SOUTHERN CALIFORNIA EDISON®
An EDISON INTERNATIONAL® Company

Commercial 3Φ Rooftop and Residential VFD A/C Testing

DOE-NERC FIDVR Workshop

September 30th, 2015

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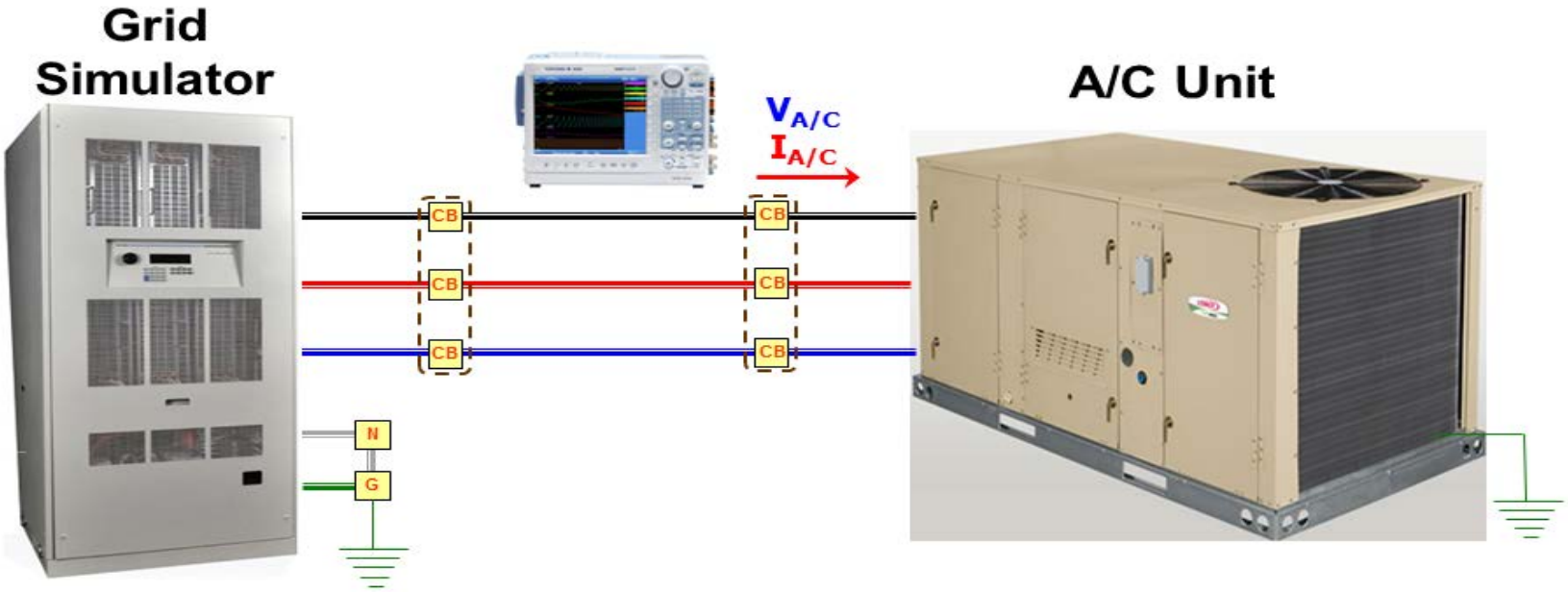
Objectives

- Assess the performance of air conditioner (A/C) units during typical grid voltage and frequency deviations, including but not limited to:
  - Stalling criteria (or lack thereof)
  - Inrush currents
  - Contactor/relay dropout
  - Harmonics contribution
- A/C performance data can be used to:
  - Build, test, and/or validate load models
  - Identify potential device impacts (Is it “grid friendly”?)
  - Explore potential stalling solutions

Laboratory Setup

- Grid Simulator
- Equipment under test
  - 3Φ Commercial Rooftop A/C Unit
  - Residential A/C Unit with VFD

