TVA Customer Resources Comprehensive Services Staff Case Studies

Music City Power Quality Group/IEEE

By Gerald D. Johns, Power Utilization Engineer
TVA Kentucky Customer Resources

November 13, 2006

TVA

Outline

1. Surge Protection on 4-Wire Delta systems-Metal Oxide Varistor Failures on 120/240 4-Wire Service

2. UPS Responses to Harmonic Distortion

3. Detuned Capacitor Bank Harmonic Filter Non-Characteristic Harmonic Considerations

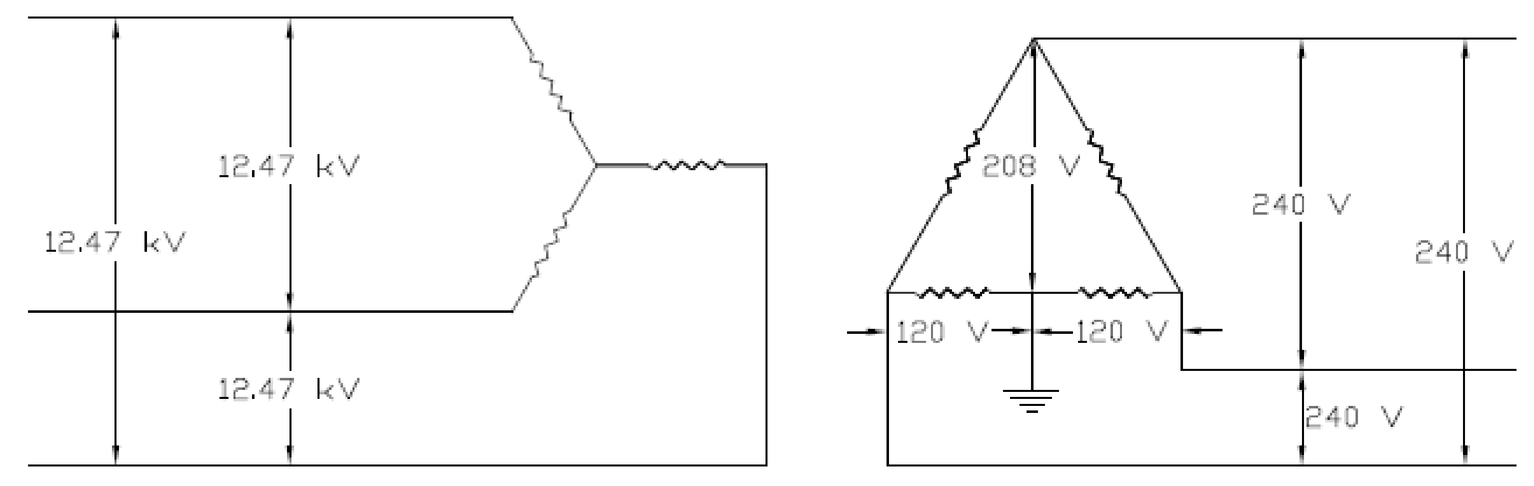
Surge Protection on 4-Wire Delta systems-Metal Oxide Varistor Failures on 120/240 4-Wire Service

Case #1 – MOV Failures on 120/240 4-Wire Service

- Radio transmitter site with 3-phase, 4-wire, 200-amp 120/240 VAC service with 208 VAC "wild-leg"
- Normal load = mixture of 3-phase 240 VAC load and single-phase 120 and 240 VAC load
- 45-kVA bank with three identical 15-kVA 7.2 kV to 120/240 VAC single-phase transformers
- Ungrounded-wye primary and delta secondary

