SOUTHERN CALIFORNIA EDISON

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Air Conditioner Stalling
Unit Level Solutions Test Report

By:

TDBU
Engineering Advancement
Power Systems Technologies

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The preparation of this white paper was conducted with support from the California Energy Commission's (CEC) Public Interest Energy Research (PIER) Program, WA# MR-049, through the California Institute of Energy and the Environment, Award Number MTX-06-01, and support from Southern California Edison (SCE).

1.0 EXECUTIVE SUMMARY

1.1 Introduction

Southern California Edison (SCE) and other utilities have been experiencing occurrences of delayed voltage recovery following faults on the electrical system (see figure 1). Under normal conditions, voltage recovers to nominal levels less than one second after the fault is cleared. In several incidents the past few years, voltage recovery has been delayed for more than 30 seconds after normal fault clearing at some SCE substations. These cases usually occur at substations located in areas with hot climates and new housing developments. This delayed voltage recovery can be attributed to the stalling of air conditioner units. SCE tested 10 residential air conditioning units to assess their response to delayed voltage recovery transients. The tests indicated that all 10 air conditioning units stalled when exposed to these types of transients. This study proposes that the installation of under-voltage protection devices such as under-voltage relays or digital programmable thermostats are possible solutions to the air conditioner stalling problem.

Figure 1 is a typical delayed voltage recovery profile on a SCE 220 KV circuit. This figure indicates that immediately after the fault, the voltage decreases to 79 percent of nominal voltage (point 1); the voltage on the distribution circuits dips even lower. This drop in voltage causes air conditioner units to stall and the stalled air conditioner units prevent the voltage from recovering to a nominal level (point 2). When the air conditioning units' thermal overload protection switches trip, the voltage recovers but overshoots the nominal voltage (in this case 6 percent above) because the capacitor banks are still connected to the circuit (point 3). This over-voltage causes another problem, the capacitor banks tripping off due to over-voltage (point 4). With the capacitors tripped off and the load (air conditioners) returning, the voltage dips below the nominal voltage (points 5 & 6). This could lead to additional problems because it makes the circuit more vulnerable to similar chains of events.

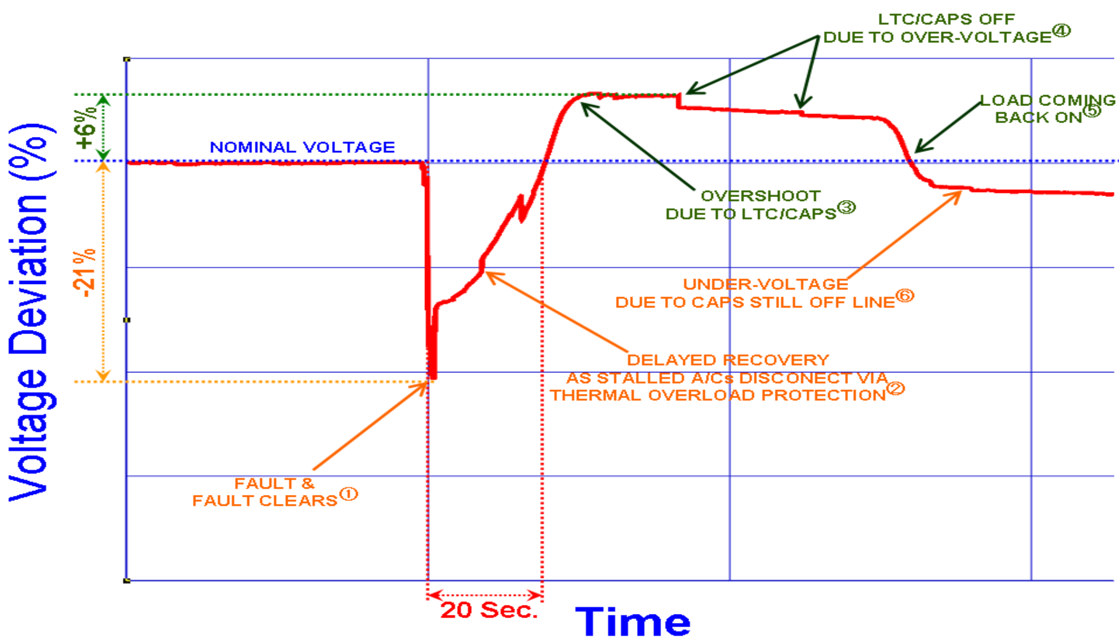


Figure 1 - Typical Delayed Voltage Recovery

1.2 Work Performed

SCE tested under-voltage protection devices and digital programmable thermostats to determine their response during under-voltage events and assess their ability to mitigate the air conditioner stalling problem. The test results will help SCE determine the best possible solutions to address the problem at its source, air conditioner units installed along the SCE power grid. SCE tested three digital programmable thermostats, seven under-voltage relays, and one load control switch (refer Table 3). All testing was conducted at its Pomona Electric Vehicle Technical Center (EVTC).

1.3 Testing Results

This summary section contains the under-voltage transients test results for selected under-voltage protection devices, load control switches, and digital programmable thermostats.

1.3.1 Digital Thermostats Test Results

Three digital programmable thermostats were tested to assess their response during under-voltage transients. The test results determined that only one thermostat had under-voltage protection, the Honeywell thermostat. Although this thermostat's under-voltage protection and response time do not currently meet SCE's proposed stall protection specifications, it may help mitigate the air conditioner stalling problem. To meet SCE's proposed stall protection specifications, this thermostat would need the following reconfigurations:

- Raise the under-voltage protection threshold to 78 percent of rated voltage
- Quicken the under-voltage response time to 250 milliseconds (15 cycles)
- Randomly time (3 to 5 minutes) the short cycle protection

A recommended additional modification is to allow the air handler fan to run when the thermostat trips off the compressor due to an under-voltage transient. This will help dissipate the stored cooling while the compressor is off.

The use of thermostats to mitigate the air conditioner stalling problem is one of the easiest retrofit solutions. In most cases retrofitting thermostats would not require a qualified electrician because in California, only branch circuits rated greater than 100 VA require a qualified electrician and most residential thermostats circuits are rated below 24 VA.

The disadvantage of using the Honeywell thermostat to mitigate the air conditioner stalling problem is that it needs the common "C" wire. This wire is used to provide power to the thermostat's electronics. The common "C" wire started being used after the release of digital programmable thermostats in the mid-1990s.

1.3.2 Under-Voltage Relays Test Results

Seven under-voltage protection relays were tested to assess their response during under-voltage transients. Test results indicate that two of the tested relays (CSE and PNNL) have the under-voltage protection needed to mitigate the air conditioner stalling problem but will require minor adjustments to meet SCE's proposed stall protection specifications. These two relays are still in developmental stages; therefore, their implementation may be delayed due to the need for further testing, certifications, mass production, and retrofit time.

The test results also indicate that three other under-voltage protection devices manufactured by Diversified Electronics (DE) have under-voltage protection that may help mitigate the air conditioner stalling problem. These three relays are off-the-shelf devices, but clearly have some disadvantages. First, they do not have a randomly distributed short cycle-prevention allowing them to restart at the same time after voltage is restored to normal conditions. This might keep the voltage depressed and cause further stalling of air conditioners. Second, they use normally open (N.O.) contacts that prevents the units from restarting if the under-voltage relay fails. All other tested under-voltage protection devices provided limited stall protection, which may help to some degree, but will not alleviate the air conditioner stalling problem. The installation of any of these under-voltage protection relays in California would require a qualified electrician for retrofit because the served circuits will be rated at more than 100-VA.

1.3.3 Load Control Switch Test Results

Cannon Technologies' load control switch was tested. These switches are mainly used to remotely control motor load during times of high system load demand. Initial testing of this device indicated it did not have the desired stall protection. Cannon Technologies claims it reconfigured this load control switch's software to meet SCE's proposed stall protection specifications. Our recent tests indicate that this device was indeed reconfigured and it now meets SCE stall protection specifications. Its disadvantage is that it will be more expensive than the average under-voltage relay; it has extra features (such as load control and demand response) and will require additional retrofitting labor because California law requires a qualified electrician when served circuits are more than 100-VA.

1.3.4 Conclusion

The most viable solution to the air conditioner stalling problem is the use of digital programmable thermostats with stall protection capability. The challenge will be working with various thermostat manufacturers to ensure that their products meet SCE's proposed stall protection specifications. It must be noted: this solution may not protect older units (those installed prior to the mid-1990s) because many do not have the common "C" wire used to power today's thermostat electronics. This remedy's effectiveness will only be realized as older air conditioners are replaced with new units having the common "C" wire. Another viable solution is the use of plug-in under-voltage protection relays that meet

SCE's proposed stall protection specifications. This fix offers easy installation on window air conditioners and plug-in air handlers. Either of these solutions would be relatively simple and less costly remedies because they will not require a certified electrician for implementation.

The next most viable solution is the use of devices such as under-voltage relays or load control switches with SCE's proposed stall protection specifications. This solution is less attractive than the others because it would require qualified electricians to perform the retrofits, adding a labor cost of $90 to $100 per installation.

Table 1 shows the test results for the various devices in our study. The potential column is an SCE assessment of how viable each device is in protecting air conditioners from stalling. Notice that the devices with the highest score are those in developmental stages.

	Manuf.	Model	UV Threshold (%V)	Response Time (sec.)	Electronics Shutdown (%V)	Re-close Delay (sec.)	Control Contacts	Potential (%)
Thermostats	Honeywell	RTH7400D1008	60%	0.760	can't tell	290	N.O.	Medium-High
	Totaline	P374-1800	none	none	can't tell	none	N.O.	none
	Ritetemp	8022C	none	none	can't tell	none	N.O.	none
Under-Voltage Relays	ICM	ICM491	86%	5.100	75%	6	N.O.	Low
	DE	CV-200RS-20 Plug-in	83%	0.300	can't tell	300	N.O.	Medium
	DE	CV-100RS Plug-in	78%	0.232	can't tell	300	N.O.	Medium
	DE	CV-240-AFN Mount-in	83%	0.483	can't tell	300	N.O.	Medium
	Kriwan	INT369	68%	0.294	can't tell	120	N.O.	Medium-Low
	CSE	N/A	78%	0.25	15%	180 ~ 300	N.C.	High
	PNNL	N/A	77%	0.033	40%	180 ~ 300	N.C.	High
LCS	Cannon	N/A	80%	0.264	33%	180 ~ 300	N.C.	High

Table 1 - Test Results

2.0 OBJECTIVE

The objective of this testing is to investigate how under-voltage protection devices and digital programmable thermostats respond to under-voltage transients. SCE tested seven under-voltage relays, one load control switch, and three digital programmable thermostats (Table 2) to assess their stall protection capabilities.