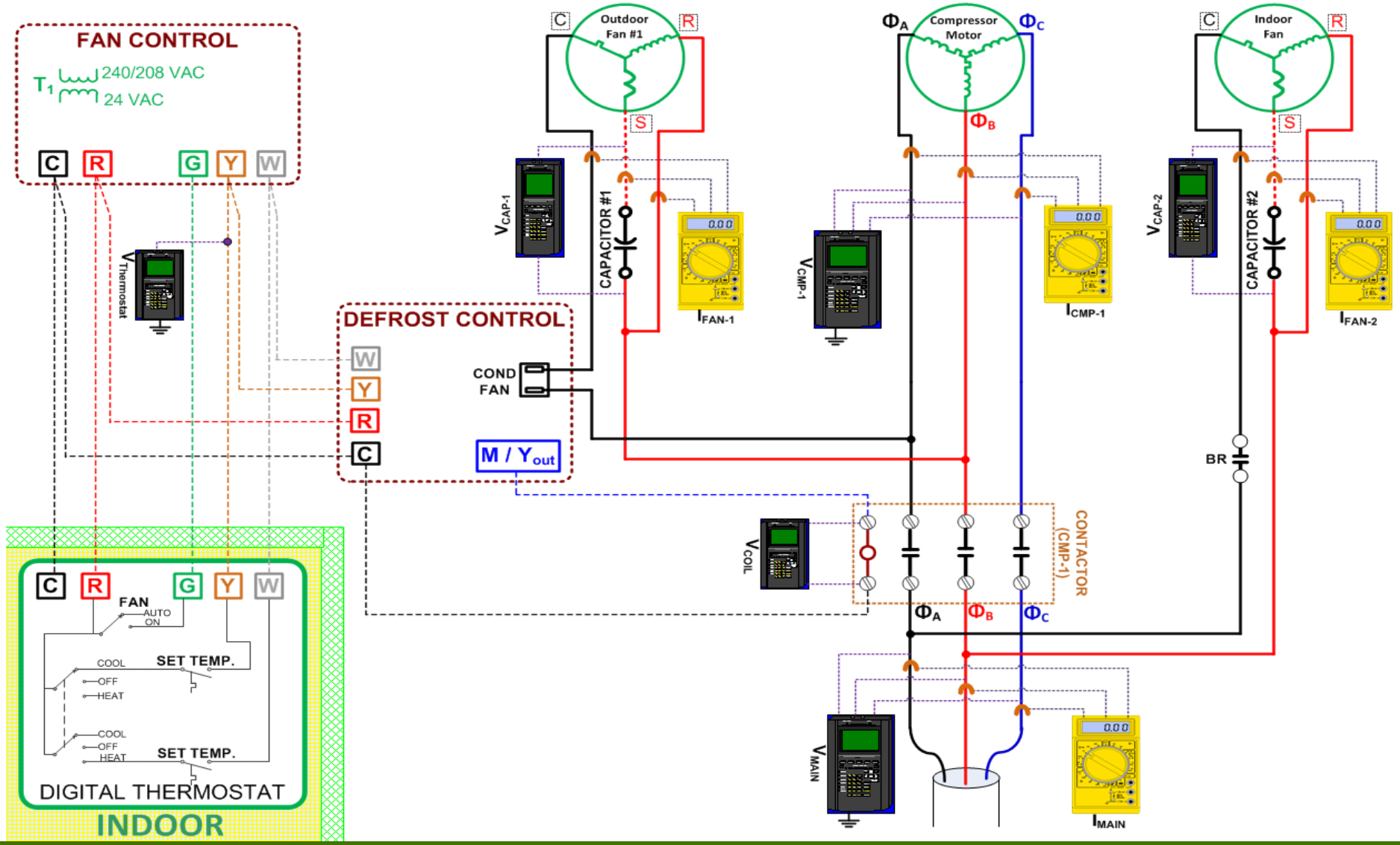
- Digital Oscilloscope
  - Voltage Probes
  - Current Transformers (CTs)
  - Thermocouples
  - Accelerometers



Tests Performed

- Compressor Shutdown
- Compressor Startup
- Balanced Under/Over-Voltage Transients
- Unbalanced Under/Over-Voltage Transients
- Under/Over-Frequency Transients
- Voltage/Frequency Oscillations
- Voltage/Frequency Ramps
- Harmonics
- Conservation Voltage Reduction

