8 | 5.8 | Load Up | 1.9 | 16.6 |
| End Shed | 0.8 | 9.0 | End Load up | 0.9 | 9.2 |
| Shed | 0.8 | 13.2 | Load Up | 0.8 | 3.1 |
| End Shed | 0.8 | 6.2 | End Load Up | 1.1 | 11.1 |
| Average Response time in seconds | **1.0** | **8.8** | Averge response time | **0.9** | **6.1** |

The average response time from the remote headend system to the pool pump was 0.94 seconds. The timing was captured manually with 0.1 second resolution from the execution of the event at the headend to:

Indication on the DR LED (indicating that a DR event command was received) on the Pentair connected Demand Response module (second column in the table)

The pump responding to the command (third column in the table)

In this case, the network time was small and the overall time delay was dominated by that of the local pump controller. Pentair notes that this could easily be made faster and is the result of a slow polling in the present software implementation.

## Loss of Communication

This test is used to validate that the Pool Pump Assembly terminates any control functions that are in effect if the communication status is not maintained. The pump was programmed to run a 30 minute filtration cycle.

The results are shown in Figure 2-20. The pump started the filtration cycle at 3:11:42 and a curtailment event was initiated 5 minutes into the filtration cycle. The EPRI software simulated a loss of communication at 3:26 by halting the issuing of comm status messages to the end device. The CTA-2045 standard requires communication modules to inform the end device of the connectivity status at least once every 5 minutes. The Pentair pump controller design is such that if three successive such status messages are missed, the pump will terminate any events and return to normal operation. As indicated in Figure 2-20, the pump terminated the curtailment event at 3:39PM, approximately 12 minutes after the issuance of communication status messages was halted.

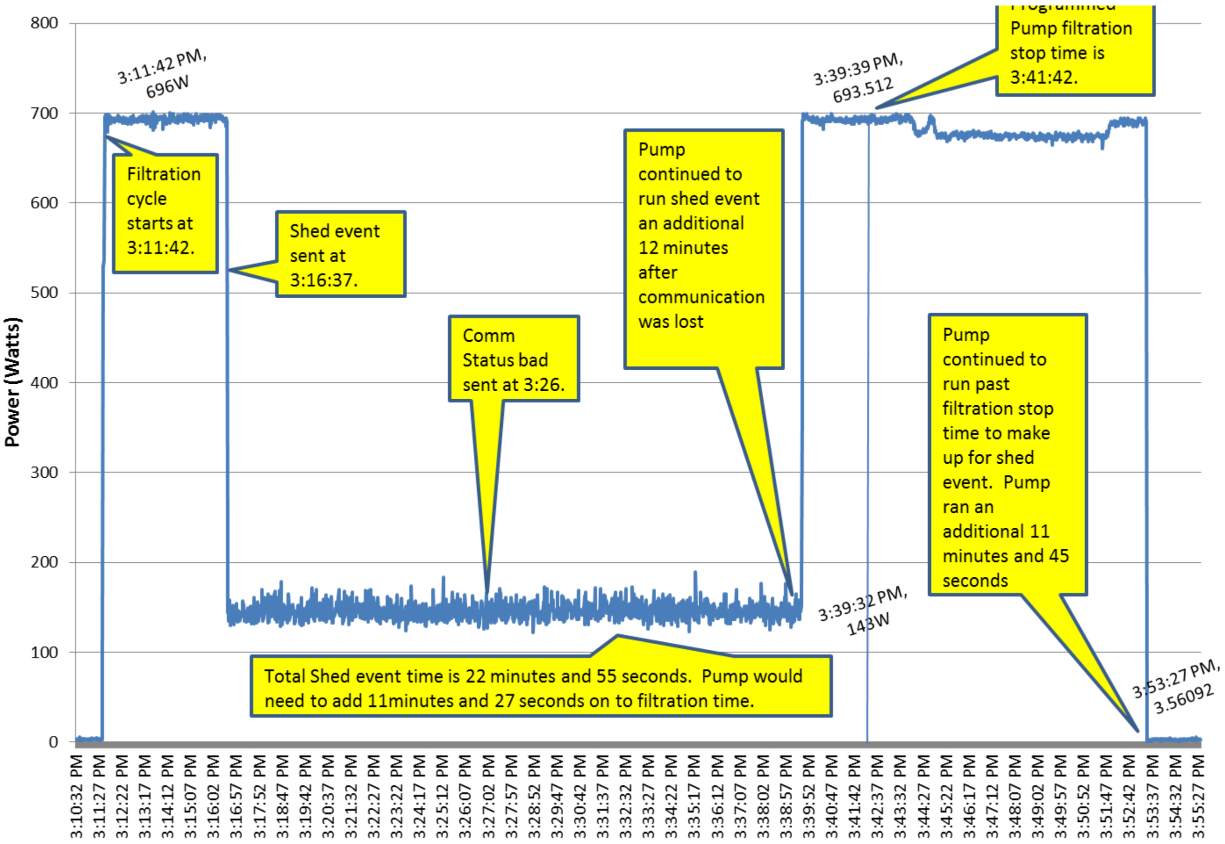


**Figure 2-20**
**Loss of Communication Test**

## Conclusions

The Pentair variable speed swimming pool pump met all the monitoring and control requirements of the project. The resulting product provides a particularly flexile resource for responding to grid events and helping to enable the grid to accommodate more clean energy.

Because variable speed pumps normally run long schedules at a very low speeds and low power consumption (compared to single speed systems), one of the most interesting capabilities is their ability to load-up, increasing their power consumption at times when there is an excess of energy. The unit tested in this project was capable of productively utilizing more than 3000[Watts], a figure that is comparable to the full energy output of a residential solar PV system.

Another notable feature is the variable power capability. With the design modification noted above to directly manage power rather than speed, this product can be very effectively utilized by local control systems to perform generation-following, helping to mitigate the impact of high variability of renewable energy such as wind or solar.

The pump system demonstrated smart responses - ensuring that its daily circulation requirements were met (and not exceeded) regardless of the type and timing of control events. This feature makes it possible for utilities and other demand-response system operators to make much greater use of the resource, aggressively managing populations of devices without risk of impeding the core mission of the device.

Working together with the other smart end devices, the pool pump's services can enable the grid to accommodate more clean energy. Achieving this outcome will require communication and control systems that can successfully connect to end devices and manage their behavior in a cohesive fashion. Such systems may also have wide-area awareness, making it possible for devices in one location to act in such a way as to address issues elsewhere that are not locally visible.

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