4-Wire Wye-Delta Transformer Bank

- Ungrounded primary neutral to avoid becoming a grounding bank

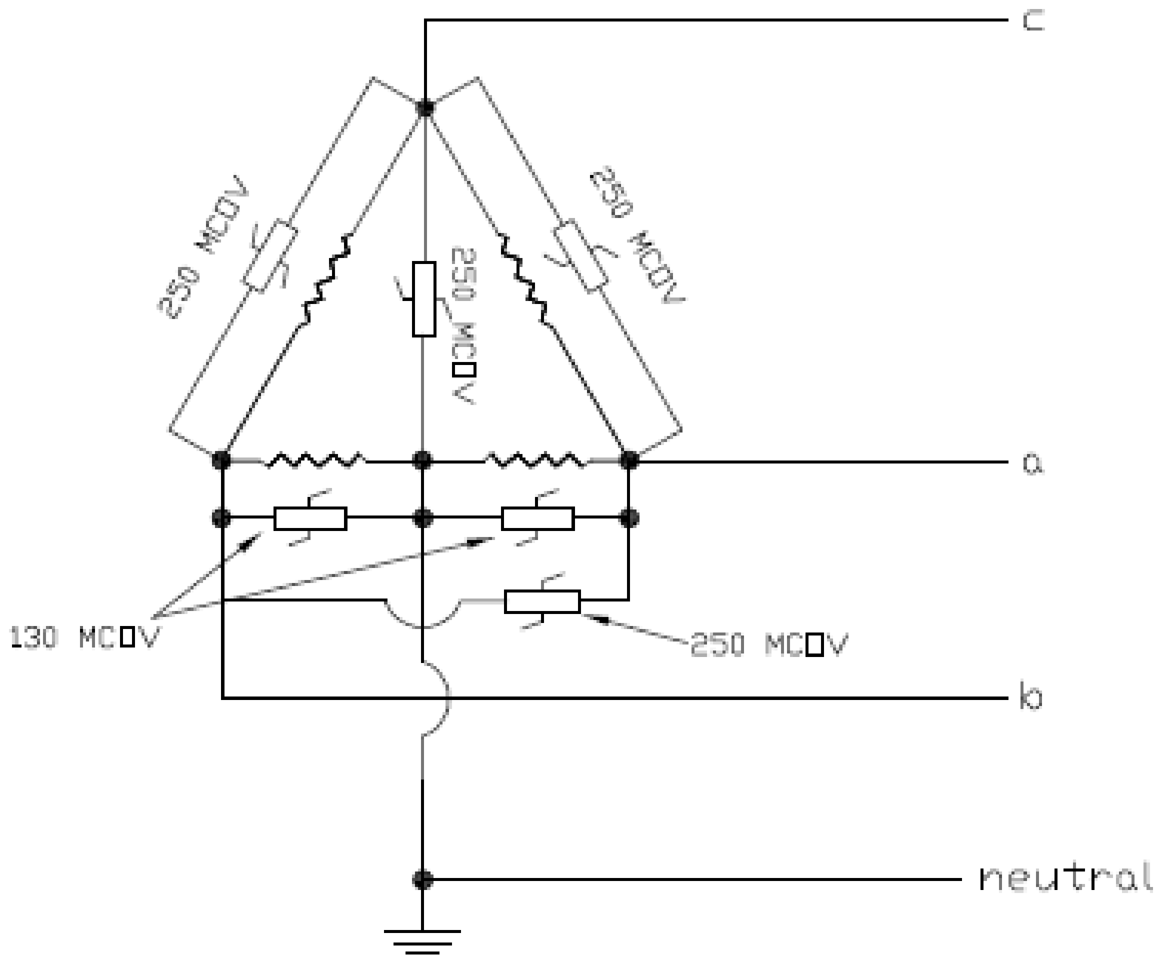


Initial Findings

- **Customer encountered MOV failures when utility company de-energized bank for maintenance**
- **MOVs suffered catastrophic failures. Some equipment was damaged.**
- **All MOV connections were made directly on the load side of the 200 amp main breaker with no intermediate fusing.**
- **A single-phase 240 VAC window unit air-conditioner, fluorescent lighting, and other electronic power supply equipment were on during the switching operations and MOV failures.**
- **5 of the six MOV's failed during this most recent event.**
- **No known failures during thunderstorms or during any other event besides utility operations**

