Motor Control and Protection

Effect of Under Voltage Transients in Commercial Buildings

John Kueck, Dan James (PNNL)

A Study and Report Have Been Completed

- To understand how typical motor protection and control responds to voltage transients.
- A selection of commercial building types was studied.
- Dan James of PNNL has extensive experience with building management systems in a variety of commercial building types and was able to provide expertise on the many different motor types and control systems in today's commercial buildings.
- We also performed tests of Energy Management Systems at BPA and had discussions with control system manufacturers to review the test results.

Purpose of Study

- Voltage transient time frames of interest and magnitudes were developed which are used in a set of tables
- Two tables are provided for each building type.
- All motor loads were considered, not just single phase air conditioners.
- In commercial buildings, more and more motors are controlled by computer based building management systems.

Voltage Transient Time Frames and Magnitudes of Interest

- Voltage transient magnitudes and durations were selected which were typical fault response levels that are of interest to system planners.
  - Dips to 75% of nominal and to 50% of nominal voltage. 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.
  - Dip durations of 5, 10 and 20 cycles, 2 seconds and 3 minutes (3 minutes is really just for interest and for recovery planning.)

Possible Motor Responses to Voltage Transients

- Motors may ride through, trip, or stall.
- Controls may ride through, drop out, or trip immediately after the event.
- When voltage recovers, motors may re-energize and re-accelerate, or delay for a few minutes, or stay stalled.

Tables Have Been Developed for the Following Commercial Building Types

- Food Service (Fast Food) (McDonalds)
- Supermarket (Albertson's)
- Other (Hotels, Residential Care)
- Office
- 20k-100k sf office building motor response
- 100k-1m sf office building motor response
- Retail (Both Big and Small, by square feet)
- 5k sf Under 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

Building and Load Characteristics

- Larger, high rise office buildings usually have an EMS. EMS typically consists of a central computer and field controllers which have EPROM memory. The field modules control relays which control contactors.
- Testing at BPA has shown that the EMS can ride though severe voltage sags down to 65% of nominal voltage. Testing has shown even though the EMS can ride through voltage transients below 65% of nominal voltage, the EMS will drop out 2 seconds after the event and then takes 3 seconds to reset.
- Roof top units have motor contactors drop out at 50 to 60% 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.

Sample Table (Office Building Load 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 minutes
AHUs	3-ph Fan Motors	Over voltage, Phase Imbalance, over current	EMS with VFD	EMS remains in control	EMS & VFD operate through event then drops out 2 seconds after event below 65% V but will automatically restart. First fan starts within 5 seconds 2nd fan if applicable re-starts at 30sec			
Fan Powered VAVs	1-ph Fractional Fan Motors	Fuse & Thermal	EMS with Contactor	EMS remains in control contactor drops out at 50% V and re-energizes 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-energizes 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 4-5 seconds and above 65%V			

(DOAS) Dedicated Outside Air System	3-ph Fan Motors	Over voltage, Phase Imbalance, over current	EMS with VFD	EMS remains in control	EMS & VFD operate through event then drops out 2 seconds after event below 65% V but will automatically restart. First fan starts within 5 seconds 2nd fan if applicable re-starts at 30sec
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 re-energizes after 1 to 8 cycles after event	Manufacturer Solid-state Control Board drops out below 65% V but will automatically restart. 300-500sec First Chiller 600sec interstaging delay for each additional chiller if applicable
	3-ph Pump Motors	Over voltage, Phase Imbalance, over current	EMS with VFD	EMS & VFD remains in control	EMS & VFD operate through event then drops out 2 seconds after event below 65% V but will automatically restart. Pump soft starts within 90 seconds

Equipment	Motors	Protection	Controls	5 cycle	10 cycle	20 cycle	2 second	
Boilers	1-ph Induced Draft Motor	Fuse & Thermal	Manufacturer Solid-state with contactor, EMS	Control Board remains in control contactor drops out at 50% V and re-energizes after 1 to 8 cycles after event	Manufacturer Solid-state Control Board drops out below 65% V but will automatically restart. 120sec First Boiler 240sec interstaging delay for each additional boiler if applicable Possible thermal trip if the voltage variance is long enough and above 50% for 2-3 seconds			
	3-ph Motors	Over voltage, Phase Imbalance, over current, & current limiting	EMS with VFD	EMS & VFD remains in control	EMS & VFD operate through event then drops 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, & current limiting	EMS with VFD	EMS & VFD remains in control	EMS & VFD operate through event then drops out 2 seconds after event below 65% V but will automatically restart. First fan starts within 5 seconds 2nd fan if applicable re-starts at 30sec			

Conclusions

- We have developed a set of load response tables for a range of commercial building types.
- We provide both the “drop out” and recovery characteristic for typical motor loads, for the voltage dips and times of interest, including both protection and control components.
- This is a “next step” in better understanding of commercial building load response to voltage transients.
- http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-24468.pdf
- fidvr.lbl.gov

Additional Info Slides

VFDs

- Variable Frequency Drives 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, depending on motor load.
- For 60% voltage and 5, 10 and 20 cycles, the VFD should be able to ride through by current limiting the motor. Depending on motor load, the VFD typically 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.

Additional Info - 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 under voltage protection is typically set at 80% of nominal voltage for 2 seconds and 60% of nominal voltage for 0.1 seconds.
- If the motor is de-energized on under voltage, it will not restart for 4 to 10 minutes.

Energy Management System

- The EMS typically consists of a central computer and field controllers which have EPROM memory. The field modules control relays which control contactors.
- Testing at BPA has shown that the EMS can ride though severe voltage sags down to 65% of nominal voltage. Testing has shown even though the EMS can ride through voltage transients below 65% of nominal voltage, the EMS will drop out 2 seconds after the event and then takes 3 seconds to reset.
- It is assumed for the tables that for voltage sag down to 65% of nominal, that the EMS rides through. For sags below 65%, the EMS will drop out the load and then reset by initiating the programed sequences in the controller from the beginning. Some loads and motors will be started relatively quickly while others may take several minutes to reengage the loads.
- Testing performed revealed that the EMS controllers tripped less at voltages above 60% when the control transformer secondary supplying power to the controller was under 50% of its max VA capacity.
- In general, testing showed that voltages variances below 60% resulted in the EMS controller resetting regardless of transformer loading.

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 tests shows contactor reclosed after two cycles. At 65% it took 8.5 cycles to reclose. At 62% it never pulled in, even after multiple seconds.