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Commercial Building Motor Protection Response Report

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Special thanks to the subject matter expert Independent review participants:

Avtar Gill: with Johnson Controls
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Motor Response and Protection in Commercial Buildings

1. Introduction

A Fault Induced Delayed Voltage Recovery (FIDVR) event is the phenomenon whereby system voltage remains at significantly reduced levels for several seconds after a transmission, sub-transmission, or distribution fault has been cleared. The effect is thought to be caused by the stalling of highly concentrated induction motor loads with constant torque. These motors stall in response to low voltage. The stalled motors draw more reactive power from the grid, and that holds down the local voltage. A vicious circle is created. After several seconds of being stalled, motor protection devices begin to act and trip the motors to prevent them from overheating. As a result, there will be a large decrease in the load on the power system, with a potential secondary effect of high system voltage. That response is particularly likely if the protection response is slower than the voltage regulation response of the system.

The project described in this report is the result of a multi-year effort by the U.S. Department of Energy to assist the Western Electricity Coordinating Council's (WECC's) Load Modeling Task Force (LMTF) as they attempt to address these modeling challenges. This is one of many tasks funded under the American Recovery and Reinvestment Act (ARRA) Interconnection Planning activities; this report updates Pacific Northwest National Laboratory's (PNNL's) progress on the motor response and protection in commercial buildings. PNNL developed building motor response tables for a given set of commercial building types with voltage variances and time frames of interest. PNNL categorized motor protection and control responses for these voltage variances and times along with energy management system control logic restart times and motor protection trip delays. PNNL identified "make and break" times of relays and contactors for the given voltage variances and recovery times. The results are shown in a set of tables giving our estimated motor response for the type of motor load, type of building, and level and duration of the voltage variance.

2. Conclusion

While motor protection schemas are quite standard for motors in specific manufacturers' equipment and for specific motor applications, there are many variables to determine when motors will drop off line and reenergize on certain FIDVR events. There are just as many factors for determining what the true motor load is in a particular type of building at a given point in time. Because of the vast amount of variables that affect motor response at the time of a FIDVR event, motor protection response in this report is referred to in general terms and cannot be definitively nailed down in all certainty. By disregarding the motors and equipment that skew the average and by widening the timing ranges and percentages, most motors can be predicted to drop offline in certain ranges and reenergize within a certain time period. Although this is not accurate for all motors, this method will capture the bulk of the motors and their response to different lengths and depths of FIDR events. This report along with the tables in Appendix A provides details on voltage responses of typical motor loads found in commercial buildings. Depending on the magnitude and duration of the voltage sag, motors may ride through, trip, or stall. When voltages recover, motors may immediately reenergize and restart, or delay for a few minutes, or stay stalled. The estimated motor response is given for both the voltage sag magnitude and voltage sag duration. These response estimates are based on experience and available test data. Good data is available for voltage sag response for many components such as relays and contactors, but little data is available for both voltage sag and recovery response. The tables in Appendix A include data from recent voltage sag and recovery tests performed by Southern California Edison (SCE) and Bonneville Power Administration (BPA) on air conditioners and energy management systems. The response of the motor can vary greatly depending on the type of

protection and control. The time duration for the voltage sag consists of those times that are of interest for bulk power system modelers. The times of interest are 5, 10, and 20 cycles, 2 seconds, and 3 minutes.

3. Table Breakdown

In the Appendix A, tables are prepared in two categories of voltage drop: voltage drop that ranges from 75% to 100% of nominal and drop that ranges from 50% to 75% of nominal. In general, most motor control equipment will ride through sags down to 75%. In some cases, for larger motors, under voltage protection will trip motors for sags to 80% of nominal for 2 seconds.

The types of commercial buildings that have been considered are as follows:

- Food Service (Fast Food) (McDonalds)
- Supermarket (Albertson's)
- Other (Hotels, Residential Care)
- Office
  - 20k – 100k sf office building motor response (small office)
  - 100k – 1m sf office building motor response (large office)
- Retail (Both Big and Small, by square feet)
  - 5k – 15k sf retail building motor table (service station)
  - 15k – 40k sf retail building motor response (strip mall)
  - 40k – 100k sf retail building motor response (big box stores)
- Warehouse

The tables in Appendix A provide columns for equipment, motors, protection, and controls. This gives the reader an understanding of the type of motor, what equipment it is used in, how it is usually protected, and what type of control system is normally used.

The commercial office building tables are broken down by square foot to indicate which of the following apply:

- Larger, high-rise office buildings usually have an energy management system (EMS) that senses outdoor temperature, planned building occupancies, day of week, etc., to operate the chillers, boilers, fans, and pumps most efficiently. The mechanical engineer and architect dictate the complexity of the mechanical systems that are present.
- Larger office buildings have variable air volume or VAV systems that also modulate the conditioned air flow throughout the building to optimize efficiency. VAV systems generally have some type of building automation system or BAS, the more complex the HVAC system the more it benefits from advanced control. Sequencing of the air handlers and optimizing that with the heating/cooling needed from the chillers and boilers sometimes makes for a complex control system. The more different mechanical systems that need to be sequenced together the more complex things can become. Small office buildings can sometimes get away with very simple thermostat controls and time clocks; in these cases, a computerized control system may not be used.

- The tables have a range of square feet of building floor area that is the typical size for each building type.
- The Commercial Building Management Survey showed that 41% of commercial office buildings use some sort of EMS. In preparation of the tables, we have adjusted this by commercial building type and size to show that essentially 100% of some commercial building types use an EMS, and other types do not use them.

Some restaurant chains, like McDonald's, have done extensive energy efficiency studies and use EMSs in the restaurants, but typically, and for simplicity, we assume EMS is not used in food service buildings. Large retail stores such as Super Walmart or Costco that also sell groceries and have refrigeration equipment loads are in the category of grocery. Stores that sell primarily dry goods are in the category of retail.

Plug loads generally include coffee makers, copiers, computers, printers, ATMs, etc. In general, plug loads will ride through sags down to 75% of nominal for 2 seconds. Below this voltage, they drop out, and computer-based loads will go through a reboot sequence on voltage recovery.

The 3-minute column is really just for general interest. Three minutes is ancient history in planning for automatic response to power system transients. The 3-minute column estimates what the motor load would be doing at this point.

4. Specific Motor Types and Applications

The following is a discussion of specific equipment types given in the Appendix A tables, providing specific background and detail that may be of interest.