MOVs Used at Customer's Facility

Figure 2 - M□V Connections Prior to Failures



Original theories that were later disregarded

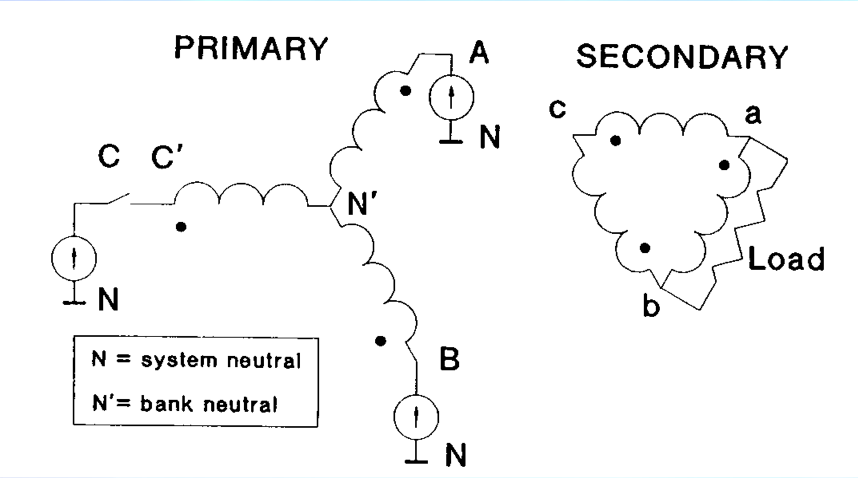
- Voltage transients created during opening and closing of the fused distribution cutouts exceeded the surge handling capabilities of the MOV's.

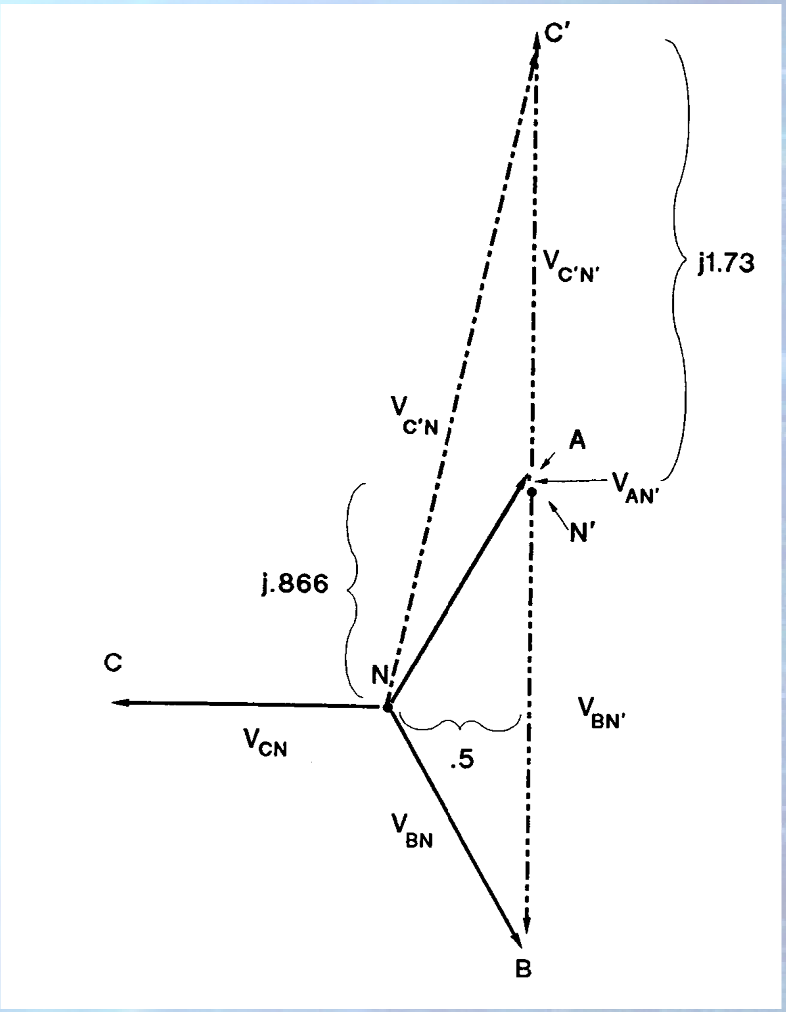
- Steady-state overvoltages realized during normal operation were degrading the MOV's and rendering them incapable of handling even low magnitude surges such as those created during energizing and de-energizing of the transformer bank.