Commercial 3Φ Rooftop A/C Testing



3Φ A/C Contactor Dropout Summary

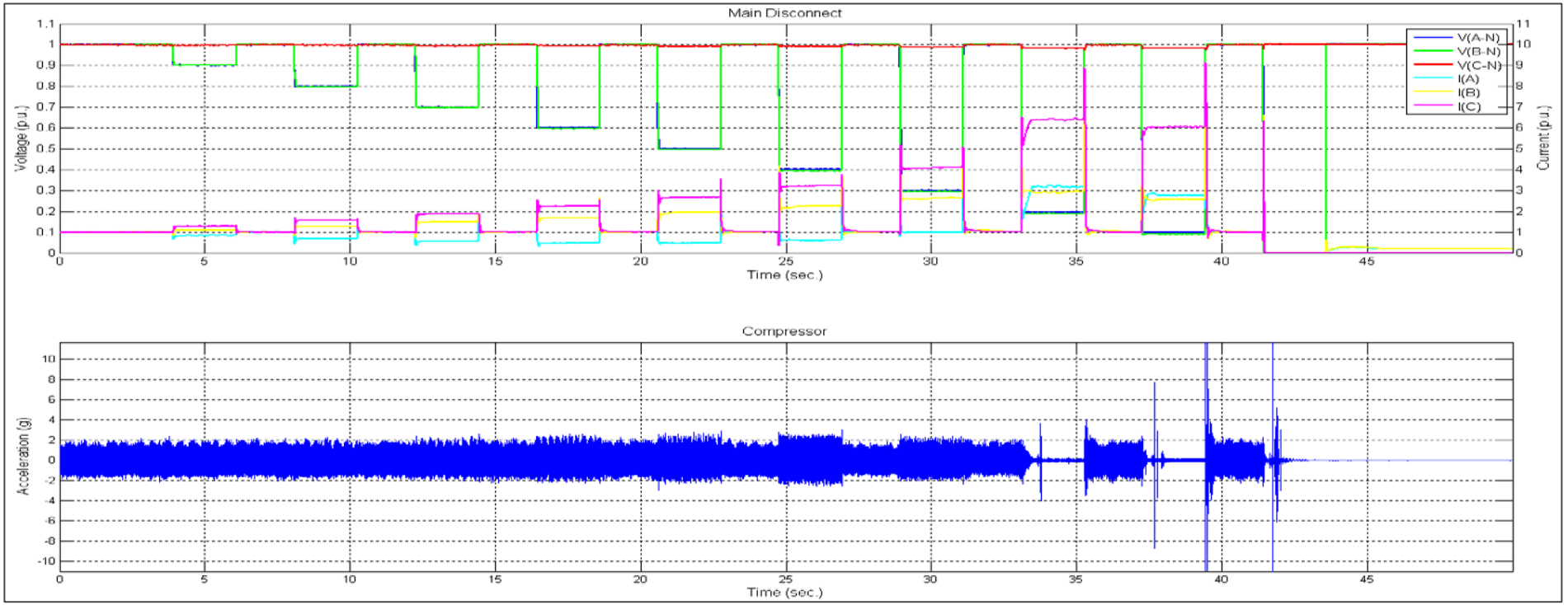
- Dropout is dependent on voltage supplying the A/C unit controls ($V_{\Phi A-\Phi B}$, $V_{\Phi B-\Phi C}$, or $V_{\Phi C-\Phi A}$)
- Dropout generally occurs between 60% - 50% voltage within 2 – 10 cycles
- Contactor often chatters before dropping out
- Contactor normally does not reclose immediately after voltage recover (unit restarts several minutes later)
  - Suggests protective relay on thermostat or local controller

3Φ A/C Stalling Results Summary

- Contactor drops out before stalling can occur for 3-phase balanced under-voltage conditions
- Most units (5 of 7) stall during 2-phase unbalanced under-voltages
  - Stalled between 30% - 10% voltage within 10.8 – 60 cycles
  - Stalling occurs quicker at lower voltages
  - Compressor restarts in 5 cycles after voltage recovers
- No stalling is observed during 1-phase unbalanced under-voltages