- **Roof Top Unit (RTU) Air Conditioner Compressor Motor**

RTU compressors motors are typically three-phase and include a dedicated local solid state control board. The motor contactors drop out at 58% to 61% voltage, which is higher than the stall voltage of about 50%. Thus, it is unlikely that the three-phase motors will be stalling during transients, unlike the single-phase compressor motors. However, for unbalanced sags, stall may occur because the contactor voltage may stay near normal when the contactor is supplied by the voltages phases that are remaining near nominal voltage. SCE testing has shown that for both balanced and unbalanced voltages, after the contactor had dropped out due to low voltage, it would not reclose after voltage recovery for several minutes. Some RTUs may be equipped with manufacturer's low voltage protection that operates after 2 seconds at 80% voltage (SCE RTU test, page 36, 53).

- **Single-Phase Air-Conditioning Unit Compressor Motor**

Recent testing of single-phase (split-phase motor type) air conditioning units by SCE found that these units typically stall between 60% and 70% nominal voltage well before they are disconnected because their power contactors drop out at about 50% to 60% voltage. It was also discovered that these single-phase compressor motors begin stalling rather quickly, normally within 3 cycles. This verifies the FIDVR theory that large numbers of single-phase air conditioning compressor motors may be stalling when voltage is between 70% and 50% of nominal. Single-phase compressor motors typically will not restart after tripping until a time delay of perhaps 3 minutes or more.

- **Local Solid State Control Board**

Reach-in and walk-in freezers, chillers, boiler elevators, and many other complex individual loads are also controlled by a local solid state control board. The board may be controlled by a local thermostat or by the EMS.

- **Variable Frequency Drives**

Variable Frequency Drives (VFD) are typically programmed to ride through short duration voltage sags by current limiting the motor. In cases where only one phase is sagging, and the motor is being operated at partial load, the motor can run for several seconds or more. In the Appendix A tables, we assume that, for 60% voltage and 5, 10, and 20 cycles, the VFD should be able to ride through by current limiting the motor. The VFD cannot ride through a 2-second or 3-minute loss of voltage unless it is equipped with energy storage. In testing, VFDs were noted to ride through sags of up to 2 seconds, or more, in duration, then trip after voltage recovery.

- **Chiller Motors**

Large chiller motors in the range of 100 to 700 HP typically have their own proprietary local control board with voltage, overcurrent, and unbalance protection. Manufacturer's undervoltage protection is typically set at 90% of nominal voltage for 2 seconds and 80% of nominal voltage for 0.1 seconds. If the motor is de-energized on under voltage, until the built in anti-cycle timers minimum off delay expires.

- **Contactors**

Contactors, in general, will drop out within 5 cycles at 50% voltage. In some cases, voltage may sag to 40% before the contactor drops, and in some cases, it may be 60%, but 50% is a good estimate. When the voltage recovers, at 70% of nominal voltage the BPA test shows the contactor reclosed after two cycles. At 65%, it took 8.5 cycles to reclose. At 62% it never pulled in, even after multiple seconds.

The following graphic Fig. 1-1 represents reasonable estimates based on voltage sag and time; exact component trip points will be determined further by point on wave, motor load, control transformer load, ambient temperature. This graphic is for quick reference only, for more definitive parameters please see the Appendix A.

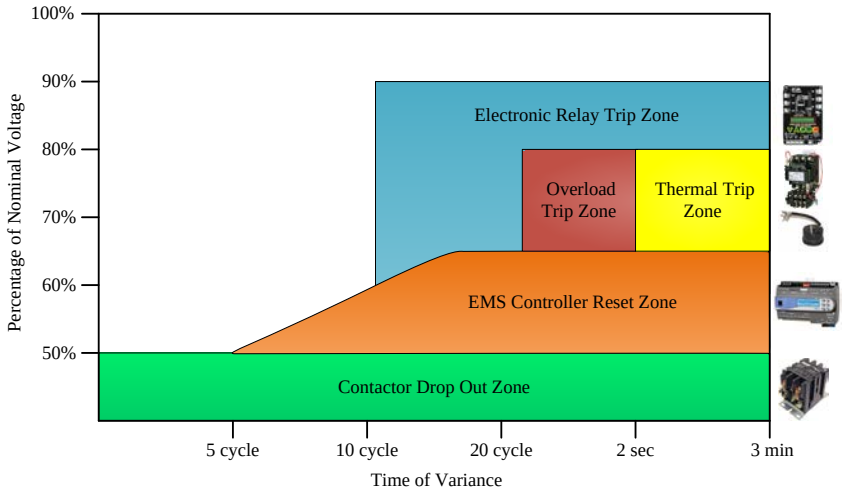

Fig. 1-1. Summary of specific type of motors

- **Energy Management System**

Testing at BPA has shown that the EMS can ride though severe voltage sags down to 65% of nominal voltage, the EMS will drop out 2 to 3 seconds after the event and then takes 3 seconds to reset. This occurred even with a battery-

backed EMS. If there are batteries in controllers that control the outputs to the equipment, it's typically just to keep the internal clock/calendar operating while power is not available. The internal batteries are not usually used to maintain normal operation during voltage dips or loss. It will be assumed for the tables in Appendix A that for voltage sag down to 65% of nominal, the EMS will ride through but not reset. For sags below 65%, the EMS will ride through the initial event but will reset 2 seconds after the event, dropping the load until the programed sequences in the controller has run from the beginning. Some loads and motors will be started relatively quickly while others may take several minutes to reengage the loads. Sometimes the controllers have built in restart programs that delay startup of equipment. If an entire building were to lose power and then have it reapplied, having everything startup at once could cause issues. So the controllers are often set to delay at varying period so that restarting all the equipment won't cause any demand surcharges or other load issues. Testing revealed that the EMS controllers tripped less at voltages above 60% when their control transformer secondary was under 50% of its max VA capacity. EMS controllers did not trip on voltages above 65% when the loading of the transformer was at 80%, which is the max allowable by the National Electrical Code. In general, testing showed that voltage variances below 60% resulted in the EMS controller resetting regardless of transformer loading. All EMS controllers that were tested showed no reaction to 5-cycle events even when the nominal voltage went to 0%.

Fig. 1-2 reflects industry standard equipment start-up timing and sequencing in energy management systems. This does not reflect custom equipment start-up timing and sequencing for unique buildings or mechanical systems designated by a design engineer or equipment not controlled by an EMS. This graphic is for quick reference only; for more exact reset times please see the Appendix A.