Testing and Voltage Recording

- Used Dranetz 658 to record transients that occurred when distribution cutouts were opened (no load).
- Recorded voltage at service entrance for 5-day period
- No significant transients were recorded when opening the cutouts under no-load conditions
- Recorded voltages consistently within MOV-rated MCOVs

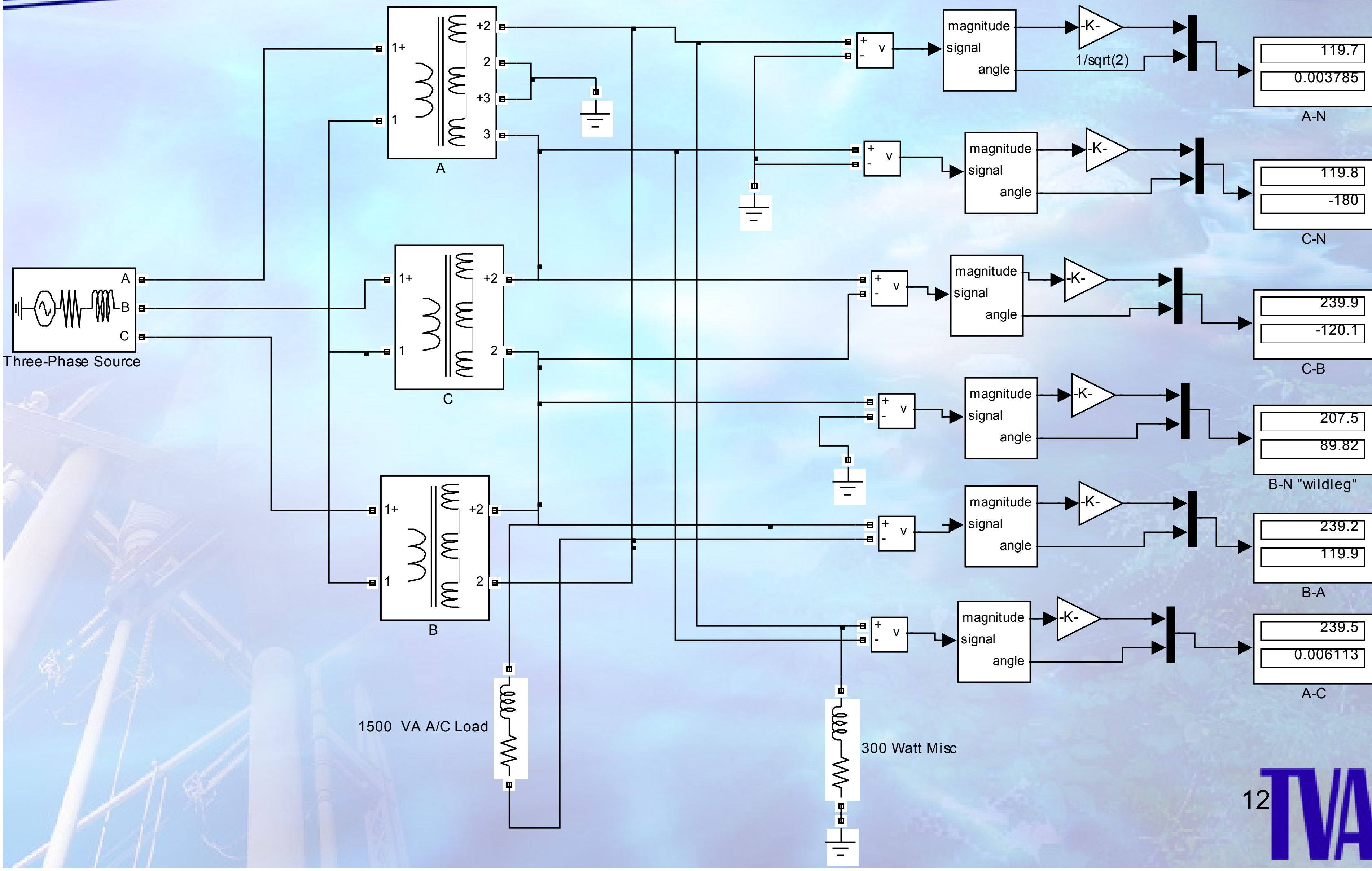
Primary neutral-shift due to load imbalance on secondary