	Manufacturer	Model Number	Name	Cost
Digital Programmable Thermostats				
1	Honeywell	RTH7400D1008	Digital Thermostat	$100
2	Totaline	P374-1800	Digital Thermostat	$70
3	Ritetemp	8022C	Digital Thermostat	$80
Under-voltage protection Relays				
1	ICM Controls	ICM491	Single Phase Line Monitor	$50
2	Diversified Electronics	CV-200RS-20 Plug-in	Voltage Band Monitor with Short Cycle Protector	$80
3	Diversified Electronics	CV-100RS Plug-in	Voltage Band Monitor with Short Cycle Protector	$80
4	Diversified Electronics	CV-240-AFN Mount-in	Under-voltage Short Cycle Protector	$80
5	CMP Corporation – Kriwan Division	INT369	Motor Protector	$80
6	Corporate Systems Engineering	N/A	A/C Under Voltage Relay	$10 *
7	Pacific Northwest National Laboratory	N/A	Grid Friendly Device	N/A
Load Control Switch				
1	Cannon	N/A	Load Control Switch	N/A

Table 2 - Tested Devices

3.0 SCE PROPOSED STALL PROTECTION PARAMETERS

Air conditioner testing performed by SCE, Electric Power Research Institute (EPRI) and the Bonneville Power Administration (BPA) indicates that air conditioners stall very quickly, within a mere 6 cycles. The stall threshold (voltage point where air conditioners start stalling) is dependent on temperature – the warmer the temperature, the higher the stalling threshold. SCE found that the average stall threshold voltage is 73 percent when outdoor temperatures reach 115 °F. The stalling threshold could be even higher when the air conditioner unit is overcharged. SCE decided to use a 78 percent stalling threshold voltage, 5 percent higher than the average and 2 percent below a typical compressor's lowest voltage nameplate rating.

Figure 2 shows the voltages of the SCE proposed stall protection parameters chosen after analyzing the air conditioner testing results.

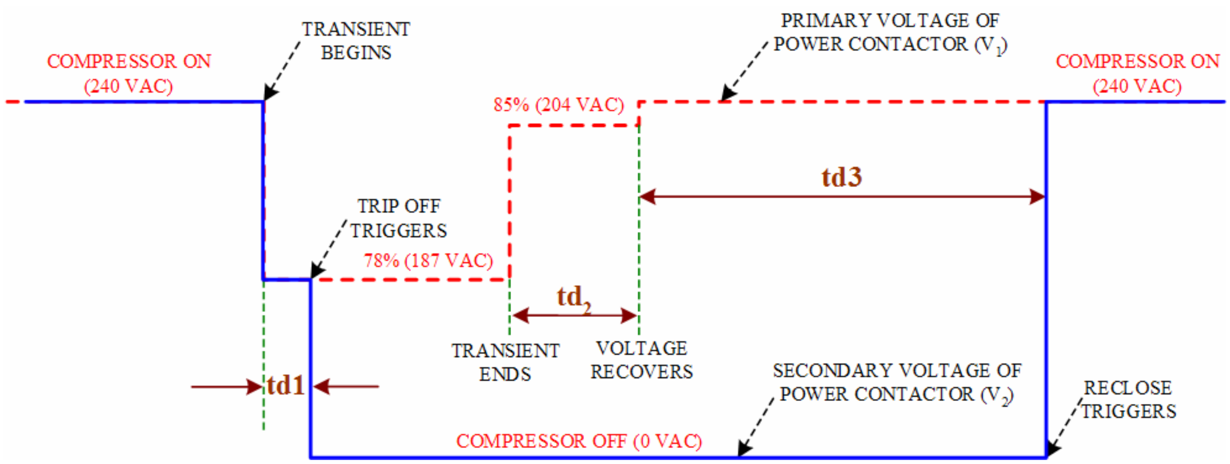


Figure 2 - Proposed Stall Protection Parameters

Table 3 provides the ideal parameters and their corresponding SCE specifications:

1	Under-voltage trip level	78 % of nominal voltage
2	Trip response time (td1)	6 – 15 cycles
3	Voltage recovery condition	85% for at least 15 sec (td2)
4	Contacts re-close delay time (td3) or short cycle protection	3 to 5 minutes, random
5	Lowest operation voltage	40% of nominal voltage
6	Contacts type	Normally closed (N.C.) contacts
7	Cold load pick up	After loss of power during an under-voltage event

Table 3 - SCE Proposed Stall Protection Specifications

In order to minimize false tripping SCE recommends measuring currents to confirm the stalling conditions. The test results indicate that when the air conditioner stalls, the current quickly (within 2 - 3 cycles) exceeds 3.0 p.u. When stall protection devices fail the use of normally closed contacts (N.C.) will not lockout the air conditioner.

Short Cycle Protection Time:
Short cycle protection time prevents the air conditioner from turning back on before the pressure bleeds off (releases). If the air conditioner is allowed to turn back on when pressure is built up, it might stall because the electrical torque would not be able to overcome the built up mechanical torque.

Cold Load Pickup Protection:
Cold load pickup protection waits for a predetermined time after power is restored before it allows the compressor to restart. This avoids high inrush currents in the distribution feeders immediately following power restoration. The high inrush currents cause a voltage drop which can result in air conditioner stalling or circuit tripping.

3.1. TRANSIENT TEST TYPE

This test report focuses on the response of under-voltage protection relays and digital programmable thermostats to under-voltage events such as the long-notch transient. The nominal rated voltage used for all the tests is 240 VAC.

Figure 3 shows the long-notch type transient used to determine how the thermostats, under-voltage protection relays, and load control switches behave during under-voltage transients. The characteristics to be examined are: under-voltage protection threshold, under-voltage response time, electronics shutdown voltage and time, short cycle protection, and cold load pickup.

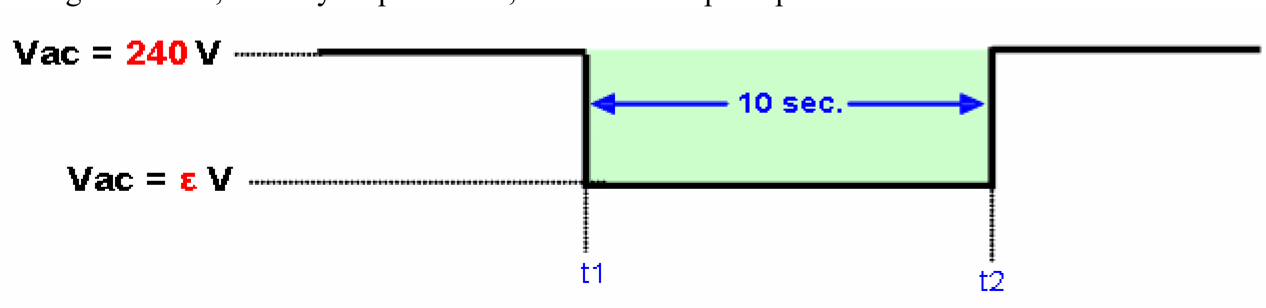


Figure 3 - Long-Notch Transient

Figure 4 shows the short-fast type of transient used to determine how the thermostats, under-voltage protection relays, and load control switches, behave during short and fast under-voltage transients such as typical transmission circuit breakers' clearing times.

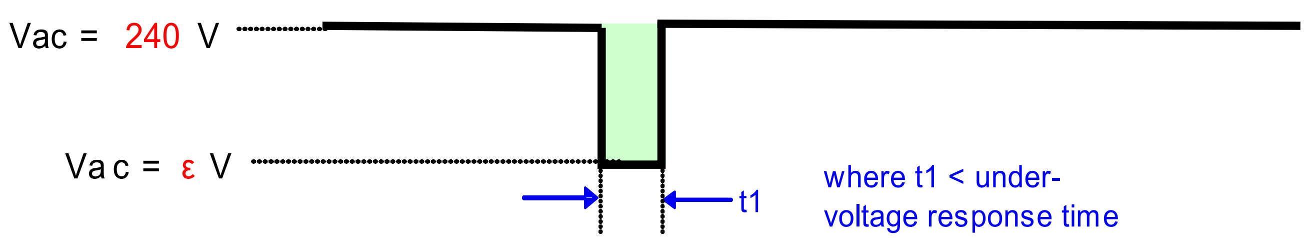


Figure 4 - Short-Fast Transient

4.0 DIGITAL PROGRAMMABLE THERMOSTATS TESTING

Testing was performed on the Honeywell, Totaline and Ritetemp devices to assess how digital programmable thermostats perform during under-voltage transients. Digital programmable thermostats are used to control the indoor temperature by turning the air conditioner compressor on and off. Thermostats have a fan switch that turns the indoor fan on and off providing cooled airflow to the served area. They also have a system switch with three settings (cool, off and heat). Of the three, we are most interested in the cool setting, the standard setting when an air conditioner is turned on. Thermostats also have a temperature setting switch that allows selection of the desired temperature. The tests were performed when the air conditioner was running properly (system switch = cool & fan switch = auto & TSET < TACTUAL), cooling down the desired area. Figure 5 refers to the typical installation of a digital programmable thermostat. The common “C” wire (purple) that runs from the air handler unit to the digital programmable thermostat came into standard use for residential air conditioners in the mid-1990s. This wire provides power to the digital programmable thermostat electronics.

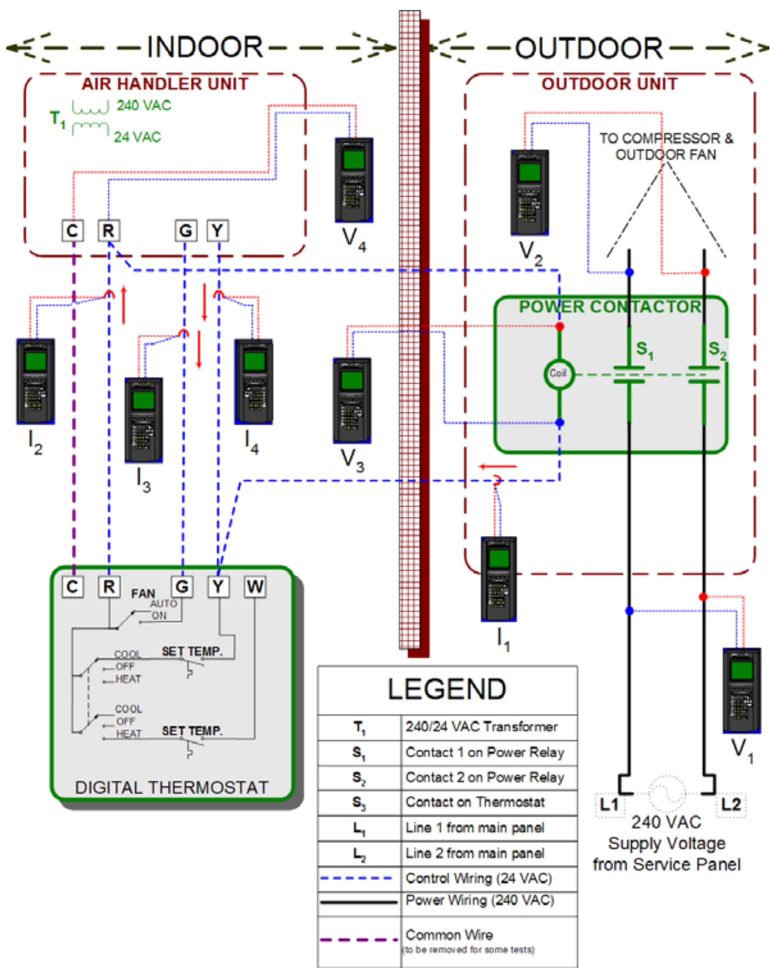


Figure 5 - Programmable Digital Thermostat Typical Installation

4.1 Honeywell Digital Programmable Thermostat Test Results

This high-end off-the-shelf digital programmable thermostat was purchased at a popular local warehouse store. The Honeywell Digital Programmable thermostat's system-button has cool, off, and heat modes. Its fan-button has on and auto positions. Its temperature-button ranges from 50°F to 99°F. This thermostat also has schedule and clock buttons. The under-voltage testing was done in the cool position (system-button = cool & fan-button = on & TSET < TACTUAL).