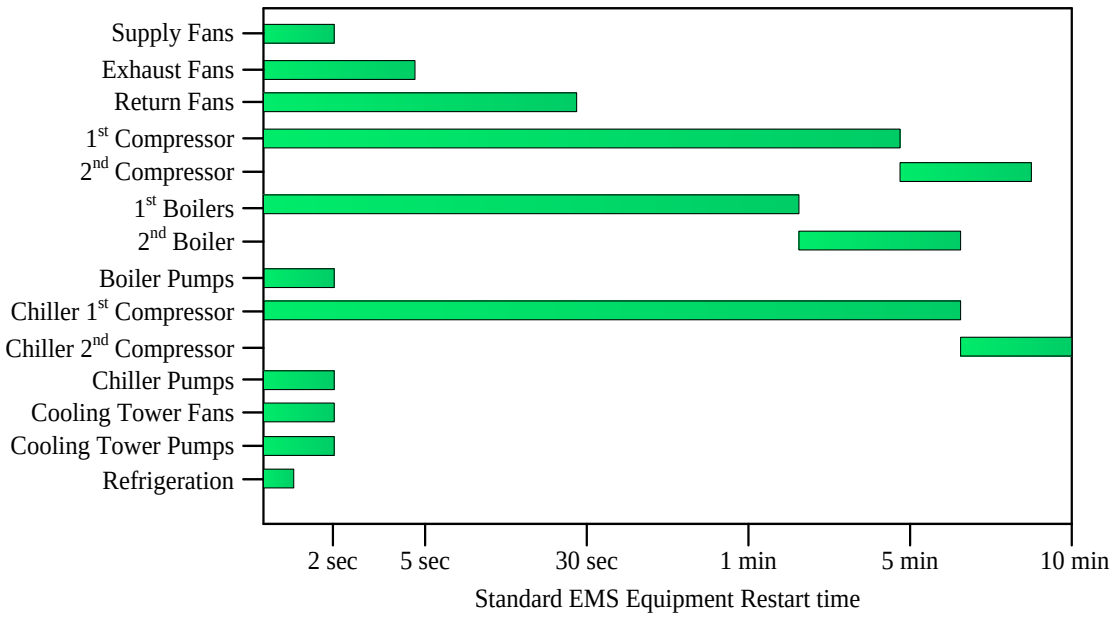

Fig. 1-2. Standard EMS equipment restart time

Appendix A: Building Motor Response Tables

A.1 Building Motor Response Tables for Voltage Sags down to 75% of Nominal Voltage

Supermarket Building Load Table
Square feet: 50,000
Voltages above 75% of nominal

<table>
<tr><th>Equipment</th><th>Motors</th><th>Protection</th><th>Controls</th><th>5 cycle</th><th>10 cycle</th><th>20 cycle</th><th>2 second</th><th>3 minute</th></tr>
<tr><td>Refrigeration and freezers</td><td>1-ph or 3-ph compressor</td><td>Fuse and thermal</td><td>Line voltage with contactor</td><td colspan="4">Motor continues to run.</td><td>Extended sag may have caused the thermal protection to trip. Auto restart after manufacturer solid state controller restart sequence of 3 to 5 min.</td></tr>
<tr><td rowspan="3">HVAC roof top units (RTUs)</td><td>3-ph compressor motors</td><td>Fuse</td><td rowspan="3">Low voltage thermostat with contactor</td><td colspan="3" rowspan="3">Motors operate through voltage variance.</td><td colspan="2" rowspan="3">Manufacturer control board may have under voltage trip.
If tripped at 2 seconds, motor will Auto restart.
Extended sag may have caused the thermal protection to trip.</td></tr>
<tr><td>3-ph indoor fans motors</td><td>Fuse</td></tr>
<tr><td>1-ph fractional condenser and induced draft motors</td><td>Fuse and thermal</td></tr>
<tr><td>Misc plug loads, computers, vending, ATMs</td><td>Exhaust fans and compressor motors, single phase, fractional HP</td><td>Thermal and fuse</td><td>Local relay</td><td colspan="5">Motors operate through voltage variance.</td></tr>
</table>

Fast Food Building Load Table
Square feet: 2,500
Voltages above 75% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Walk-in refrigeration and freezers	1-ph or 3-ph compressors	Fuse and thermal	Line voltage with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. If tripped at 2 seconds, motor will Auto restart. Extended sag may have caused the thermal protection to trip.	
	1-ph fractional evaporator and condenser fan motors	Fuse and thermal	Line voltage with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. If tripped at 2 seconds, motor will Auto restart. Extended sag may have caused the thermal protection to trip.	
HVAC RTUs	3-ph compressors motors	Fuse and thermal	Low voltage thermostat with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. If tripped at 2 seconds, motor will Auto restart. Extended sag may have caused the thermal protection to trip.	
	3-ph indoor fans motors	Fuse	Low Voltage Thermostat with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. If tripped at 2 seconds, motor will Auto restart	
	1-ph fractional condenser and induced draft motors	Fuse and thermal	Low voltage thermostat with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. If tripped at 2 seconds, motor will Auto restart. Extended sag may have caused the thermal protection to trip.	
HVAC make-up air unit (MAU) and exhaust fan	3-ph motors exhaust and supply fan motors	Fuse and thermal	Line voltage start/stop switch with contactor	Motors operate through voltage variance.			Extended sag may have caused the thermal protection to trip.	
	1-ph fractional hp induced draft motors	Fuse and thermal	Low voltage thermostat with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. Extended sag may have caused the thermal protection to trip.	
Ice Machines	1-ph motor compressor	Thermal	Solid-state with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. Auto restart after solid-state reboot and program restart sequence.	
	1-ph fractional condenser fan and water pump motors	Thermal	Solid-state with relay from control board	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. Auto restart after solid-state reboot and program restart sequence.	
Soft Serve Ice Cream Machine	1-ph or 3-ph motor compressor	Thermal	Line voltage with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. Auto restart after solid-state reboot and program restart sequence.	

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
	1-ph fractional condenser fan and pump motors	Thermal	Line voltage with contactor	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. Auto restart after solid-state reboot and program restart sequence.	
Reach-in Refrigeration and freezers	1-ph fractional compressor condenser and evaporator fan motors	Thermal	Solid-state with relay from control board	Motors operate through voltage variance.			Manufacturer control board may have under voltage trip. Auto restart after solid-state reboot and program restart sequence.	