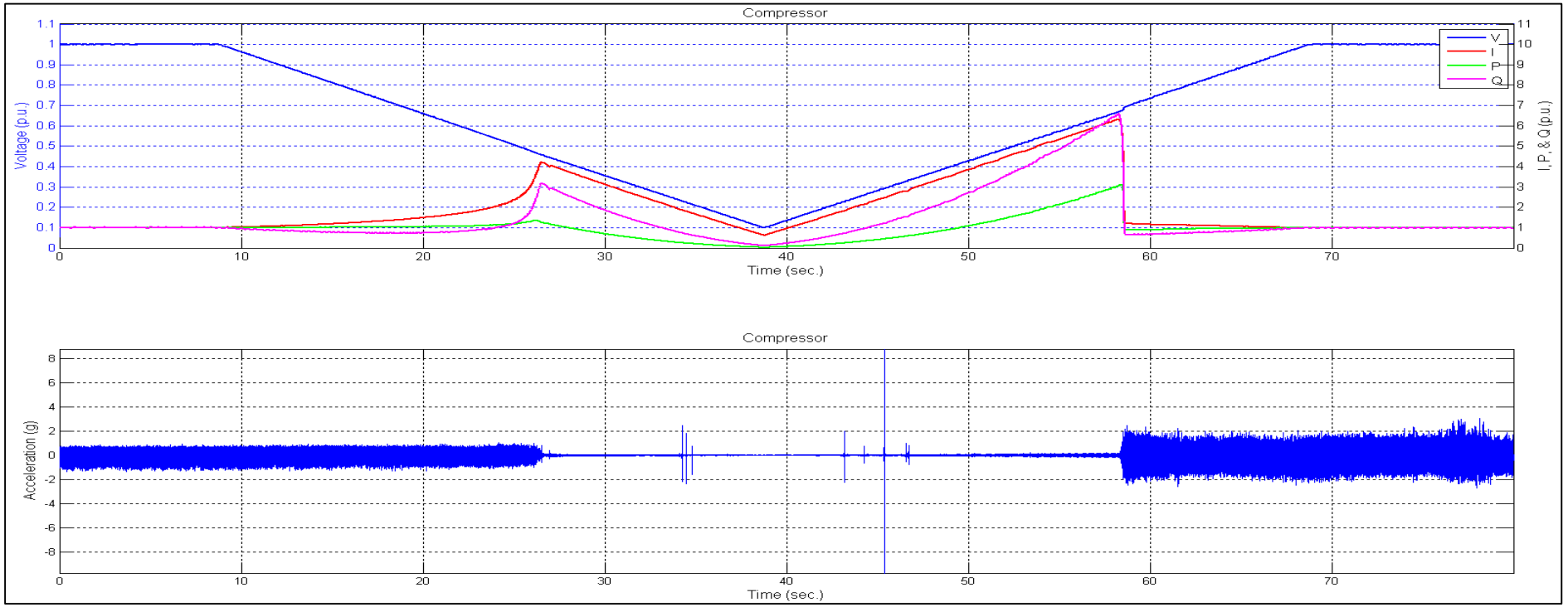
3Φ A/C Stalling Results (Sample)

- Compressor performance during unbalanced under-voltage (Phases A & B) transients:
  - Stalled at 20% V_{L-N} in 24 cycles
  - Stalled at 10% V_{L-N} in 12.6 cycles