Test results indicate that this thermostat's:

- ♦ Under-voltage protection threshold is 60 percent, but only works with the common wire "C"
- ♦ Under-voltage protection response is 1.2 seconds at the voltage threshold and 0.4 seconds at lower under-voltages
- ♦ Short cycle protection time is approximately 5 minutes and the compressor is not protected when the under-voltage transient persists longer than 5 minutes, allowing the compressor to restart, which can cause the compressor to stall for 6 cycles
- ♦ Short cycle protection is activated by:
    - Under-voltage trip off
    - Change in system-button positions
    - Actual temperature increases above the set temperature
    - Power loss and initial electronics power on (cold load pick up protection)
- ♦ Cold load pickup protection is 5 minutes after power is restored

Although this thermostat's under-voltage protection is lower and the under-voltage response time is longer than SCE's proposed stall protection specifications, this thermostat could help mitigate the air conditioner stalling problem. But, in order for this thermostat to meet SCE's specifications for stall protection, it would need the following changes:

- ☑ Raise the under-voltage threshold to 78 percent
- ☑ Shorten its response time to about 6 to 15 cycles (100 to 300 milliseconds)
- ☑ Randomize the cycle protection time
- ☑ Prevent the compressor from restarting during under-voltages

Additional improvements needed for this thermostat include:

- ☒ The fan should be allowed to run when the thermostat trips off the compressor due to an under-voltage transient. This will allow the fan to dissipate any coolant stored in the cooling coil
- ☒ The compressor should not be allowed to restart during under-voltages lower than 85 percent
- ☒ The internal energy storage device (capacitor) should be enlarged. This will allow the thermostat to work at lower voltages for longer periods of times; it currently takes 0.5 seconds but needs at least 4 seconds

4.1.1 Specifications

Table 4 provides the specifications for the tested Honeywell digital programmable thermostat.

<table>
<tr><td colspan="5">Manufacturer</td><td colspan="10">Honeywell</td></tr>
<tr><td colspan="5">Model Number</td><td colspan="10">RTH7400D1008</td></tr>
<tr><td colspan="5">Name</td><td colspan="10">Digital Programmable Thermostat</td></tr>
<tr><td colspan="15">Line Terminals Ratings</td></tr>
<tr><td colspan="5">Voltage</td><td colspan="10">24 VAC</td></tr>
<tr><td colspan="5">Frequency</td><td colspan="10">50/60 Hz</td></tr>
<tr><td colspan="5">Time Delay</td><td colspan="10">Not specified</td></tr>
<tr><td colspan="5">Cycle Protection Time</td><td colspan="10">5 minutes</td></tr>
<tr><td colspan="15">Selector Buttons</td></tr>
<tr><td colspan="3">System</td><td colspan="3">Fan</td><td colspan="3">Temperature Selector</td><td colspan="3">Schedule</td><td colspan="3">Clock</td></tr>
<tr><td colspan="15">Terminals</td></tr>
<tr><td colspan="3">Common “C”</td><td colspan="3">Return “R”</td><td colspan="3">Green “G”</td><td colspan="3">Yellow “Y”</td><td colspan="3">White “W”</td></tr>
<tr><td colspan="15">Contacts</td></tr>
<tr><td colspan="5">Cooling</td><td colspan="5">Heating</td><td colspan="5">Fan</td></tr>
<tr><td colspan="5">“R” and “Y” terminals</td><td colspan="5">“R” and “W” terminals</td><td colspan="5">“R” and “G” terminals</td></tr>
<tr><td colspan="5">Picture</td><td colspan="10"></td></tr>
</table>

Table 4 - Honeywell Digital Programmable Thermostat Specifications

4.1.2 Non-Installed Testing

These tests monitored the Honeywell thermostat’s response to different settings without any external connections. The following observations were noted:

- When the thermostat had no batteries the thermostat electronics shut down and its resistance among all terminals was infinity
- When the batteries were installed, the thermostat went into short cycle protection (wait state), which took approximately 5 minutes to clear
- With batteries installed and the thermostat in cool mode (system switch = cool & fan switch = on & TSET < TACTUAL) the short cycle protection timed out. This caused:
  - The R-G (fan switch) terminal’s resistance to lower, indicating the fan switch was in the “on” position
  - The short cycle protection wait state to be enabled only if:
    - There were any change in the system’s switch position ending in the “cool” position
    - The actual temperature equaled or surpassed the set temperature (TSET > TACTUAL) indicating no further cooling was needed at the time

4.1.3 Installed Testing

The following tests were performed on the Honeywell thermostat with all the standard residential connections (including the common wires, batteries) and after the short cycle protection "wait" state timed out.

4.1.3.1 System, Fan and Temperature Buttons Testing

The system fan and temperature buttons are used to control the cooling and heating functions of the thermostat. They were tested to assess their functionality. With the thermostat in cool mode (system switch = cool & fan switch = auto & TSET < TACTUAL) and the compressor and fan running normally, the following observations were made:

- The fan switch changes did not activate any function while the compressor was running
- When the system switch was turned off the compressor shut down and cycle protection activated immediately, the fan ran normally
- When the system switch was turned to 'off' or 'heat' and then back to 'cool' the short cycle protection activated immediately, the fan ran normally
- When the actual temperature equaled the set temperature, the compressor shut down immediately and the short cycle protection activated immediately, the fan ran normally
- The fan only ran when the system switch was in the cool position or the fan switch was on

4.1.3.2 Under-Voltage Transient Testing

Tests were done to assess how the thermostat behaves during under-voltage transients. The under-voltage transients were applied with the thermostat in 'cool' mode (system switch = cool & fan switch = auto & TSET < TACTUAL) and the compressor running normally. The following observations were made:

- Its under-voltage threshold is 60 percent of the rated voltage
- Its under-voltage protection response time is 1.2 seconds at 60 percent of the rated voltage and 0.6 seconds at 50 percent of the rated voltage
- Its short cycle protection timed out in approximately 5 minutes
- Allowed the compressor to restart for 6 cycles during under-voltage transients but only after short cycle protection timed out
- It has no protection for transients faster than 0.65 seconds
- Its electronics never shut down because it had batteries; therefore, it had under-voltage protection even at total power loss

Table 5 provides the test results for the Honeywell Digital Programmable Thermostat.

V_{SAG} (%)	t_{SAG} (Sec.)	$t_{RESPONSE}$ (Sec.)	Comments
Long Under-voltage Transient Test			
62	10	N/A	Nothing
60	10	1.2	* Compressor and fan tripped off * Short cycle-protection "wait" mode was enabled * Compressor came back on in approx. 5 min. NOTE: The indoor fan was shut down after compressor tripped off by an under-voltage transient. The fan remained off until the short cycle-prevention timed out.
60	10	1.26	
60	10	1.28	
55	10	0.6	
50	10	0.6	
Short-Fast Under-voltage Transient Test			
40	0.45	0.45	* Power contactor opened * The compressor and the fan tripped off at end of transient * Short cycle-protection "wait" mode was enabled * Compressor came back on in approx. 5 min. NOTE: The indoor fan was shut down after compressor tripped off by an under-voltage transient. The fan remained off until the short cycle-prevention timed out.
0	0.40	0.40	
60	0.80	0.283	* Compressor and fan tripped off * Short cycle-protection "wait" mode was enabled * Compressor came back on in approx. 5 min.
60	0.50	none	No under-voltage protection, transient too fast
60	0.65	none	
40	0.25	none	* Power contactor opened * No thermostat protection, Transient too fast * Electronics did not die
40	0.35	none	
0	0.10	none	
0	0.20	none	
0	0.30	none	

Table 5 - Honeywell Digital Programmable Thermostat Test Results

4.1.3.3 Under-Voltage Testing without Batteries

This test was performed maintaining all the previous connections and settings with one exception; the batteries were removed. The common "C" and return "R" wires powered the thermostat electronics. The tests indicate this thermostat's under-voltage threshold was 58 percent of the rated voltage. The tests also indicate that it had an energy storage device allowing it to work for some time (0.5 seconds) at low voltages before its electronics shutdown. The thermostat's cycle protection was activated at voltage recovery to protect the compressor. Table 6 summarizes the test results.

V_{SAG} (%)	t_{SAG} (Sec.)	$t_{HOLD\text{-}ON}$ (Sec.)	Comments
60	10	N/A	Electronics did not shutdown
58	10	0.44	* Electronics shutdown in 0.5 sec after applying the transient * Short cycle-protection was activated at voltage recovery * Restart in approximately 5 minutes after voltage recovery
55	10	0.66	
50	10	0.40	

Table 6 - Honeywell Digital Programmable Thermostat without Batteries Test Results

4.1.3.4 Under-Voltage Testing with Batteries and without Common "C" Wire

The removal of the "C" wire causes the thermostat to have no under-voltage protection.

4.1.3.5 Under-Voltage Testing without Batteries and Common "C" Wire

The removal of the "C" wire and batteries makes the thermostat inoperable. The thermostat electronics are powered by batteries and/or the 24-volt transformer with common "C" and return "R" wires. Without a source of energy to operate its electronics this thermostat becomes inoperable.

4.2 Totaline Digital Programmable Thermostat Test Results

This high-end off-the-shelf digital programmable thermostat was purchased from a local air conditioner contractor. The Totaline Digital Programmable thermostat's system switch has cool, off, and heat positions. Its fan switch has on and auto settings. Its temperature-setting button has ranges from 35°F to 90°F. It has additional buttons for programming temperatures and setting the clock. Under-voltage testing was done with the button set to the cool position (system switch = cool & fan switch = on & TSET < TACTUAL). This thermostat did not have a battery compartment; therefore, does not require batteries.

Test results indicated the Totaline thermostat:

- ♦ Does not have any under-voltage protection
- ♦ Short cycle protection
  - Did not activate with total power loss or electronics shutdown
  - Activated when the actual temperature rose above the set temperature or with changes to the system switch settings
  - Lasted approximately 5.5 minutes
- ♦ Does not have a cold load pickup protection after its electronics shuts down

Testing concluded that this thermostat provides no under-voltage protection; therefore, it would not mitigate the air conditioner stalling problem.

4.2.1 Specifications

Table 7 provides the specifications for the tested Totaline digital programmable thermostat.

Manufacturer	Totaline				
Model Number	P374-1800				
Name	Digital Programmable Thermostat				
Line Terminals Ratings					
Voltage	24 VAC				
Frequency	50/60 Hz				
Time Delay	Not specified				
Cycle Protection Time	5 minutes				
Selector Buttons					
Mode (System)	Fan	Temperature Selector	Outside Temperature	Humidity	Program/Clock
Terminals					
Common "C"	Return "R"	Green "G"	Yellow "Y"	White "W"	
Contacts					
Cooling	Heating	Fan			
"R" and "Y" terminals	"R" and "W" terminals	"R" and "G" terminals			
Picture					

Table 7 - Totaline Digital Programmable Thermostat Specifications

4.2.2 Non-Installed Testing

These tests were performed to observe the thermostat's response to setting changes without any external connections. Since this thermostat does not have batteries, it needs no power to turn on its electronics. All its terminals had infinite resistance among each other.