Office Building Load Table
10,000 sf through 100,000 sf
Voltages above 75% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Custom DX-AHUs or AHUs with air cooled chillers	3-ph fan motors	Over voltage, phase imbalance, over current, current limiting or fuse and thermal	EMS with VFD or equipment manufacturer solid state control tied into ems	EMS remains in control. Motors operate through voltage variance.				Auto restart after EMS controller and VFD reboot and program restart sequence
	3-ph compressor motors	Electronic Phase Monitor Fused And Thermal	EMS or equipment manufacturer solid state control tied into EMS	EMS remains in control. Motors operate through voltage variance.				Manufacturer control board may have under voltage trip. Auto restart after controller reboot and program restart sequence
Fan powered VAVs	1-ph fractional fan motors	Fuse and Thermal	EMS with contactor	EMS remains in control. Motors operate through voltage variance.				Auto restart after EMS controller and VFD reboot and program restart sequence
Fan coil units	1-ph Fractional HP Fan Motors	Thermal	EMS with contactor	EMS remains in control. Motors operate through voltage variance.				Auto restart after EMS controller and VFD reboot and program restart sequence
Building general exhaust fans	1 and 3-ph fan motors	Over voltage, Phase imbalance, over current, and current limiting or fuse and thermal	EMS with VFD or line voltage thermostats or manual start/stop switch	EMS and VFD remains in control. Motors operate through voltage variance.				EMS controller and VFD reboot and program restart sequence / or restart instantaneously
CRAC computer room air conditioner	1-ph or 3-ph compressor	Over voltage, phase imbalance, over current, or fuse and thermal	Manufacturer solid-state with contactor or low voltage standalone thermostats	Manufacturer solid-state remains in control. Motors operate through voltage variance.				Manufacturer control board may have under voltage trip. Auto restart after manufacturer solid state controller restart sequence / or restart after

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
								start-up delay
	1-ph or 3-ph fan motor	Over voltage, phase imbalance, over current, or fuse and thermal		Manufacturer solid-state remains in control. Motors operate through voltage variance.				Manufacturer control board may have under voltage trip. Auto restart after manufacturer solid state controller restart sequence / or restart instantaneously
Boilers	1-ph induced draft motor	Fuse and thermal	Manufacturer Solid-state with contactor	Manufacturer solid-state remains in control. Motors operate through voltage variance.				Manufacturer control board may have under voltage trip. Auto restart after manufacturer solid state controller restart sequence
	3-ph motors	Over voltage, phase imbalance, over current, and current limiting	EMS with VFD	EMS and VFD remains in control. Motors operate through voltage variance.				Auto restart after EMS controller and VFD reboot and program restart sequence
Domestic hot water pumps	1-ph fractional motor	Circuit breaker and thermal	EMS with relay / or Manual switch	EMS remains in control. Operate through voltage variance.				Auto restart after EMS controller reboot and program restart sequence
Other plug loads	Elevators, computers, refrigeration, includes small delis and vending equipment, ATMs, telecommunications equipment.							

Office Building Load Table
Square feet: 100,000 to 1,000,000
Voltages above 75% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
AHUs	3-ph fan motors	Over voltage, phase imbalance, over current, and current limiting	EMS with VFD	EMS and VFD remains in control Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program restart sequence
Fan powered VAVs	1-ph fan motors	Fuse and thermal	EMS with contactor	EMS remains in control Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program restart sequence
(DOAS) dedicated **o**ut**s**ide **a**ir **s**ystem	3-ph fan motors	Over voltage, phase imbalance, over current, and current limiting	EMS with VFD	EMS and VFD remains in control Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program restart sequence
Chillers	3-ph compressor motors	Over voltage, phase imbalance, over current	Manufacturer solid-state controller tied into EMS	Manufacturer Solid-state remains in control Compressor operates through voltage variance.			May trip offline due to under voltage protection. Auto restart **after** manufacturer solid state controller restart sequence	
	3-ph pump motors	Over voltage, phase imbalance, over current, and current limiting	EMS with VFD	EMS and VFD remain in control. Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program restart sequence
Boilers	1-ph induced draft motor	Fuse and Thermal	Manufacturer Solid-state with contactor	EMS remains in control. Motors operate through voltage variance.			May trip offline due to under voltage protection. Auto restart **after** manufacturer solid state controller restart sequence	
	3-ph motors	Over voltage, Phase Imbalance, over current, and current limiting	EMS with VFD	EMS remains in control. Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program restart sequence
Cooling towers	3-ph fan motor	Over voltage, Phase Imbalance, over current, and current limiting	EMS with VFD	EMS and VFD remain in control. Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program restart sequence
Fan coil units	1-ph fractional fan motors	Fuse and Thermal	EMS with Contactor	EMS remains in control. Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
								restart sequence
Building general exhaust fans	1 and 3-ph fan motors	Over voltage, Phase Imbalance, over current, and current limiting **or** fuse and thermal	EMS with VFD or Line voltage thermostat / **or** manual start/stop switch	EMS and VFD remain in control. Motors operate through voltage variance.				Auto restart **after** EMS controller and VFD reboot and program restart sequence
(CRAC) computer **r**oom **a**ir **c**onditioner	1-ph or 3-ph compressor motor	Over voltage, phase imbalance, over current, **or** fuse and thermal	Manufacturer solid-state with contactor / **or** low voltage standalone thermostats	Manufacturer solid-state remains in control. Compressors operate through voltage variance.			May trip offline due to under voltage protection. Auto restart **after** manufacturer solid state controller restart sequence	
	1-ph or 3-ph fan motor	Over voltage, phase imbalance, over current, **or** fuse and thermal		Manufacturer solid-state remains in control Motors operate through voltage variance.			May trip offline due to under voltage protection. Auto restart **after** manufacturer solid state controller restart sequence	
Domestic cold water pumps	3-ph pump motor	Over voltage, phase imbalance, over current, and current limiting	Manufacturer solid-state with VFD	Manufacturer solid-state remains in control. Motors operate through voltage variance.			May trip offline on voltage imbalance. Auto restart with equipment staging delay	
Domestic hot water pumps	1-ph fractional pump motor	Circuit breaker and thermal	EMS with relay / **or** manual switch	Manufacturer solid-state remains in control. Motors operate through voltage variance.				May trip offline due to under voltage protection. Auto restart **after** manufacturer solid state controller restart sequence
Sewage rejection	3-ph pump motor	Fused with current overload	Line voltage mag-starter start/stop level switch	Motors operate through voltage variance.				
Other loads	Elevators, computers, refrigeration, cooking includes small delis and vending equipment, ATMs, telecommunications equipment, medical equipment, and manufacturing performed in commercial buildings.							