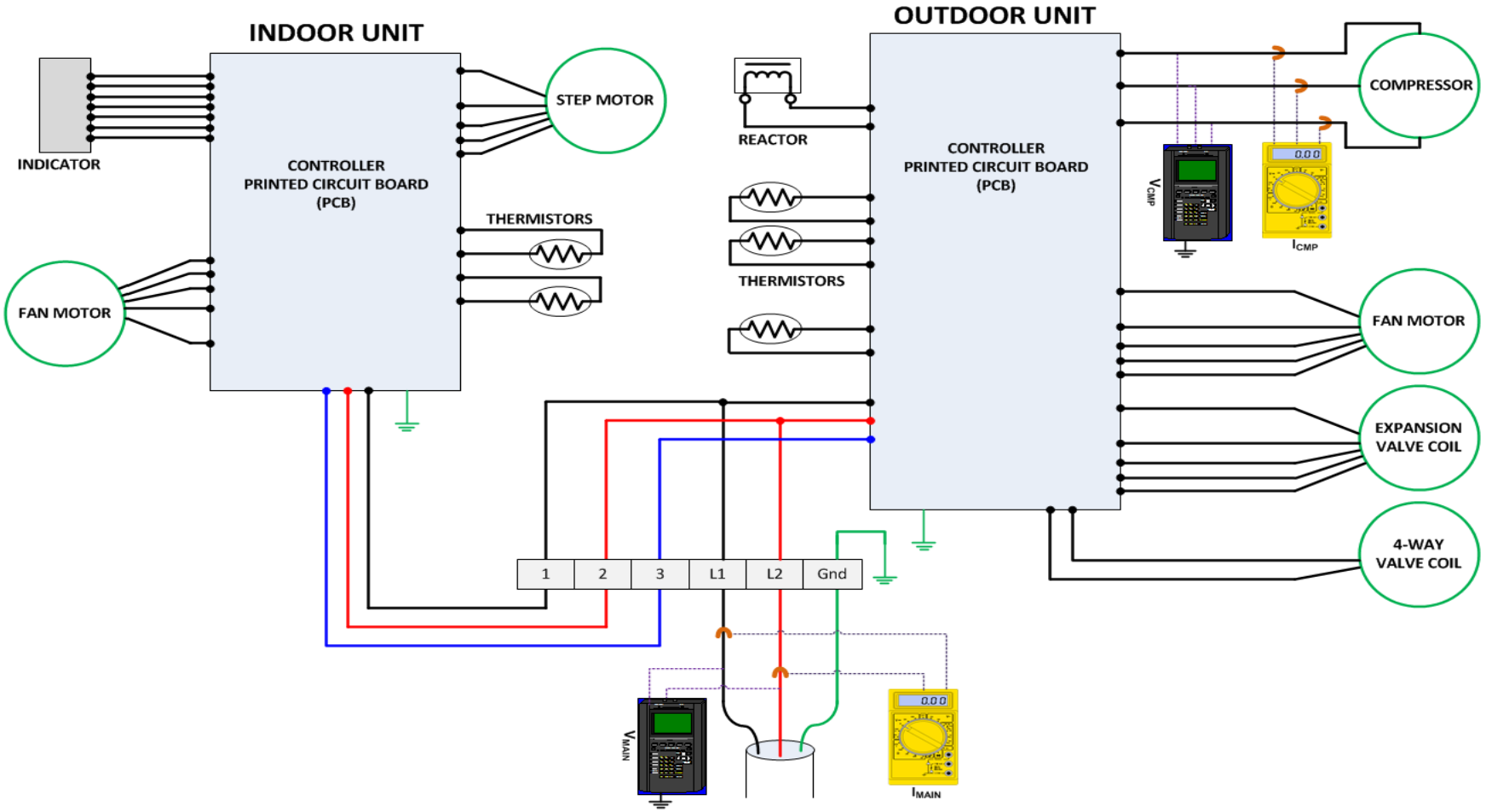


3Φ A/C Stalling (Modified Units)

- Units were modified such that controls were powered separately to bypass dropout
- Captured I, P, and Q at different balanced voltage levels, including at the stalling and restarting point