4.2.3 Installed Testing

These tests were performed with all the standard residential connections including the common "C" wire. The short cycle protection caused by power loss clears this thermostat's memory and allows the compressor to restart following the power loss.

4.2.2.1 System, Fan, and Temperature Setting Buttons Testing

Tests were performed to assess the functionality of the system, fan, and temperature-setting buttons used for controlling the cooling and heating functions of the thermostat. When the thermostat was in the cool mode (system switch = cool & fan switch = auto &

TSET < TACTUAL) and the compressor was running normally, the following observations were made:

- The compressor and indoor fan ran normally
- Fan switch changes did not change anything while the compressor was running
- When the system switch was turned off, the compressor shut down and the short cycle protection activated immediately, the fan ran normally
- When the system switch was turned to ‘off’ or ‘heat’ and then back to the ‘cool’ position, the short cycle protection activated immediately, the fan ran normally
- When the actual temperature reached the set temperature, the compressor shut down and the short cycle protection activated immediately, the fan ran normally
- The fan ran when the system switch was in the ‘cool’ position and/or the fan switch was in the ‘on’ position

4.2.2.2 Under-Voltage Testing

These tests were performed to assess how the Totaline thermostat behaves during under-voltage transients. The under-voltage transients were applied when the thermostat was in the cool mode (system switch = cool & fan switch = auto & TSET < TACTUAL) and the compressor was running normally. Table 8 shows the test results indicating this thermostat’s lack of under-voltage protection. We also found that neither total power loss nor electronics shutdown protected the compressor when power was restored.

V_{SAG} (%)	t_{SAG} (Sec.)	$t_{RESPONSE}$ (Sec.)	Comments
Long Under-voltage Transient Test			
60	10	none	Nothing
50	10	none	* Power contactor opened for all of the transient period * No short cycle-protection after voltage recovery
45	10	none	
43	10	none	* Electronics shutdown in 0.6 sec for the duration of the transient period * Power contactor opened for transient period and approx. 3.1 sec after recovery * No short cycle-protection after voltage recovery
40	10	none	
Short-Fast Under-voltage Transient Test			
40	0.70	none	* Electronics shutdown in 0.6 sec for the duration of the transient period * Power contactor opened for transient period and approx. 3.1 sec after recovery * No short cycle-protection after voltage recovery
40	1.00	none	
40	0.30	none	* Electronics did not shutdown * Power contactor opened for the duration of the transient period * No short cycle-protection after voltage recovery
40	0.50	none	
0	0.30	none	

Table 8 - Totaline Digital Programmable Thermostat Test Results

4.2.2.3 Under-Voltage Testing Without Batteries

This test was not possible because this thermostat does not require batteries.

4.2.2.4 Under-Voltage Testing without Common “C” Wire

The removal of the “C” wire causes the thermostat to be inoperable because this wire powers this thermostat’s electronics.

4.3 Ritetemp Digital Programmable Thermostat Test Results

This high-end off-the-shelf digital programmable thermostat was purchased from a local air conditioner contractor. The thermostat's mode (system) switch has cool mode, off, and heat positions. Its fan switch has on and auto positions. Its temperature-setting button has ranges from 35°F to 90°F. It has additional buttons for programming temperatures and setting the clock. Under-voltage testing was done with the button settings in the cool position (system switch = cool & fan switch = on & TSET < TACTUAL).

Test results indicate the Ritetemp thermostat:

- Does not have any under-voltage protection
- Short cycle protection
  - Lasted approximately 5 minutes
  - Activates with changes to system switch settings or when temperature settings equal the actual temperature
- Does not have a cold load pickup protection after its electronics shut down

This thermostat does not have any under-voltage protection; therefore, it would not help mitigate the air conditioner stalling problem.

4.3.1 Specifications

Table 9 provides specifications for the tested Ritetemp digital programmable thermostat.

Manufacturer	Ritetemp			
Model Number	8022C			
Name	Digital Programmable Thermostat			
Line Terminals Ratings				
Voltage	24 VAC			
Frequency	50/60 Hz			
Time Delay	Not specified			
Cycle Protection Time	5 minutes			
Selector Buttons				
Mode (System)	Fan			
Select Buttons				
Outside Temperature	Filter	Program	Time	Temperature Selector
Terminals				
Common "C"	Return "R"	Green "G"	Yellow "Y"	White "W"
Contacts				
Cooling	Heating	Fan		
"R" and "Y" terminals	"R" and "W" terminals	"R" and "G" terminals		
Picture				

Table 9 - Ritetemp Digital Programmable Thermostat Specifications

4.3.2 Non-Installed Testing

These tests were performed to observe the thermostat's response to different settings without any external connections. The thermostat did not work without a battery installed because its electronics were shut down. Without batteries, the resistance between "R" (return) and "G" (green) terminals follow the fan switch settings. The resistance among all other terminals is infinite, meaning they are isolated from each other.

When the batteries were removed the electronics took about 1.5 minutes to shut down. The short cycle protection activates immediately when batteries are installed or when the cool temperature is lower than the actual temperature. It took approximately 5.5 minutes for the short cycle protection to clear. With the batteries installed and thermostat settings in cool mode (system switch = cool & fan switch = on & TSET < TACTUAL), the following observations were made:

- The R and G fan switch terminals had low resistance indicating the fan switch was in the "on" position

- The short cycle protection (wait state) enabled immediately if the actual temperature reached or surpassed the set temperature (TSET > TACTUAL) and cooling of the desired area was accomplished
- Short cycle protection was not enabled by any system switch position changes

4.3.3 Installed Testing

These tests were performed on the Ritetemp thermostat with all the standard residential connections including the common wire "C" and batteries.

4.3.2.1 System, Fan, and Temperature Setting Switches Testing

These tests were performed to assess the functionality of the system, fan, and temperature-setting switches used to control the cooling and heating functions of the thermostat. When the thermostat was in the cool mode (system switch = cool & fan switch = auto & TSET < TACTUAL) with the compressor running normally, it was observed:

- The compressor and indoor fan ran normally
- Fan switch changes did not activate any function while the compressor was running
- When the system switch was turned off, the compressor shut down and the short cycle protection activated immediately, the fan ran normally
- When the system switch was turned to 'off' or 'heat' and then back to the 'cool' position, the short cycle protection activated immediately, the fan ran normally
- When the actual temperature equaled the set temperature, the compressor shut down immediately and the short cycle protection activated immediately, the fan ran normally
- The fan only ran when the system switch was in the cool position or the fan switch was on

4.3.2.2 Under-Voltage Testing

These tests were performed to assess how the thermostat behaves during under-voltage transients. The under-voltage transients were applied when the thermostat had batteries in place, was in 'cool' mode (system switch = cool & fan switch = auto & TSET < TACTUAL) and the compressor was running normally. Table 10 provides the test results, revealing that this thermostat does not have any under-voltage protection and neither total power loss nor electronics shutdown activated the cycle protection.

V_{SAG} (%)	t_{SAG} (Sec.)	$t_{RESPONSE}$ (Sec.)	Comments
Power contactor opened			
70	10	none	Nothing
65	10	none	
60	10	none	
50	10	none	* Power Contactor opened for all of the transient period * Electronics did not shutdown * Cycle protection did not activate at voltage recovery
40	10	none	
20	10	none	
0	10	none	

Table 10 - Ritetemp Digital Programmable Thermostat Test Results

4.3.2.3 Under-Voltage Testing with Batteries and without Common "C" Wire

This test revealed that the thermostat did not provide any under-voltage protection even with both batteries and the "C" wire installed.

4.3.2.4 Under-Voltage Testing without Batteries and Common "C" Wire

The thermostat electronics shut down; therefore, the thermostat does not function without batteries and without the "C" wire.

5.0 UNDER-VOLTAGE PROTECTION DEVICES

Under-voltage protection devices were tested to assess how well they perform during under-voltage transient events. These devices are used to protect motors from dangerously high currents that can damage the compressor windings. Eight under-voltage protection devices were tested, two of which were prototypes.

Figure 6 shows a typical wire-in under-voltage protection relay connection in the control circuit loop. The under-voltage protection device monitors the supply voltage and disconnects the control circuit when a predetermined under-voltage condition is present. The device has four terminals: two are connected to the supply voltage (240 VAC) for monitoring the voltage, and two (contact S4) are connected in series with the control circuit loop and serve to open the air conditioner power contactor. These under-voltage relays typically have a normally open (N.O.) and/or a normally closed (N.C.) contact. This loop usually begins at the 24 VAC side of the potential transformer, goes through the thermostat contact and power contactor coil, and then returns to the power transformer. For testing purposes, the thermostat relay contact was omitted from the control circuit loop as shown in Figure 6. The under-voltage protection device's contacts will only open if a predetermined under-voltage condition is present in the supply voltage. Digital programmable thermostats were not used in this test because they were evaluated in a separate set of tests.

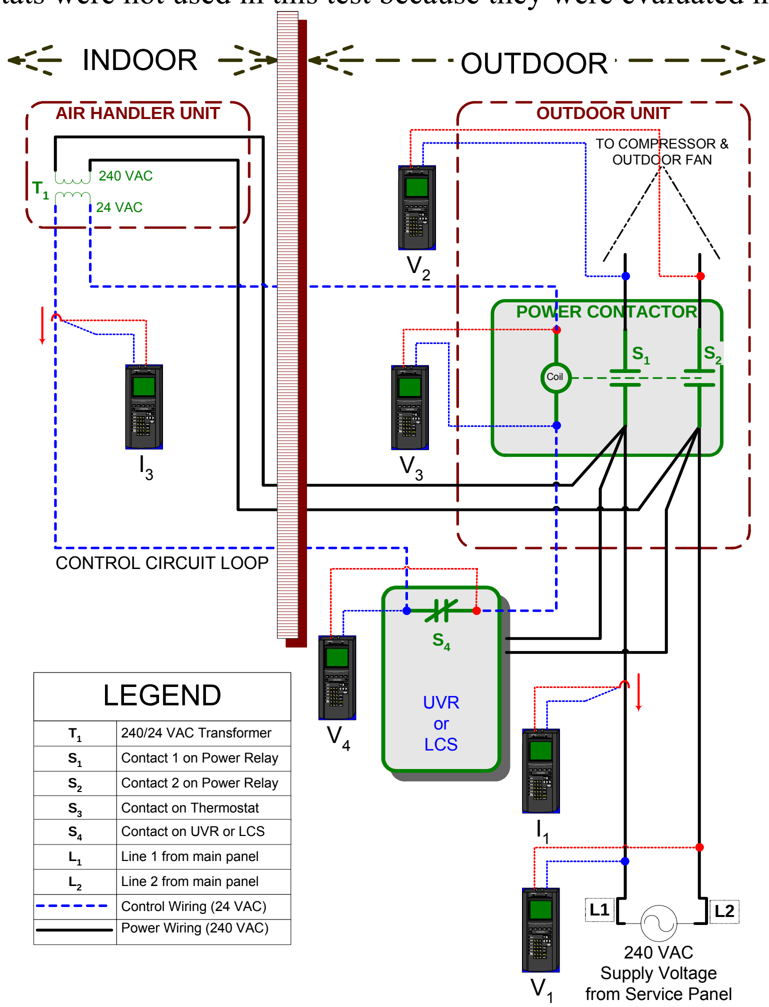


Figure 6 - Under-Voltage Protection Device Test Setup Installation

Figure 7 shows the typical plug-in under-voltage protection connection used for this test. This type of under-voltage protection device does not have control contacts; it only has power contacts in line with the supply voltage. This under-voltage relay monitors the supply voltage and disconnects its output voltage when a predetermined under-voltage condition is present. This type of relay has a plug-in side which is connected to a power outlet and has a outlet side where the loads are connected. For this test, a load will not be needed to determine proper operation. In an actual installation the load would be in the air handler unit, window air conditioner, or the power transformer because the contacts have low amperage ratings and would not be able to handle the normal full motor load of split A/C compressors.