Retail Building Load Table
Square feet: 5,000 and under
Voltage above 75%

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
HVAC RTUs	3-ph compressor motors	Fuse	Manufacturer solid state **or** Low voltage standalone thermostats manufacturer solid state **or** Low voltage standalone thermostats	Manufacturer control continues to operate.				If tripped offline by under voltage or over current, auto restart **after** manufacturer solid state controller restart sequence Extended sag may have caused the thermal protection to trip. Auto restart
	3-ph indoor fans motors	Fuse						
	1-ph fractional condenser and induced draft motors	Fuse and thermal						
Exhaust fans	1-ph fractional motor	Circuit breaker and thermal	Manual switch	Motors operate through voltage variance.				Extended sag may have caused the thermal protection to trip. Auto restart
Walk-in refrigeration and freezers	1-ph or 3-ph compressors	Fuse and thermal	Line voltage with contactor	Manufacturer control continues to operate. Motors operate through voltage variance.				Extended sag may have caused the thermal protection to trip. Auto restart
	1-ph fractional evaporator and condenser fan motors	Fuse and thermal	Line voltage with contactor					Extended sag may have caused the thermal protection to trip. Auto restart
Reach-in refrigeration and freezers	1-ph fractional compressor motors	Fuse and thermal	Manufacturer solid-state with contactor	Manufacturer solid-state remains in control. Motors operate through voltage variance.				If tripped by thermal, auto restart **after** manufacturer solid state controller restart sequence

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
	1-ph fractional condenser and evaporator fan motors	Fuse and Thermal		Manufacturer solid-state remains in control. Motors operate through voltage variance.				If tripped offline by thermal, auto restart **after** manufacturer solid state controller restart sequence
Other plug loads	Gas pumps, refrigerated display cases, ice bins, TVs and monitors, cooking equipment							

Retail Building Load Table
Square feet: 15,000 to 40,000
Voltages above 75% of nominal

<table>
<tr><th>Equipment</th><th>Motors</th><th>Protection</th><th>Controls</th><th>5 cycle</th><th>10 cycle</th><th>20 cycle</th><th>2 second</th><th>3 minute</th></tr>
<tr><td rowspan="3">HVAC RTUs</td><td>3-ph compressor motors</td><td>Fuse</td><td rowspan="3">EMS with VFD or Manufacturer solid state tied into EMS with contactors or Low voltage standalone thermostats</td><td colspan="4" rowspan="3">EMS and VFD remains in control.
Motors operate through voltage variance.</td><td rowspan="3">If tripped offline by under voltage or thermal protection, auto restart after EMS controller reboot and program restart sequence / or restart instantaneously

Extended sag may have caused the thermal protection to trip. Auto restart</td></tr>
<tr><td>3-ph indoor fans motors</td><td>Fuse</td></tr>
<tr><td>1-ph fractional condenser and induced draft motors</td><td>Fuse and thermal</td></tr>
<tr><td>Exhaust fans</td><td>1-ph fractional horsepower motor</td><td>Circuit breaker and thermal</td><td>EMS with relay / or manual switch</td><td colspan="5">Motors operate through voltage variance
Extended sag may have caused the thermal protection to trip. Auto restart</td></tr>
<tr><td>Other plug loads</td><td colspan="8">Elevators, computers, refrigeration, cooking includes small delis and vending equipment, ATMs, telecommunications equipment</td></tr>
</table>

Retail Building Load Table
Square feet: 15,000 to 100,000
Voltages above 75% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
RTUs	3-ph fan motors	Over voltage, phase imbalance, over current, current limiting or fuse and thermal	EMS with VFD **or** Manufacturer solid state tied into EMS with contactors **or** Low voltage standalone thermostats	EMS and VFD remains in control Motors operate through voltage variance				If tripped offline auto restart **after** EMS controller reboot and program restart sequence / **or** restart instantaneously
	3-ph compressor motors	Fused and thermal	EMS with contactors **or** Manufacturer solid state tied into EMS **or** Low voltage standalone thermostats	EMS remains in control Compressor operates through voltage variance				If tripped offline by thermal or under voltage, auto restart **after** EMS controller reboot and program restart sequence
Exhaust fans	1-ph fractional fan motor	Circuit breaker and thermal	EMS with relay / **or** manual switch	EMS remains in control Motors operate through voltage variance				If tripped offline, auto restart **after** EMS controller reboot and program restart sequence / **or** restart instantaneously
Other plug loads	Elevators, escalators, computers, refrigeration, cooking includes small delis and vending equipment, ATMs, telecommunications equipment							

Warehouse Building Load Table
Square Feet 20,000
Voltages above 75% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Gas fired unit heaters	1-ph fractional fan motors	Thermal	Low voltage thermostat switch with contactor	Motors operate through voltage variance				Thermostat reboot and program restart sequence
Exhaust fans	1-ph fan motors	Thermal	Line voltage start/stop switch with contactor	Motors operate through voltage variance Extended sag may have caused the thermal protection to trip. Auto restart				
Paddle fans	1-ph fan motors	Thermal	Manual start/stop switch	Motors operate through voltage variance Extended sag may have caused the thermal protection to trip. Auto restart				
Other plug loads	Electric forklift charging, TV and monitors, computers, copiers, fax, printers, refrigerators, microwaves, box fans. Ride through.							

A.2 Building Motor Response Tables for Voltage Variance Range of 75 to 50% of Nominal

Supermarket Building Load Table
Square feet: 50,000 (Albertson's)
Voltages between 75% and 50% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
RTUs	3-ph indoor fan motors	Fused **possibly** voltage monitored **possibly** overload relays	EMS with contactors **or** Manufacturer solid state tied into EMS with contactors **or** Low voltage standalone thermostats	EMS remains in control Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event	EMS and VFD drop out 2 seconds after event below 65% V, but will automatically restart with voltage recovery. First fan starts within 5 seconds, second fan if applicable restarts at 30 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** overload trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	3-ph compressor motors	Fused and thermal **possibly** voltage monitored	EMS with contactors **or** Manufacturer solid state tied into EMS **or** Low voltage standalone thermostats		EMS drops out 2 seconds after event below 65% V, but will automatically restart with voltage recovery; 270 seconds first compressor, 150-second interstaging delay for each additional compressor if applicable. Contactors operate through voltage variance but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph fractional condenser and induced draft motors	Fused and thermal **possibly** voltage monitored	EMS with contactors **or** Manufacturer solid state tied into EMS **or** Low voltage standalone thermostats		EMS and VFD drop out 2 seconds after event below 65% V, but will automatically restart. 270 seconds with the first compressor, 150-second interstaging delay for each additional compressor if applicable. Contactors operate through voltage variance but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Refrigeration and freezers	1-ph or 3-ph compressor motors	Fuse and Thermal	Line voltage with contactor	Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event	Automatically restart. 300 seconds for compressor and all associated 1-ph fans.			
Misc plug loads	Exhaust fans and compressor motors, single phase, fractional HP drop out at 50% to 60% voltage, time delay on restart of computer-based loads.							