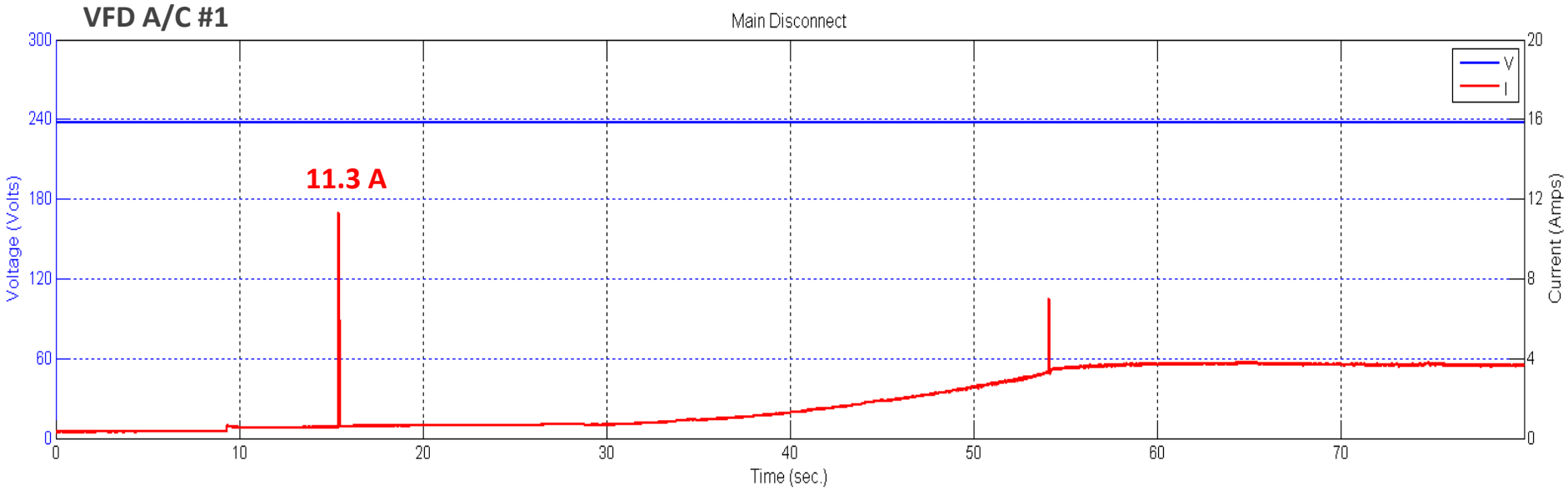


Residential VFD A/C Testing



VFD A/C Compressor Startup

- VFD A/C units display low inrush current compared to conventional units
  - Largest inrush current: 11.3 Amps within 1.8 cycles
  - Compressor current ramps up in 20 – 50 seconds
  - Consumption increases periodically to meet temperature demand

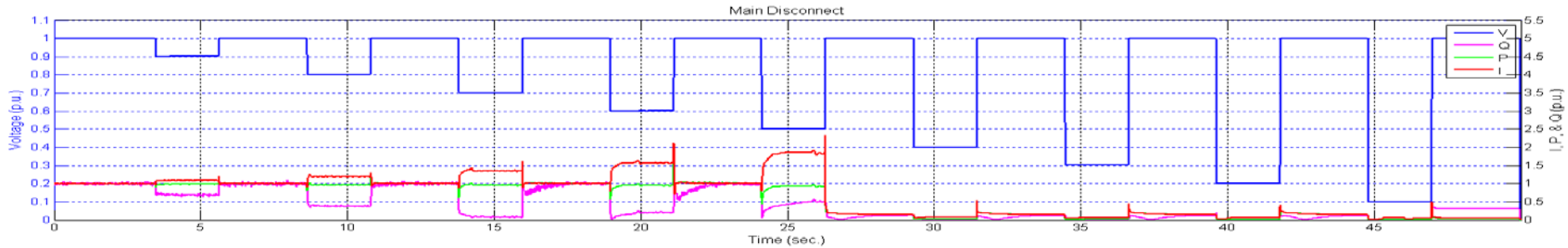


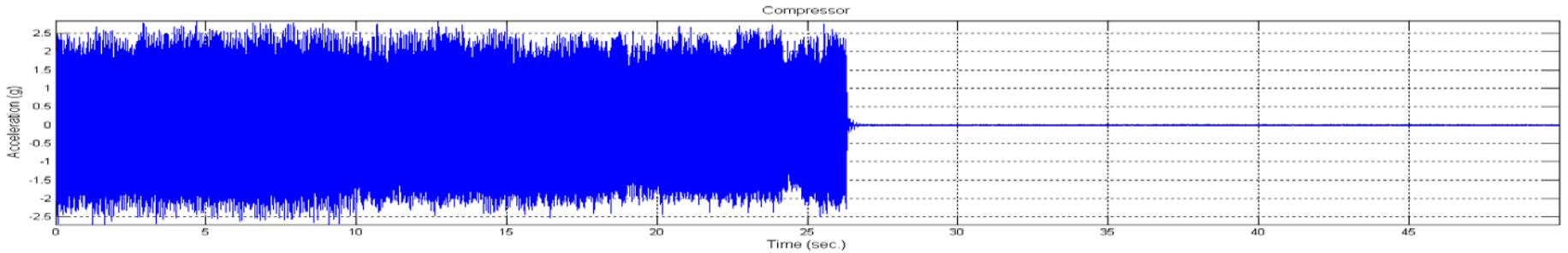
VFD A/C Controls Dropout Summary

- No stalling behavior was observed
- Compressor usually disconnects at the end of a voltage sag or up to 3 cycles after voltage recovers
  - May be due to inrush of current during voltage recovery
- Compressor rides through shorter sags (down to 0%)
  - Shorter voltage sags range from 1 to 6 cycles
- Compressor does not restart immediately after controls drop out (unit restarts several minutes later)
  - Suggests protective relay on the local controller