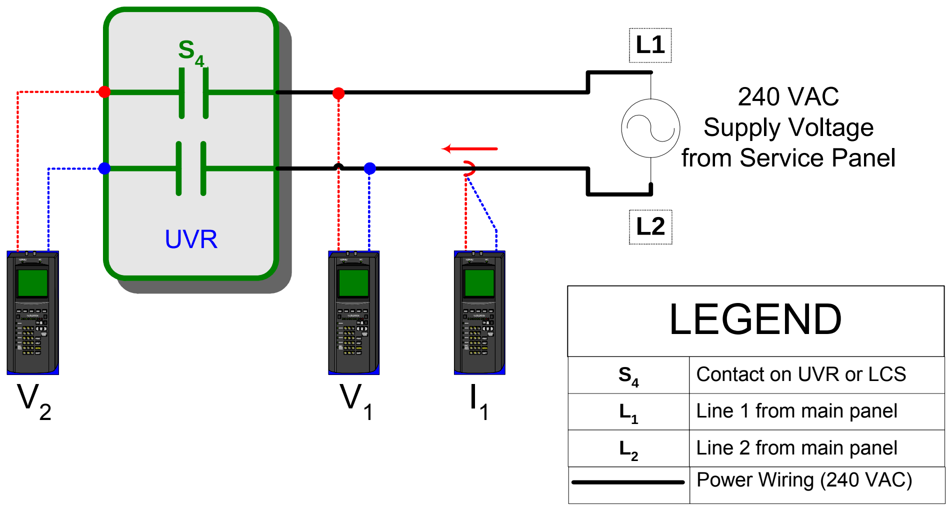


Figure 7 - Plug-in Type Under-Voltage Protection Device Test Setup Installation

5.1 ICM Controls Under-Voltage Relay Test Results

The ICM Controls under-voltage relay has two knobs that can be manually adjusted. The first is the voltage tripping set point knob with a range of 190 VAC (80 percent) to 270 VAC (110 percent) of the full rated voltage. We set this knob to the lowest set point, 190 VAC for all the performed tests. The second knob is the under-voltage delay time knob and its settings go from 6 seconds to 10 minutes. We set this knob to the lowest set point, 6 seconds, for most of the performed tests. This under-voltage relay has two sets of contacts, normally closed (N.C.) and normally open (N.O.), for under-voltage protection. We used the normally closed (N.C.) contacts for this test.

Test results indicate this device's:

- Under-voltage protection threshold is 86 percent
- Under-voltage protection response time is approximately 4.8 seconds
- Short cycle protection time is 6 seconds
- Cold load pickup protection does not work

- This under-voltage protection device does not have adequate under-voltage protection logic to mitigate the air conditioner stalling problem.

5.1.1 Specifications

Table 11 provides the specifications for the tested ICM Controls under-voltage relay.

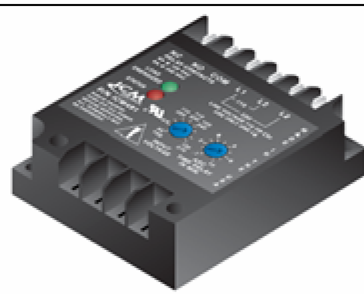
Manufacturer	ICM Controls	
Model Number	ICM491	
Part Number	ICM491	
Name	Single Phase Line Monitor	
Line Terminals Ratings		
Voltage	240 VAC	
Frequency	50/60 Hz	
Time Delay	0.045 seconds	
Short Cycle Time Delay	0.1 to 10 minutes	
Selector Voltage Switch	**190 to 270 VAC**	**95 – 135 VAC**
High Voltage cut-out	Selected + 12%	
High Voltage cut-in	Selected + 8%	
Low Voltage cut-out	Selected - 12%	
Low Voltage cut-in	Selected - 8%	
Control Contacts Terminals Ratings		
Amperage	5 Amps @ 277 VAC	
Contacts Type	Normally Open (N.O.) & Normally closed (N.C.)	
Picture		

Table 11 - ICM Controls Under-Voltage Relay Specifications

5.1.2 Non-Power Test

This test was performed on the ICM relay to find out the type of control contacts this under-voltage protection relay has and to assess whether it was safe to install the device and initiate testing. Table 12 lists the impedance measurements taken from the tested unit. The resistance for the line terminals (L1 and L2) was infinite making it safe for installation. The resistance among the control contacts terminals was infinite and 3.9 Ω, normally open and normally closed contacts respectively.

Power Terminals Resistance $L1 - L2_{240}$	2.63 MΩ
Power Terminals Resistance $L1 - L2_{120}$	2.67 MΩ
N.O. Control Contacts Terminals Resistance NO – COM	Infinite Ω
N.C. Control Contacts Terminals Resistance NC – COM	3.9 Ω
Power Line 1 (L1)- Control Contacts Terminal Resistance L1 – NO L1 – NC L1 – COM	Infinite Ω
Power Line 2 @ 240 ($L2_{240}$)- Control Contacts Terminal Resistance $L2_{240}$ – NO $L2_{240}$ – NC $L2_{240}$ – COM	Infinite Ω
Power Line 2 @ 120 ($L2_{120}$)- Control Contacts Terminal Resistance $L2_{120}$ – NO $L2_{120}$ – NC $L2_{120}$ – COM	Infinite Ω

Table 12 - ICM Under-Voltage Relay Impedance

5.1.3 Under-Voltage Protection

Tests indicate this under-voltage relay's threshold is 86 percent of the full rated voltage (240 VAC). The ICM under-voltage relay provided protection from 86 percent down to 78 percent with the equal protection response times of 4.8 seconds.

The device has a time delay knob that can be adjusted from 6 seconds to 10 minutes. The test results reveal that this knob was not accurate because its response time was 5.28 seconds when set at 6 seconds and its response time measured 4.97 seconds when set at 120 seconds.

5.1.4 Electronics Shutdown

The electronics shut down when the voltage dipped below 76 percent of the full rated voltage for more than 100 milliseconds. With the electronics shut down, this device did not open its control contacts to protect the compressor against under-voltages.

5.1.5 Short Cycle Protection Time

Testing indicates that this under-voltage protection device has a short cycle protection time of 5 seconds when its control contacts open due to an under-voltage. This device did not have any short cycle protection when the electronics came back on following an under-voltage shutdown. This device does not have cold load pickup protection after its electronics shut down.

5.1.6 Test Details

Table 13 provides test details for the ICM Controls under-voltage relay.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{DELAY-SETTING}$ (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Under-voltage Protection Test				
88	10	6	none	Nothing happened
86	10	6	4.8	* Control contacts opened * Control contacts re-closed 4.8 sec after voltage recovery * No short cycle protection (only 6 seconds)
80	140	120	4.97	
80	20	6	6	
78	10	6	4.8	
0	30	6	N/A	* Allowed the compressor to restart * No startup delay time, therefore no cold load pickup protection
80	20	120	none	* Nothing because the transient was shorter than the set delay time (120 sec)
75	10	6	none	* Control contacts did not open because electronics died * No short cycle protection
60	10	6	none	
55	10	6	none	* Control contacts did not open because electronics died * Power contactor opened for all of the transient period * No short cycle protection
50	10	6	none	
Short-Fast Long Under-voltage Protection Test				
<50	>0.1	6	none	* Control contacts did not open because electronics died * Power contactor opened for all of the transient period * No short cycle protection
40	2.5	6	none	
0	2.5	6	none	
60	2.5	6	none	* Control contacts did not open because electronics died * No short cycle protection

Table 13 - ICM Under-Voltage Relay Test Results

5.2 Diversified Electronics 240-VAC Plug-in Under-Voltage Relay Test Results

The Diversified Electronics CV-200RS-20 Plug-in under-voltage relay is suitable for use in window type air conditioner units and air conditioner air handlers equipped with 240 VAC plug-in type cords. It does not have control loop contacts but instead has high amperage rating contacts (20 amperes at 240 VAC) between the input and output line terminals. This device can withstand a locked rotor current of 72 amperes for a short period of time. It has a voltage selector switch used to choose voltages rated 240 VAC or 230 VAC. All tests performed on this device were done with the selector switch at 240 VAC, the standard SCE residential voltage.

Test results indicate that this device's:

- Under-voltage protection threshold is 83 percent and does not work for voltage transients faster than 4 cycles
- Under-voltage response time is approximately 300 to 100 milliseconds, with longer response times at the higher voltages
- Short cycle protection time is 5 minutes, without randomization
- Cold load pickup protection is approximately 5 minutes
- Contacts are normally open (N.O.)
- Protects the air conditioner from really low under-voltage transients

Although this device has a higher under-voltage threshold than SCE's proposed stall protection specifications, it could help to mitigate the air conditioner stalling problem. Its under-voltage protection threshold and response delay time are close to SCE's proposed stall protection parameters. Additionally, this device has a good short cycle protection time, similar to what SCE suggests, but without randomization.

It has two disadvantages; first, it has N.O. contacts, which locks out the air conditioner when the under-voltage relay fails. Second, implementation could be difficult because the protected device must have a plug-in electric cord.

5.2.1 Specifications

Table 14 provides the specifications for the tested Diversified Electronics CV-200RS-20 Plug-in under-voltage relay.

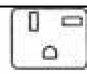
Manufacturer	Diversified Electronics	
Model Number	CV-200RS-20	
Part Number	CV-200RS-20	
Name	Voltage Band Monitor with Short Cycle Protector	
Line Terminals Ratings		
Voltage	240 VAC	
Frequency	50/60 Hz	
Short Cycle Time Delay	5 min.	
Selector Voltage Switch	**230 VAC**	**240 VAC**
Drop-out Under-voltage	190 VAC	202 VAC
Pick-up Under-voltage	198 VAC	210 VAC
Drop-out Over-voltage	243 VAC	258 VAC
Pick-up Over-voltage	253 VAC	268 VAC
Contacts Terminals Ratings		
Amperage	20 Amps @ 240 VAC	
Lock Rotor Amps (LRA)	72 Amps	
Contacts Type	Normally Open (N.O.)	
Receptacle Type		
Picture		

Table 14 - Diversified Electronics CV-200RS-20 Plug-in Under-Voltage Relay Specifications

5.2.2 Non-Power Test

This test was performed on this relay to determine what type of control contacts the under-voltage protection has and assess whether it was safe to install the device and initiate its testing. Table 15 lists the impedance readings for this device. The resistance among the input power terminals (H1, N1, G1) was infinite, just as it was with the output power terminals (H2, N2, G2). The resistance between the input and output line terminals was infinite, as they were normally open contacts. All the resistance readings indicated it was safe for installation.