Fast Food Building Load Table
Square feet: 2,500
Voltages between 75% and 50% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Walk-in refrigeration and freezers	1-ph or 3-ph compressors	Fuse and thermal	Line voltage with contactor	Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.	Automatically restart. 300 seconds for compressor and all associated 1-phase fans. **Possible** thermal trip if the voltage variance is longer than 2 to 3 seconds and above 50% V.			
	1-ph fractional evaporator and condenser fan motors	Fuse and thermal	Line voltage with contactor					
RTUs	3-ph indoor fan motors	Fused **Possibly** Overload relays	Low voltage thermostat with contactor	Thermostat remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Thermostat will drop out below 65% V, but will automatically restart. Fan starts within 30 seconds. **Possible** overload trip if the voltage variance is long enough and above 65%.			
	3-ph compressor motors	Fuse and thermal	Low voltage thermostat with contactor		Thermostat will drop out below 65% V, but will automatically restart the compressor within 300 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph fractional condenser and induced draft motors	Fuse and thermal	Low voltage thermostat with contactor		Thermostat will drop out below 65% V, but will automatically restart the fans with the compressor within 300 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
HVAC make-up air unit **MAU** and exhaust fan	3-ph motors exhaust and supply fan motors	Fused **possibly** overload relays	Line voltage start/stop switch with contactor	Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event. **Possible** overload trip if the voltage variance is long enough and above 50%.				
	1-ph fractional HP induced draft motors	Fuse and thermal	Low voltage thermostat with contactor	Thermostat remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Thermostat will drop out below 65% V, but will automatically restart the Induced draft motors. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V			
Ice machines	1-ph motor compressor	Thermal	Solid-state with contactor	Control board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Solid-state control board will drop out below 65% V. Manual reset needed. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph fractional condenser fan and water pump motors	Thermal	Solid-state with relay from control board	Motor will continue to operate through voltage variance.	Solid-state control board will drop out below 65% V. Manual reset needed. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Soft serve ice cream machine	1-ph motor compressor	Thermal	Solid-state with contactor	Control board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Solid-state control board will drop out below 65% V. Manual reset needed. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph fractional condenser fan and water pump motors	Thermal	Solid-state with contactor		Solid-state control board will drop out below 65% V. Manual reset needed. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Reach-in refrigeration and freezers	1-ph fractional compressor condenser and evaporator fan motors	Thermal	Solid-state with relay from control board	Motor will continue to operate through voltage variance.	Solid-state control board will drop out below 65% V. Manual reset needed. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			

Office Building Load Table
Square feet: 10,000 through 100,000
Voltages between 75% and 50% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Custom DX-AHUs or AHUs with air cooled chillers	3-ph fan motors	Over voltage, phase imbalance, over current, or fuse and thermal	EMS with VFD **or** equipment manu-facturer solid state control tied into EMS	EMS remains in control.	EMS and VFD operate through event then drop out 2 seconds after event below 65% V, but will automatically restart. First fan starts within 5 seconds, second fan if applicable restarts at 30 seconds.			
	3-ph compressor motors	Electronic phase monitor fused and thermal	EMS **or** equipment manufactur ers solid state control tied into EMS	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS drops out 2 seconds after event below 65% V, but will automatically restart. 270 to 300 seconds first compressor, 150 to 240 second interstaging delay for each additional compressor if applicable. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Fan powered VAVs	1-ph fractional fan motors	Fuse and thermal	EMS with contactor	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS drops out 2 seconds after event below 65% V, but will automatically restart. Fan starts within 5 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and re-energize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Fan coil units	1-ph fractional fan motors	Thermal	EMS with contactor	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS drops out 2 seconds after event below 65% V, but will automatically restart. Fan starts within 5 seconds, Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and re-energize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65%V.			
Building general exhaust fans	1 and 3-ph fan motors	Over voltage, phase imbalance, over current, **or** fuse and thermal	EMS with VFD or line voltage thermostats / **or** manual start/stop switch	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS and VFD drop out 2 seconds after event below 65% V, but will automatically restart. First fan starts within 5 seconds, second fan if applicable restarts at 30 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and re-energize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later			

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Computer **R**oom **A**ir **C**onditioner	1-ph or 3-ph compressor	Over voltage, phase imbalance, over current, **or** fuse and thermal	Manufacturer Solid-state with contactor / **or** low voltage standalone thermostats	Manufacturer solid-state control board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Manufacturer solid-state control board drops out below 65% V, but will automatically restart. 270 to 300 seconds first compressor, 150 to 240 second interstaging delay for each additional compressor if applicable. **Possible** thermal trip if the voltage variance is longer than 3 to 4 seconds and above 65% V.			
	1-ph or 3-ph fan motor	Over voltage, phase imbalance, over current, **or** fuse and thermal			Manufacturer solid-state control board drops out 2 seconds after event below 65% V, but will automatically restart. Fan starts within 5 seconds **Possible** thermal trip if the voltage variance is longer than 3 to 4 seconds and above 65% V.			
Boilers	1-ph induced draft motor	Fuse and thermal	Manufacturer solid-state with contactor	Control Board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Manufacturer solid-state control board drops out below 65% V, but will automatically restart. 120 seconds first boiler, 240 seconds interstaging delay for each additional boiler if applicable. **Possible** thermal trip if the voltage variance is longer than 3 to 4 seconds and above 65% V.			
	3-ph pump motor	Over voltage, phase imbalance, over current, and current limiting	EMS with VFD	EMS and VFD remain in control.	EMS and VFD operate through event, then drop out 2 seconds after event below 65% V, but will automatically restart. Pump starts within 90 seconds.			
Domestic hot water pumps	1-ph fractional motor	Circuit breaker and thermal	EMS with relay / **or** Manual switch	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS drops out 2 seconds after event below 65% V, but will automatically restart within 10 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 2 to 4 seconds and above 65% to 50% V.			
Other plug loads	Elevators, computers, includes small delis and vending equipment, ATMs, telecommunications equipment, drop out at 50%, and computer based loads will go through a reboot sequence on voltage recovery.							