VFD A/C Controls Dropout Summary

Unit	130 cycle Transients		12 cycle Transients		3 cycle Transients	
	$V_{trip / dropout}$ (%)	$t_{trip / dropout}$ (cyc)	$V_{trip / dropout}$ (%)	$t_{trip / dropout}$ (cyc)	$V_{trip / dropout}$ (%)	$t_{trip / dropout}$ (cyc)
VFD A/C #1	52%	15	55%	13.2	51%	3.6
VFD A/C #2	56%	7.8	55%	9	N/A	N/A
VFD A/C #3	58%	130.8	58%	12.6	59%	4.2
VFD A/C #4	69%	130.1	49%	12.9	N/A	N/A
VFD A/C #5	41%	130.8	20%	12.6	N/A	N/A
VFD A/C #6	81%	131.1	56%	12.2	N/A	N/A
VFD A/C #7	62%	129.6	60%	12	54%	4.2

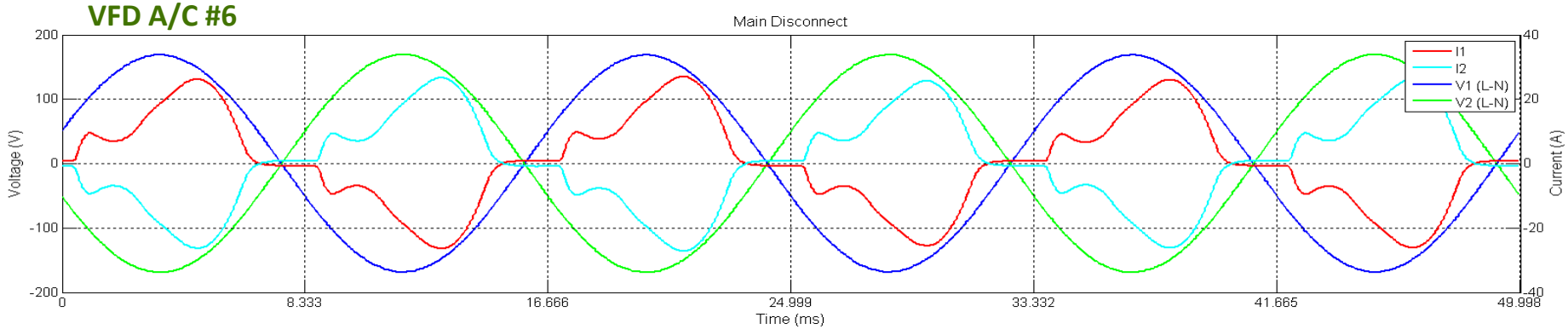


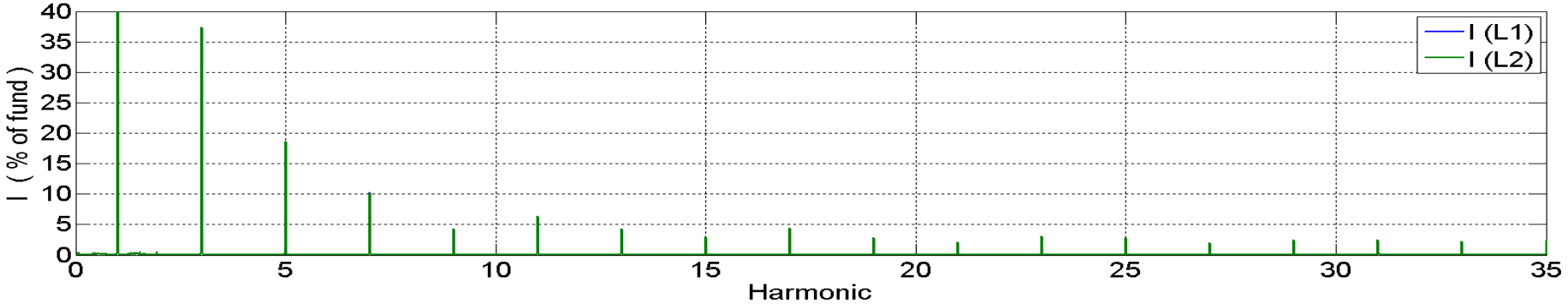


VFD A/C Harmonics Contribution

- VFD A/C #1, 4, 5, 7 current THD is 11% - 16.9% of fund.
- VFD A/C #3 current THD is ~29% of fund.
- VFD A/C #2 & #6 current THD is 39% - 47.5% of fund

VFD A/C #6





Thank You.