Input/Output L1 Power Terminal Resistance L1H1 – L1H2	Infinite Ω
Input/Output L2 Power Terminal Resistance L2H1 – L2H2	4.0 Ω
Input/Output Ground (G) Power Terminal Resistance G1 – G2	4.0 Ω
Input Power (L1 and L2) Terminals Resistance L1H1 – L2H1	Infinite Ω
Input Power (L1) - Ground Terminals Resistance L1H1 – G	Infinite Ω
Input Power (L2) - Ground Terminals Resistance L2H1 – G	Infinite Ω
Output Power (L1 and L2) Terminals Resistance L1H2 – L2H2	Infinite Ω
Output Power (L1) - Ground Terminals Resistance L1H2 – G	Infinite Ω
Output Power (L2) - Ground Terminals Resistance L2H2 – G	Infinite Ω

Table 15 - Diversified Electronics CV-200RS-20 Plug-in Under-Voltage Relay Impedances

5.2.3 Under-Voltage Protection

Tests indicate this relay's under-voltage threshold is 83 percent of the full rated voltage (240 VAC). It protects from 83 percent down to 50 percent with response times varying from 100 to 300 milliseconds; the longest response time being at the under-voltage threshold. It also protects for voltages below 50% with about the same response time of the power contactor, 2 cycles. This under-voltage relay did not respond to transients faster than 6 cycles (100 milliseconds).

5.2.4 Electronics Shutdown

It was hard to determine the electronics shutdown threshold for this device because it has normally open (N.O.) contacts. When the electronics shut down, the line contacts open and as soon as the voltage recovers the cold load pickup protection activates.

5.2.5 Short Cycle Protection Time

Tests indicate this device has a short cycle protection time of approximately 290 sec (~ 5 minutes). This short cycle protection time is activated by almost any under-voltage event (except transients faster than 6 cycles) including total power loss for any period.

5.2.6 Test Details

Table 16 provides test details for the Diversified Electronics CV-200RS-20 Plug-in under-voltage relay.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Under-voltage Protection Test			
85	40	N/A	Nothing happened
83	40	0.300	* Control contacts opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
80	40	0.190	
70	40	0.132	
60	40	0.100	
55	40	0.100	
50	40	0.100	* Control contacts opened * Power Contactor opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
Short-Fast Under-voltage Protection Test			
60	0.065	none	Nothing because transient too fast
60	0.100	0.084	* Control contacts opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
40	0.100	0.067	* Control contacts opened * Power Contactor opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
40	0.065	0.067	
0	0.250	0.032	
0	0.100	0.650	
0	0.065	0.087	

Table 16 - Diversified Electronics CV-200RS-20 Plug-in Under-Voltage Relay Test Results

5.3 Diversified Electronics CV-100RS Plug-In Under-Voltage Relay Test Results

Diversified Electronics CV-100RS plug-in under-voltage relay is suitable for use in window type air conditioner units or for air conditioner air handlers equipped with 120 VAC plug-in type cords. It does not have control loop contacts; instead, it has high amperage rating contacts 15 amperes at 240 VAC. This device can withstand a locked rotor current of 40 amperes for short period of time. It has a voltage selector switch used to select the rated voltage, 120 VAC or 110 VAC. All tests performed on this device were done with the selector switch at 120 VAC, an SCE residential voltage.

Test results indicate that this device's:

- Under-voltage protection threshold is 78 percent and does not work for voltage transients faster than 3 cycles
- Under-voltage response time is approximately 233 milliseconds at the threshold and faster for lower voltage transients
- Short cycle protection time is 5 minutes, without randomization
- Cold load pickup protection activates after its electronics shut down
- Contacts are normally open (N.O.)

Its under-voltage threshold and response delay time are close to SCE's proposed stalled protection parameters. This device has a good short cycle protection time and could be used to protect air handler units rated 120 VAC.

This relay has good under-voltage protection logic to mitigate the air conditioner stalling problem. It has two disadvantages. First, it can only be used in air conditioners rated 120 VAC. Second, it has N.O. contacts, which locks out the air conditioner when the under-voltage relay fails.

5.3.1 Specifications

Table 17 provides the specifications for the tested Diversified Electronics CV-100RS plug-in under-voltage relay.

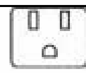
Manufacturer	Diversified Electronics	
Model Number	CV-100RS	
Part Number	CV-100RS	
Name	Voltage Band Monitor with Short Cycle Protector	
Line Terminals Ratings		
Voltage	120 VAC	
Frequency	50/60 Hz	
Short Cycle Time Delay	5 min.	
Selector Voltage Switch	**110 VAC**	**120 VAC**
Drop-out Under-voltage	87 VAC	95 VAC
Pick-up Under-voltage	95 VAC	103 VAC
Drop-out Over-voltage	120 VAC	131 VAC
Pick-up Over-voltage	128 VAC	140 VAC
Contacts Terminals Ratings		
Amperage	15 Amps @ 120 VAC	
Lock Rotor Amps (LRA)	40 Amps	
Contacts Type	Normally Open (N.O.)	
Receptacle Type		
Picture		

Table 17 - Diversified Electronics CV-100RS Plug-in Under-voltage Relay Specifications

5.3.2 Non-Power Test

This test was performed on this relay to determine what type of control contacts the under-voltage protection the device has and assess whether it was safe to install and initiate testing. Table 18 lists the impedance readings for this device. The resistance among the input power terminals (H1, N1, G1) was infinite, just as it was with the output power terminals (H2, N2, G2). The resistance between the input and output hot terminals was infinite, as they were normally open contacts. All the resistance readings indicated it was safe for installation.

Input/Output Hot Terminals Resistance H1 – H2	Infinite Ω
Input/Output Neutral Terminals Resistance N1 – N2	7.2 Ω
Input/Output Ground Terminal Resistance G1 – G2	4.0 Ω
Input Hot and Neutral Terminals Resistance H1 – N1	Infinite Ω
Input Hot and Ground Terminals Resistance H1 – G1	Infinite Ω
Input Neutral and Ground Terminals Resistance N1 – G1	Infinite Ω
Output Hot and Neutral Terminals Resistance H2 – N2	Infinite Ω
Output Hot and Ground Terminals Resistance H2 – G2	Infinite Ω
Output Neutral and Ground Terminals Resistance N2 – G2	Infinite Ω

Table 18 - Diversified Electronics CV-100RS Plug-In Under-Voltage Relay Impedances

5.3.3 Under-Voltage Protection

Tests indicate that this under-voltage relay's threshold is 78 percent of the full rated voltage (240 VAC). The DE 120 relay works from 78 percent down to 0 percent and its response times range from 17 to 232 milliseconds; the longest response time is at the under-voltage threshold. This under-voltage relay does not respond for transients faster than 3 cycles (50 milliseconds). This device's response time is good because it quickens as the voltage decreases.

5.3.4 Electronics Shutdown

It is hard to determine the electronics shutdown threshold because it has normally open (N.O.) contacts. This is because when the electronics shut down, the line contacts open and as soon as the voltage recovers the cold load pickup protection activates.

5.3.5 Short Cycle Protection Time

Tests indicate that this device has a short cycle protection time of approximately 290 sec (~ 5 minutes). This short cycle protection time is activated by almost any under-voltage event (except transients faster than 3 cycles) including total power loss for any period.

5.3.6 Test Details

Table 19 provides test details for the Diversified Electronics CV-100RS plug-in under-voltage relay.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Undervoltage Transient Test			
80	10	N/A	Nothing happened
78	10	0.232	* Control contacts opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
75	10	0.150	
70	10	0.117	
60	10	0.084	
50	10	0.067	* Control contacts opened * Power Contactor opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
40	10	0.050	
Short-Fast Undervoltage Transient Test			
60	0.100	0.084	* Control contacts opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
60	0.050	none	Nothing because transient was too fast
40	0.050	0.033	* Control contacts opened * Power Contactor opened * Control contacts re-closed 5 minutes after voltage recovery * Good short cycle-protection
0	0.050	0.017	
0	0.100	0.017	

Table 19 - Diversified Electronics CV-100RS Plug-In Under-Voltage Relay Test results

5.4 Diversified Electronics Mount-In Under-Voltage Relay Test Results

The Diversified Electronics CV-240-AFN mount-in under-voltage relay can be installed into the air conditioner outdoor unit using quick connectors. Its contacts have a high amperage rating making it suitable for circuits drawing fewer than 20 amperes at 240 VAC, especially for control loop circuits. This device can withstand a locked rotor current of 52 amperes for a short period of time.

Test results indicate that this device's:

- Under-voltage protection threshold is 83 percent and does not work for voltage transients faster than 15 cycles
- Under-voltage response time is approximately 500 milliseconds
- Short cycle protection time is 5 minutes, without randomization
- Cold load pickup protection activates after its electronics shut down
- Contacts are normally open (N.O.)

This under-voltage protection device can help mitigate the air conditioner stalling problem if its under-voltage protection threshold and response time are adjusted to meet SCE's proposed specifications.

5.4.1 Specifications

Table 20 provides the specifications for the tested Diversified Electronics CV-240-AFN mount-in under-voltage relay.

Manufacturer	Diversified Electronics
Model Number	CV-240-AFN
Part Number	CV-240-AFN
Name	Under-voltage Short Cycle Protector
Line Terminals Ratings	
Voltage	240 VAC
Frequency	50/60 Hz
Short Cycle Time Delay	5 min.
Pick-up and Drop-out Voltages	
Drop-out Under-voltage	202 VAC
Pick-up Under-voltage	210 VAC
Drop-out Over-voltage	N/A
Pick-up Over-voltage	N/A
Control Contacts Terminals Ratings	
Amperage	20 Amps @ 240 VAC
LRA	52 Amps
Type	Normally Open (N.O.)
Picture	

Table 20 - Diversified Electronics CV-240-AFN Mount-in Under-Voltage Relay Specifications

5.4.2 Non-Power Test

This test was performed on the this relay to determine what type of control contacts this device has and assess whether it was safe to install and initiate testing. Table 21 lists the impedance readings for this device. The line terminal (L1 and L2) resistance was infinite making it safe for installation. The resistance among the control contacts terminals was infinite, as they were normally open contacts. All the resistance readings indicated it was safe for installation.

Power Line (L1 and L2) Terminals Resistance L1 – L2	Infinite Ω
Control Contacts Terminals Resistance M1 – M2	Infinite Ω
Power - Control Contacts Terminal Resistance L1 – M1 L1 – M2 L2 – M2	Infinite Ω

Table 21 - Diversified Electronics CV-240-AFN Mount-in Under-Voltage Relay Impedance

5.4.3 Under-Voltage Protection

Tests indicated that this under-voltage relay's threshold is 83 percent of the full rated voltage (240 VAC). The Diversified Electronics mount-in relay works from 83 percent down to 30 percent voltage with equal response times of 500 milliseconds. The response time varies for voltages below 30 percent – from the long end at 140 milliseconds, to the shortest at 100 milliseconds. This under-voltage relay does not respond to transients faster than 12 cycles (250 milliseconds).

5.4.4 Electronics Shutdown

It was hard to determine the electronics shutdown threshold for this device because it has normally open (N.O.) contacts, but it seems to be at 30 percent of full rated voltage. If the electronics shut down, the control contacts open. As soon as the voltage recovers the cold load pickup protection activates.