Office Building Load Table
Square feet: 100,000 to 1,000,000
Voltages between 75% and 50% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
AHUs	3-ph fan motors	Over voltage, phase imbalance, over current	EMS with VFD	EMS remains in control.	EMS and VFD operate through event, then drop out 2 seconds after event below 65% V, but will automatically restart. First fan starts within 5 seconds, second fan if applicable restarts at 30 seconds.			
Fan powered VAVs	1-ph fractional fan motors	Fuse and thermal	EMS with contactor	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS drops out 2 seconds after event below 65% V, but will automatically restart. Fan starts within 5 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
(DOAS) dedicated **o**ut**s**ide **a**ir **s**ystem	3-ph fan motors	Over voltage, phase imbalance, over current	EMS with VFD	EMS remains in control.	EMS and VFD operate through event, then drop out 2 seconds after event below 65% V, but will automatically restart. First fan starts within 5 seconds, second fan if applicable restarts at 30 seconds.			
Chillers	3-ph compressor motors	Over voltage, phase imbalance, over current	Manufacturer solid-state controller tied into EMS	Control board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Manufacturer solid-state control board drops out below 65% V, but will automatically restart. 300 to 500 seconds first chiller, 600-second interstaging delay for each additional chiller if applicable.			
	3-ph pump motors	Over voltage, phase imbalance, over current	EMS with VFD	EMS and VFD remain in control.	EMS and VFD operate through event, then drop out 2 seconds after event below 65% V, but will automatically restart. Pump soft starts within 90 seconds.			
Boilers	1-ph induced draft motor	Fuse and thermal	Manufacturer solid-state with contactor, EMS	Control board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Manufacturer solid-state control board drops out below 65% V, but will automatically restart. 120 seconds first boiler, 240-second interstaging delay for each additional boiler if applicable. **Possible** thermal trip if the voltage variance is long enough and above 65% for 2 to 3 seconds.			
	3-ph motors	Over voltage, phase imbalance, over current, and current limiting	EMS with VFD	EMS and VFD remain in control.	EMS and VFD operate through event, then drop out 2 seconds after event below 65% V, but will automatically restart. Pump starts within 90 seconds.			
Cooling towers	3-ph fan motor	Over voltage, phase imbalance, over current,	EMS with VFD	EMS and VFD remain in control.	EMS and VFD operate through event, then drop out 2 seconds after event below 65% V, but will automatically restart. First fan starts within 5 seconds, second fan if applicable restarts at 30 seconds.			

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
		and current limiting						
Fan coil units	1-ph fractional fan motors	Thermal	EMS with contactor	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS drops out 2 seconds after event below 65% V, but will automatically restart. Fan starts within 5 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Building general exhaust fans	1 and 3-ph fan motors	Over voltage, phase imbalance, over current, **or** fuse and thermal	EMS with VFD or line voltage thermostats / **or** manual start/stop switch	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS and VFD drops out 2 seconds after event below 65% V, but will automatically restart. First fan starts within 5 seconds, second fan if applicable restarts at 30 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergize 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later.			
CRAC	1-ph or 3-ph compressor	Over voltage, phase imbalance, over current, **or** fuse and thermal	Manu-facturer solid-state with contactor / **or** low voltage standalone thermostats	Manufacturer solid-state control board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Manufacturer solid-state control board drops out below 65% V, but will automatically restart. 270 to 300 seconds first compressor, 150 to 240 seconds interstaging delay for each additional compressor if applicable. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph or 3-ph fan motor	Over voltage, phase imbalance, over current, **or** fuse and thermal			Manufacturer solid-state control board drops out 2 seconds after event below 65% V, but will automatically restart. Fan starts within 5 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Domestic cold water pumps	3-ph pump motor	Over voltage, phase imbalance, over current	Manu-facturer solid-state with VFD	Manufacturer solid-state control board remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Manufacturer solid-state control board drops out 2 seconds after event below 65% V, but will automatically restart. Pumps soft start within 5 seconds.			
Domestic hot water pumps	1-ph fractional motor	Circuit breaker and thermal	EMS with relay / **or** manual switch	EMS remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS drops out 2 seconds after event below 65% V, but will automatically restart within 10 seconds. Contactors operate through voltage variance, but drop out when EMS drops offline 2 seconds after event. Or, if the voltage dips below 50% V, the contactor will drop and reenergizes 1 to 8 cycles after event, and then drop out again when the EMS drops 2 seconds later. **Possible** thermal trip if the voltage variance is longer than 3 to 4 seconds and above 65% V.			

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Sewage rejection	3-ph pump motor	Fused with current overload	Line voltage mag-starter start/stop level switch	Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.			Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event. **Possible** overload trip if the voltage variance is long enough and above 50% V.	
Other loads	Elevators, computers, includes small delis and vending equipment, ATMs, telecommunications equipment, drop out at 50%, and computer based loads will go through a reboot sequence on voltage recovery.							

Retail Building Load Table
Square feet: 5,000 and under
Voltage between 75% and 50% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
RTUs	3-ph indoor fan motors	Fused **possibly** overload relays	Low voltage thermostat with contactor	Thermostat remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Thermostat will drop out below 65% V, but will automatically restart. Fan starts within 30 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	3-ph compressor motors	Fuse and thermal	Low voltage thermostat with contactor		Thermostat will drop out below 65% V, but will automatically restart the compressor within 300 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph fractional condenser and induced draft motors	Fuse and thermal	Low voltage thermostat with contactor		Thermostat will drop out below 65% V, but will automatically restart the fans with the compressor within 300 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Walk-in refrigeration and freezers	1-ph or 3-ph compressors	Fuse and thermal	Line voltage with contactor	Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.	Automatically restart. 300 seconds for compressor and all associated 1-phase fans. **Possible** thermal trip if the voltage variance is longer than 2 to 3 seconds and above 50% V.			
	1-ph fractional evaporator and condenser fan motors	Fuse and thermal	Line voltage with contactor					
Exhaust fans	1-ph fractional motor	Circuit breaker and thermal	Manual switch	Contactor drops out at 50% V. Reenergizes 1 to 8 cycles after event.			Contactor drops out at 50% V Reenergizes after 1 to 8 cycles after event. **Possible** Thermal trip if the voltage variance is long enough and above 50% V.	
Reach-in refrigeration and freezers	1-ph fractional compressor condenser and evaporator fan motors	Thermal	Solid-state with relay from control board	Motor will continue to operate through voltage variance.	The solid-state control board will drop out below 65% V. Manual reset needed. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Other plug loads	Gas pumps, refrigerated display cases, ice bins, TVs and monitors, cooking equipment drop out at 75% voltage and computer based loads will restart after reboot sequence.							

Retail Building Load Table
Square feet: 15,000 to 40,000
Voltages between 75% and 50% of nominal

<table>
<tr><th>Equipment</th><th>Motors</th><th>Protection</th><th>Controls</th><th>5 cycle</th><th>10 cycle</th><th>20 cycle</th><th>2 second</th><th>3 minute</th></tr>
<tr><td rowspan="3">RTUs</td><td>3-ph indoor fan motors</td><td>Fused possibly overload relays</td><td rowspan="3">EMS or Manufacturer solid state tied into ems with contactors or Low voltage standalone thermostats</td><td rowspan="3">Thermostat remains in control.

Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.</td><td colspan="4">EMS or thermostat will drop out below 65% V, but will automatically restart. Fan starts within 30 seconds.

Possible thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.</td></tr>
<tr><td>3-ph compressor motors</td><td>Fuse and thermal</td><td colspan="4">EMS or thermostat will drop out below 65% V, but will automatically restart the compressor within 300 seconds.

Possible thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.</td></tr>
<tr><td>1-ph fractional condenser and induced draft motors</td><td>Fuse and thermal</td><td colspan="4">EMS or thermostat will drop out below 65% V, but will automatically restart the fans with the compressor within 300 seconds.

Possible thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.</td></tr>
<tr><td>Exhaust fans</td><td>1-ph fractional motor</td><td>Circuit breaker and thermal</td><td>Manual switch</td><td colspan="3">Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.</td><td>Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.

Possible thermal trip if the voltage variance is long enough and above 50% V.</td></tr>
<tr><td>Other plug loads</td><td colspan="8">Elevators, computers, refrigeration, cooking includes small delis and vending equipment, ATMs, telecommunications equipment drop out at 75% voltage, and recover immediately with voltage recovery except for computer-based load with a reboot sequence.</td></tr>
</table>

Retail Building Load Table
Square feet: 15,000 to 100,000
Voltages between 75% and 50% of nominal

<table>
<tr><th>Equipment</th><th>Motors</th><th>Protection</th><th>Controls</th><th>5 cycle</th><th>10 cycle</th><th>20 cycle</th><th>2 second</th><th>3 minute</th></tr>
<tr><td rowspan="3">RTUs</td><td>3-ph indoor fan motors</td><td>Fused possibly overload relays</td><td rowspan="3">EMS
or
Manufacturer solid state tied into EMS with contactors
or
Low voltage standalone thermostats</td><td rowspan="3">Thermostat remains in control.

Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.</td><td colspan="4">EMS or thermostat will drop out below 65% V, but will automatically restart. Fan starts within 30 seconds.

Possible thermal trip if the voltage variance is longer than 4-5 seconds and above 65% V.</td></tr>
<tr><td>3-ph compressor motors</td><td>Fuse and thermal</td><td colspan="4">EMS or thermostat will drop out below 65% V, but will automatically restart the compressor within 300 seconds.

Possible thermal trip if the voltage variance is longer than 4-5 seconds and above 65% V.</td></tr>
<tr><td>1-ph fractional condenser and induced draft motors</td><td>Fuse and thermal</td><td colspan="4">EMS or thermostat will drop out below 65% V, but will automatically restart the fans with the compressor within 300 seconds.

Possible thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.</td></tr>
<tr><td>Exhaust fans</td><td>1-ph fractional motor</td><td>Circuit breaker and thermal</td><td>Manual switch</td><td colspan="3">Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.</td><td>Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.

Possible thermal trip if the voltage variance is long enough and above 50% V.</td></tr>
<tr><td>Other plug loads</td><td colspan="8">Elevators, escalators, computers, refrigeration, vending equipment, ATMs, telecommunications equipment drops out at 75% voltage and restarts with voltage recovery, except for computer-based, which must go through reboot sequence.</td></tr>
</table>

Warehouse Building Load Table
Square feet: 20,000
Voltages between 75% and 50% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Gas fired unit heaters	1-ph fractional fan motors	Thermal	Low voltage thermostat with contactor	Thermostat remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS or Thermostat will drop out below 65% V. but will automatically restart. Fan starts within 30 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Exhaust fans	1-ph fractional motor	Thermal	Manual switch	Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.			Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event. **Possible t**hermal trip if the voltage variance is long enough and above 50% V.	
Paddle fans	1-ph fractional motor	Thermal	Manual switch	Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event.			Contactor drops out at 50% V. Reenergizes after 1 to 8 cycles after event. **Possible** thermal trip if the voltage variance is long enough and above 50%.	
Other plug loads	Electric forklift charging, TV and monitors, computers, copiers, fax, printers, refrigerators, microwaves, box fans will drop off at 75% and restart with voltage recovery. Computer-based loads will go through reboot sequence.							

Other Building Load Table
Voltages between 75% and 50% of nominal

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	3 minute
Single phase heat pumps	1-ph fractional HP motors	Fuse and thermal	Low voltage thermostat with contactor	Stall between 60% and 70%. Disconnect at 50%. Do not restart for 3 to 5 minutes.	Thermostat will drop out below 65% V, but will automatically restart. Fan starts within 30 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph compressor motor	Fuse and thermal	Battery backed low voltage thermostat with contactor	Drop out at 50% V and restart at 90%V.	Thermostat will drop out below 65% V, but will automatically restart the compressor within 300 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
RTUs	3-ph indoor fan motors	Fused **possibly** overload relays	EMS **or** Manufacturer solid state tied into EMS with contactors **or** Low voltage standalone thermostats	Thermostat remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	Thermostat will drop out below 65% V, but will automatically restart. Fan starts within 30 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	3-ph compressor motors	Fuse and thermal			Thermostat will drop out below 65% V, but will automatically restart the compressor within 300 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
	1-ph fractional condenser and induced draft motors	Fuse and thermal			Thermostat will drop out below 65% V, but will automatically restart the fans with the compressor within 300 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Electric heat fan motors	1-ph fractional fan motors	Thermal	Low voltage thermostat with contactor	Thermostat remains in control. Contactor drops out at 50% V and reenergizes after 1 to 8 cycles after event.	EMS or thermostat will drop out below 65% V, but will automatically restart. Fan starts within 30 seconds. **Possible** thermal trip if the voltage variance is longer than 4 to 5 seconds and above 65% V.			
Misc. plug loads, computers, vending, ATMs	Exhaust fans and compressor motors, single phase, fractional HP	Thermal and fuse	Local relay	Battery-backed devices remain on. Others drop out at 50% V. 1-minute delay on voltage recovery.				

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