5.4.5 Short Cycle Protection Time

Tests indicated this device has a short cycle protection time of approximately 290 sec (~ 5 minutes). This short cycle protection time is activated by almost any under-voltage event (except transients faster than 3 cycles) including when there is total power loss for any period of time.

5.4.6 Test Details

Table 22 provides test details for the Diversified Electronics CV-240-AFN mount-in under-voltage relay.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{POWER\ CONTACTOR\text{-}OPEN}$ (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Under-voltage Transient Test				
85	10	N/A	N/A	Nothing happened
83	10	N/A	0.483	* Control contacts opened * Control contacts re-closed 5 minutes after voltage recovery * Good cycle protection
80	10	N/A	0.483	
70	10	N/A	0.516	
60	10	N/A	0.483	
55	10	0.033	0.462	* Power contactor (P.C.) opened * Control contacts opened * Control contacts re-closed 5 minutes after voltage recovery * Good cycle protection * Impossible to tell where electronics start failing
50	10	0.033	0.483	
40	10	0.033	0.440	
30	10	0.016	0.424	
20	10	0.016	0.140	
10	10	0.033	0.100	
Short-Fast Under-voltage Transient Test				
60	<0.250	N/A	N/A	Nothing because transient was too fast
40	<0.240	N/A	N/A	* Power contactor opened for the transient time then re-closed normally * Control contacts did not get tripped off * No cycle protection
0	<0.250	N/A	N/A	

Table 22 - Diversified Electronics CV-240-AFN Mount-in Under-Voltage Relay Test Results

5.5 Kriwan Under-Voltage Relay Test Results

The Kriwan mount-in under-voltage relay can be installed into the compressor unit using quick connectors. This device is commonly used on high-end air conditioner units with Copeland compressors. Its contacts have a low amperage rating of 2.5 amperes at 240 VAC making it only suitable for control circuits. This device also has thermal protection capabilities; its three thermocouples connections protect the compressors against high temperature conditions. These thermocouples were not used during testing instead three resistors were installed to simulate normal temperature conditions.

The test results indicate that this device's:

- Under-voltage protection threshold is 68 percent and does not work for voltage transient faster than 9 cycles
- Under-voltage response protection time is approximately 300 milliseconds
- Short cycle protection time is 2 minutes, without randomization
- Cold load pickup protection activates after its electronics shut down
- Contacts are normally open (N.O.)

This under-voltage protection device can help mitigate the air conditioner stalling problem if its under-voltage protection threshold and short cycle protection time are adjusted to meet SCE's proposed stall protection parameters.

5.5.1 Specifications

Table 23 provides the specifications for the tested Kriwan mount-in under-voltage relay.

Manufacturer	CMP Corporation – Kriwan Division	
Model Number	INT369	
Part Number	22A276S21	
Name	Motor Protector	
Line Terminals Ratings		
Voltage	240 VAC	
Frequency	50/60 Hz	
Short Cycle Time Delay	120 ± 20 seconds	
Selector Voltage Switch	**120 VAC Automatic**	**240 VAC Automatic**
Drop-out Under-voltage	85 VAC	170 VAC
Contacts Terminals Ratings		
Amperage	2.5 Amps @ 240 VAC	
Contacts Type	Normally Open (N.O.)	
Receptacle Type	N/A	
Picture		

Table 23 - Kriwan Under-Voltage Relay Specifications

5.5.2 Non-Power Test

This test was performed on this relay to determine what type of control contacts this under-voltage protection device has and to assess whether it was safe to install and initiate testing. Table 24 lists the impedance readings for this device. The line terminals (L1 and L2) resistance was 4-KΩ, a high resistance value making it safe for installation. The resistance among the control contacts terminals was infinite, as they have normally open contacts (N.O.). The resistance between each temperature sensor terminal and the common and temperature sensor terminals was 8.04 K-Ω and 6.36 K-Ω respectively. All the resistance readings indicate it was safe for installation.

Power Line (L1 and L2) Terminals Resistance L1 – L2	4 KΩ
Control Contacts Terminals Resistance M1 – M2	Infinite Ω
Power - Control Contacts Terminal Resistance L1 – M1 L1 – M2 L2 – M2	Infinite Ω
Temperature Sensor Terminals Resistance S1 – S2 S1 – S3 S2 – S3	8.04 KΩ
Common - Temperature Sensor Terminals Resistance C – S1 C – S2 C – S3	6.36 KΩ

Table 24 - Kriwan Under-Voltage Relay Impedance

This under-voltage relay also provides temperature protection for events brought on by under-voltage transients or other factors. Temperature sensors located in the motor casing are used to monitor the motor temperature. Because the device didn't have temperature sensors, installation of three resistors (560 Ω) was necessary before testing. These three resistors were installed connecting each of the temperature terminals to the common terminal in the under-voltage protection relay.

5.5.3 Under-Voltage Protection

Tests indicate that the under-voltage protection threshold of this device was 68 percent of the full rated voltage (240 VAC). The Kriwan relay's under-voltage protection works from 68 percent down to 40 percent with equal response times of 300 milliseconds. The response time varies for voltages below 40 percent. This under-voltage protection relay does not respond to transients faster than 9 cycles (150 milliseconds).

5.5.4 Electronics Shutdown

Since this device has normally open contacts it is difficult to tell where the electronics begin to fail. The electronics seem to start failing at approximately 40 percent for transients longer than 300 milliseconds.

5.5.5 Short Cycle Protection Time

The short cycle protection time for this device was 2 minutes. Under-voltage transients lower than the under-voltage threshold and longer than 300 milliseconds activate cycle protection. This cycle protection is also activated at initial power-up and 2 minutes pass before it allows the compressor to start up.

5.5.6 Test Details

Table 25 provides test details for the Kriwan under-voltage relay.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{POWER\ CONTACTOR-OPEN}$ (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Under-voltage Transient Test				
70	10	N/A	N/A	Nothing happened
68	10	N/A	0.440	* Control contacts opened * Control contacts re-closed 2 minutes after voltage recovery * Cycle protection (2 minutes)
65	10	N/A	0.350	
60	10	N/A	0.300	
55	10	N/A	0.300	
50	10	0.016	0.300	* Power contactor opened * Control contacts opened * Control contacts re-closed 2 minutes after voltage recovery * Cycle protection (2 minutes) * Impossible to tell where electronics shutdown (might be 40% because there the response time changes drastically)
45	10	0.016	0.300	
40	10	0.016	0.300	
40	20	0.016	0.300	
35	10	0.016	0.241	
10	10	0.016	0.200	
5	10	0.033	0.200	
Short-Fast Under-voltage Transient Test				
60	0.250	0.016	0.300	* Control contacts opened * Control contacts re-closed 2 minutes after voltage recovery * Cycle protection (2 minutes)
20	0.500	0.016	0.200	* Power contactor opened * Control contacts opened * Control contacts re-closed 2 minutes after voltage recovery * Cycle protection (2 minutes) * Impossible to tell where electronics shutdown (might be 40% because there the response time changes drastically)
0	0.500	0.016	0.500	
0	0.150	0.016	0.067	
60	0.100	N/A	N/A	Nothing because transient was too fast
60	0.150	N/A	N/A	
40	0.150	N/A	N/A	
0	0.100	N/A	N/A	

Table 25 - Kriwan Under-Voltage Relay Test Results

5.6 CSE Under-Voltage Relay Test Results

Corporate Systems Engineering (CSE) developed this device using SCE's proposed stall protection specifications, yielding the proper under-voltage protection logic to mitigate the air conditioner stalling problem. The CSE under-voltage relay can be installed by connecting quick connectors into the compressor unit. Its contacts have a low amperage rating of 3 amperes at 240 VAC making it suitable only for control circuits.

Test results indicated that this device's:

- Under-voltage protection threshold was 78 percent and does not work for voltage transients faster than 15 cycles
- Under-voltage response time is approximately 250 milliseconds
- Short cycle protection time is 3 to 5 minutes, with randomization
- Cold load pickup protection activates after its electronics shut down
- Contacts are normally closed (N.C.),

This device's electronics shut down too quickly. Its electronics need to remain active at 40 percent for at least 20 seconds and it must have a cold load pickup to meet SCE's proposed stall protection specifications. Overall, with the recommended adjustments, this device has the capability to mitigate the air conditioner stalling problem. It must be noted that this is a prototype and not yet a commercially available product.

5.6.1 Specifications

Table 26 provides the specifications for the tested CSE under-voltage relay.

Manufacturer	Corporate Systems Engineering
Model Number	N/A
Part Number	N/A
Name	A/C Under Voltage Relay
Line Terminals Ratings	
Voltage	240 VAC
Frequency	50/60 Hz
Short Cycle Time Delay	3~5 minutes in with randomization
Selector Voltage Switch	**N/A**
Drop-out Under-voltage	187 VAC
Contacts Terminals Ratings	
Amperage	3 Amps @ 24 VAC
Contacts Type	Normally closed (N.C.)
Receptacle Type	N/A
Picture	

Table 26 - CSE Under-Voltage Relay Specifications

5.6.2 Non-Power Test

This test was performed on the CSE relay to determine what type of control contacts this under-voltage protection device has and to assess whether it was safe to install for testing. Table 27 lists the impedance readings for this device. The line terminals (L1 and L2) resistance was infinite Ω, a high resistance value, making it safe for installation. The resistance among the control contacts terminals was 1.4 Ω. It has normally closed (N.C.) contacts.

Power Terminals Resistance L1 – L2	Infinite Ω
Control Contacts Terminals Resistance M1 – M2	4 KΩ
Power - Control Contacts Terminal Resistance L1 – M1 L1 – M2 L2 – M2	Infinite Ω

Table 27 - CSE Under-Voltage Relay Impedance

5.6.3 Under-Voltage Protection

Tests indicate the under-voltage protection threshold of this device was 78 percent of the full rated voltage (240 VAC). The CSE relay's under-voltage protection works from 78 percent down to 15 percent with equal response times of 250 milliseconds. This under-voltage protection relay does not respond to transients faster than 15 cycles (250 milliseconds).

5.6.4 Electronics Shutdown

The electronics started failing at approximately 15 percent for 10-second transients. This device does not have cold load pickup protection after its electronics shut down.

5.6.5 Short Cycle Protection Time

The short cycle protection time of this device was 3 to 5 minutes with randomization. Under-voltage transients lower than the under-voltage threshold and initial startup activate this short cycle protection.

5.6.6 Test Details

Table 28 provides the test details for the CSE under-voltage relay.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{POWER\ CONTACTOR\text{-}OPEN}$ (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Under-voltage Transient Test				
80	10	N/A	N/A	Nothing happened
78	10	N/A	0.500	* Control contacts opened * Control contacts re-closed 3~5 minutes randomly after voltage recovery * Good short cycle-protection
75	10	N/A	0.250	
70	10	N/A	0.250	
65	10	N/A	0.250	
60	10	N/A	0.250	
55	10	N/A	0.250	
50	10	0.016	0.250	* Power contactor opened in 1 cycle * Control contacts opened * Control contacts re-closed 3~5 minutes randomly after voltage recovery * Good short cycle-protection * Electronics OK
40	20	0.016	0.250	
40	10	0.016	0.250	
30	10	0.016	0.250	
20	10	0.016	0.250	
15	10	0.016	0.250	
10	10	0.016	0.250	* Power contactor opened in 1 cycle * Control contacts chat then opened. Re-closed 3~5 minutes randomly after voltage recovery * Good short cycle-protection * Electronics start dying
Short-Fast Under-voltage Transient Test				
60	0.250	N/A	N/A	Nothing because transient was too fast
60	0.132	N/A	N/A	
60	0.100	N/A	N/A	
40	0.132	0.016	N/A	* Power contactor opened for the transient time then re-closed normally * Control contacts did not opened * No cycle protection * No cold load pickup -- at 0 VAC the memory clears and there is no cycle protection at start up
0	0.132	0.016	N/A	
0	0.100	0.016	N/A	

Table 28 - CSE Under-Voltage Relay Test Results

5.7 PNNL Grid-Friendly Device Test Results

The PNNL grid-friendly device (GFD) contains a grid-friendly appliance (GFA) chip with circuitry that reduces the 240 VAC to a circuit board voltage level of 5 VDC. The GFA is an electronics chip mainly used to mitigate frequency transients. PNNL has reconfigured the GFA using SCE's proposed stall protection specifications.

Test results indicated this device's:

- Under-voltage protection threshold is 78 percent
- Under-voltage response time is approximately 33 milliseconds
- Short cycle protection time is 3 to 4 minutes, with randomization
- Cold load pickup protection is not available
- Contacts are normally closed (N.C.) and normally opened (N.O.), in this test N.C. contacts were used
- Electronics shut down 20 seconds after the voltage reached 40 percent

This device needs a cold load pickup to meet SCE's proposed stall protection specifications. Overall, with the recommended adjustments, this device has the capability to mitigate the air conditioner stalling problem. It is important to mention that most of this device's parameters can be adjusted as needed but it is a prototype device needing further testing and certifications.

5.7.1 Specifications

Table 29 provides the specifications for the tested PNNL grid-friendly device.

Manufacturer	Pacific Northwest National Laboratory
Model Number	N/A
Part Number	N/A
Name	Grid Friendly Device
Line Terminals Ratings	
Voltage	240 VAC
Frequency	50/60 Hz
Short Cycle Time Delay	3~5 minutes in with randomization
Selector Voltage Switch	**N/A**
Drop-out Under-voltage	185 VAC
Contacts Terminals Ratings	
Contacts Type	Normally closed (N.C.) & Normally Open (N.O.)
Receptacle Type	N/A
Picture	Final product is under design

Table 29 - PNNL Grid-Friendly Device Specifications

5.7.2 Under-Voltage Protection

Tests indicated the under-voltage protection threshold for this device was 77 percent of the full rated voltage (240 VAC). The PNNL grid-friendly device's under-voltage protection works from 77 percent down to 40 percent with equal response times of 33 milliseconds (2 cycles).

5.7.3 Electronics Shutdown

The electronics started failing at approximately 40 percent for 10-second transients. If the electronics shut down, the compressor is allowed to restart immediately after voltage recovery; therefore, this device does not have cold load pickup protection.

5.7.4 Short Cycle Protection Time

The short cycle protection time for this device was 3 to 5 minutes with randomization. Under-voltage transients lower than the under-voltage threshold and initial startup activate this cycle protection.

5.7.5 Test Details

Table 30 provides the test details for the PNNL grid-friendly device.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{POWER\ CONTACTOR\text{-}OPEN}$ (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Under-voltage Transient Test				
78	10	N/A	N/A	Nothing happened
77	10	N/A	0.033	* Control contacts opened * Control contacts re-closed 3~5 minutes randomly after voltage recovery * Good short cycle-protection
75	10	N/A	0.033	
60	10	N/A	0.033	
50	10	0.016	0.033	* Power contactor (P.C.) opened in 1 cycle * Control contacts opened * Control contacts re-closed 3~5 minutes randomly after voltage recovery * Good short cycle-protection * Electronics OK
40	10	0.016	0.033	
40	20	0.016	0.033	
35	10	0.016	N/A	* Power contactor (P.C.) opened in 1 cycle * Control contacts did not open * No short cycle-protection after voltage recovery * Electronics shutdown threshold
30	10	0.016	N/A	
Short-Fast Under-voltage Transient Test				
Not needed because the under-voltage response time of this device was 2 cycles				

Table 30 - PNNL Grid-Friendly Device Test Results

5.8 Cannon Technologies Load Control Switch (LCS) Test Results

The Cannon Technologies load control switch (LCS) is used to remotely control motor load. Initial testing of this device indicated it can provide limited under-voltage protection. Cannon Technologies was asked to update the LCS software to meet SCE's proposed stall protection parameters. Recent tests indicate that the device was indeed reconfigured to SCE's specifications

Test results indicate this device's:

- Under-voltage protection threshold is 80 percent and does not work for voltage transients faster than 15 cycles
- Under-voltage protection response time is approximately 280 milliseconds
- Short cycle protection time is 4 minutes to 4.5 minutes, with randomization
- Cold load pickup protection activates after electronics shutdown

This device has normally closed contacts (N.C.), as proposed by SCE; therefore, an N.C. contact failure would not lockout the air conditioner. The electronics shut down at 33 percent (a good reading), which is below SCE's proposed stall protection parameters. This device has the capability to mitigate the air conditioner stalling problem. It is important to mention that all parameters can be adjusted if needed.

5.8.1 Specifications

Table 31 provides the specifications for the tested Cannon Technologies load control switch.

Manufacturer	Cannon Technologies
Name	Load Control Switch
Line Terminals Ratings	
Voltage	240 VAC
Frequency	50/60 Hz
Short Cycle Time Delay	3~4 minutes in with randomization
Selector Voltage Switch	**N/A**
Drop-out Under-voltage	192 VAC
Contacts Terminals Ratings	
Amperage	N/A
Contacts Type	Normally closed (N.C.) & Normally Open (N.O.)
Receptacle Type	N/A
Picture	

Table 31 - Cannon Technologies Load Control Switch Specifications

5.8.2 Under-Voltage Protection

Tests indicate the under-voltage protection threshold of this device was 80 percent of the full rated voltage (240 VAC). The under-voltage protection works from 80 percent down to 35 percent with a response time between 200 and 280 milliseconds, the fastest response occurring at the lower voltages.

5.8.3 Electronics Shutdown

The electronics started failing at approximately 33 percent for 10-second transients. This device has cold load pickup protection after its electronics shut down and at startup.

5.8.4 Short Cycle Protection Time

The short cycle protection time of this device was 3 to 4 minutes with randomization. This short cycle-prevention was activated either by under-voltage transients lower than the under-voltage threshold or initial startup.

5.8.5 Test Details

Table 32 provides the test details for the Cannon Technologies load control switch.

V_{SAG} (%)	t_{SAG} (sec.)	$t_{POWER\ CONTACTOR\text{-}OPEN}$ (sec.)	$t_{RESPONSE}$ (sec.)	Comments
Long Under-voltage Transient Test				
85%	10	N/A	N/A	Nothing happened
80%	10	N/A	2.000	* Control contacts opened * Control contacts re-closed 3~5 minutes randomly after voltage recovery * Good short cycle protection
75%	10	N/A	0.250	
70%	10	N/A	0.350	
65%	10	N/A	0.332	
60%	10	N/A	0.267	
55%	10	N/A	0.232	
50%	10	0.033	0.282	* Power contactor (P.C.) opened in ~2 cycles * Control contacts opened * Control contacts re-closed 3~5 minutes randomly after voltage recovery * Good short cycle protection
45%	10	0.033	0.216	
40%	10	0.033	0.200	
35%	10	0.033	0.250	
33%	10	0.033	0.335	* Power contactor (P.C.) opened in ~2 cycles * Control contacts opened for couple cycles then re-closed * Electronics shutdown * No short cycle protection after voltage recovery
30%	10	0.033	0.267	
100%	10	N/A	0.500	* It has Cold load pickup

Table 32 - Cannon Technologies Load Control Switch Specifications

6.0 CONCLUSION

Comprehensive testing of selected digital programmable thermostats, under-voltage protection devices, and load control switches has lead to the following conclusions regarding the air conditioner stalling problem.

Of the three digital programmable thermostats tested for their response to under-voltage transients only one thermostat had under-voltage protection, the Honeywell. This thermostat may help mitigate the air conditioner stalling problem, but its under-voltage protection and response times do not currently meet SCE's proposed stall protection specifications. The use of digital programmable thermostats with proposed under-voltage protection is one of the easiest retrofitting solutions because it would not require a certified electrician. Here in California, retrofitting thermostats would not require a qualified electrician because only branch circuits rated greater than 100 VA require a qualified electrician and most residential thermostats circuits are rated below 24 VA.

The tests revealed that with minor adjustments, two of the seven under-voltage protection relays tested would be able to satisfy SCE's proposed stall protection specifications to mitigate the air conditioner stalling problem. The CSE and PNNL relays have good under-voltage protection. These two relays are prototypes and still in developmental stages; therefore, their implementation may be delayed due to the need for further testing, certifications, mass production, and retrofit time.

Three under-voltage protection devices manufactured by Diversified Electronics (DE) were tested that may have the under-voltage protection that help mitigate the air conditioner stalling problem. These three relays are off-the-shelf devices making them conveniently attainable, but they also come with disadvantages. First, two of them are plug-in devices making them suitable only for window air conditioners and maybe plug-in air handler units. Second, they do not have a randomly distributed short cycle-prevention to allow them to restart at different times after voltage is restored to normal conditions. Third, they use normally open (N.O.) contacts that prevent the units from restarting if the under-voltage relay fails. All other tested under-voltage protection devices provided limited stall protection; while helping to some degree, they will not alleviate the air conditioner stalling problem. Another disadvantage is the retrofit cost – installing any of these under-voltage protection relays in California would require a qualified electrician for retrofit because the served circuits are rated at more than 100-VA, except for the plug-in devices.

One load control switch manufactured by Cannon Technologies was tested. These switches are primarily used to remotely control motor load during times of high system load demand. Initial testing of the device indicated it did not have the desired stall protection, but Cannon Technologies responded and reconfigured the load control switch's software to meet SCE's proposed stall protection specifications. This switch would be the most expensive remedy due to its special features (such as load control and demand response) and retrofit labor costs – its served circuits exceed 100-VA requiring retrofitting by a qualified electrician.

The tests revealed that the most viable solution to the air conditioner stalling problem would be realized by using digital programmable thermostats with stall protection capability. This would require working with various thermostat manufacturers to ensure that their products meet SCE's proposed stall protection specifications. It must be noted: this solution may not protect older units (those installed prior to the mid-

1990s) because many do not have the common "C" wire used to power today's thermostat electronics. This remedy's effectiveness will only be realized as older air conditioners are replaced with new units having the common "C" wire. Another viable solution is the use of plug-in under-voltage protection relays that meet SCE's proposed stall protection specifications. This fix offers easy installation on window air conditioners and plug-in air handlers. Either of these solutions would be relatively simple and less costly remedies because they will not require a certified electrician for implementation.

The next most effective solution is the use of devices such as under-voltage relays or load control switches with SCE's proposed stall protection specifications. This solution is less attractive than the others because it would require qualified electricians to perform the retrofits adding a labor cost of $90 to $100 per installation.