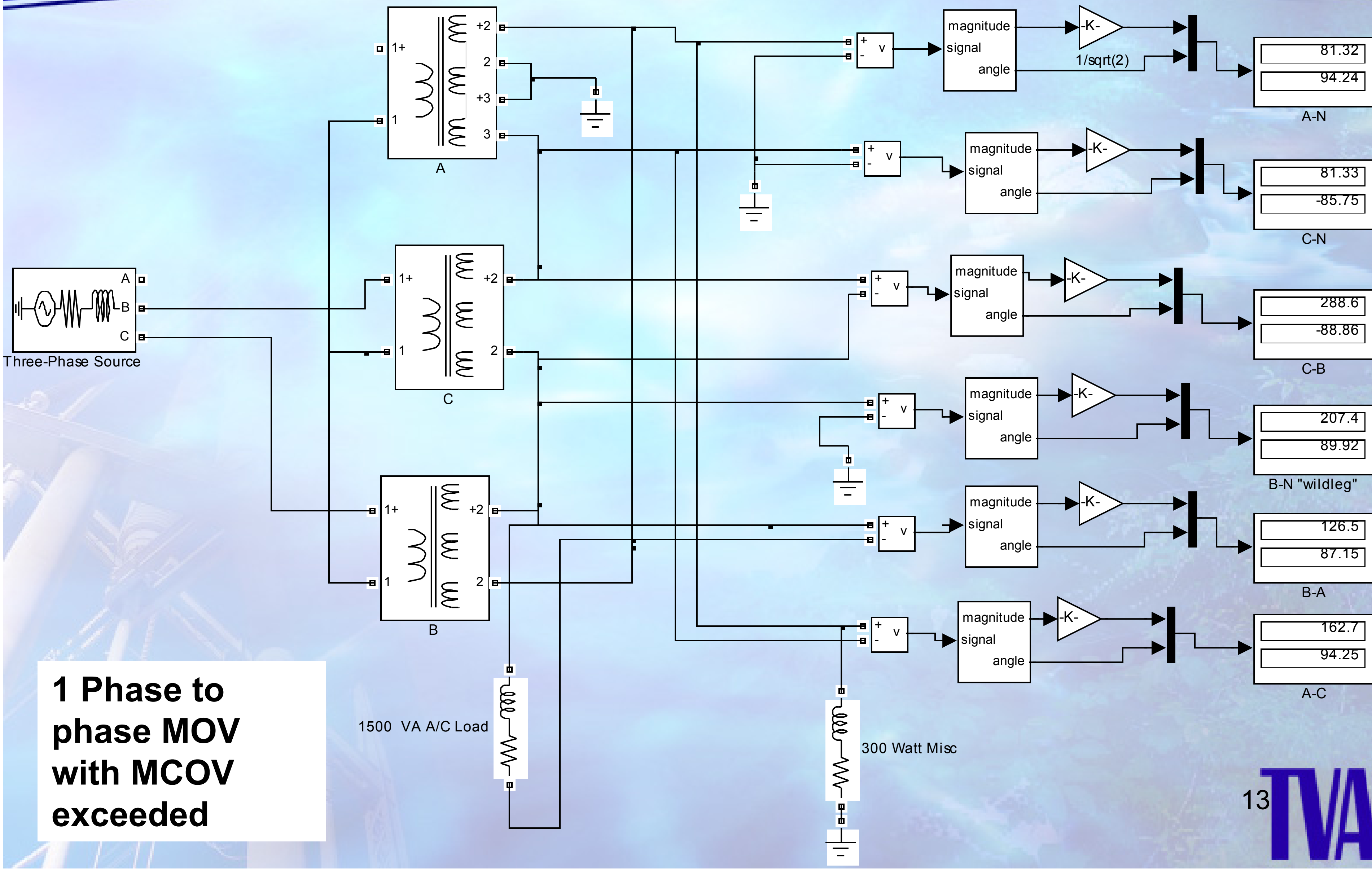
Source: Walling, R.A., Hartana, R.K., Ros, W.J., "Self-Generated Overvoltages Due to Open-Phasing of Ungrounded-Wye Delta Transformer Banks", IEEE Transactions on Power Delivery, Vol. 10, January 1995, pp. 526-533.

Simulation #1 – Steady-state conditions before any cutout opened



TVA

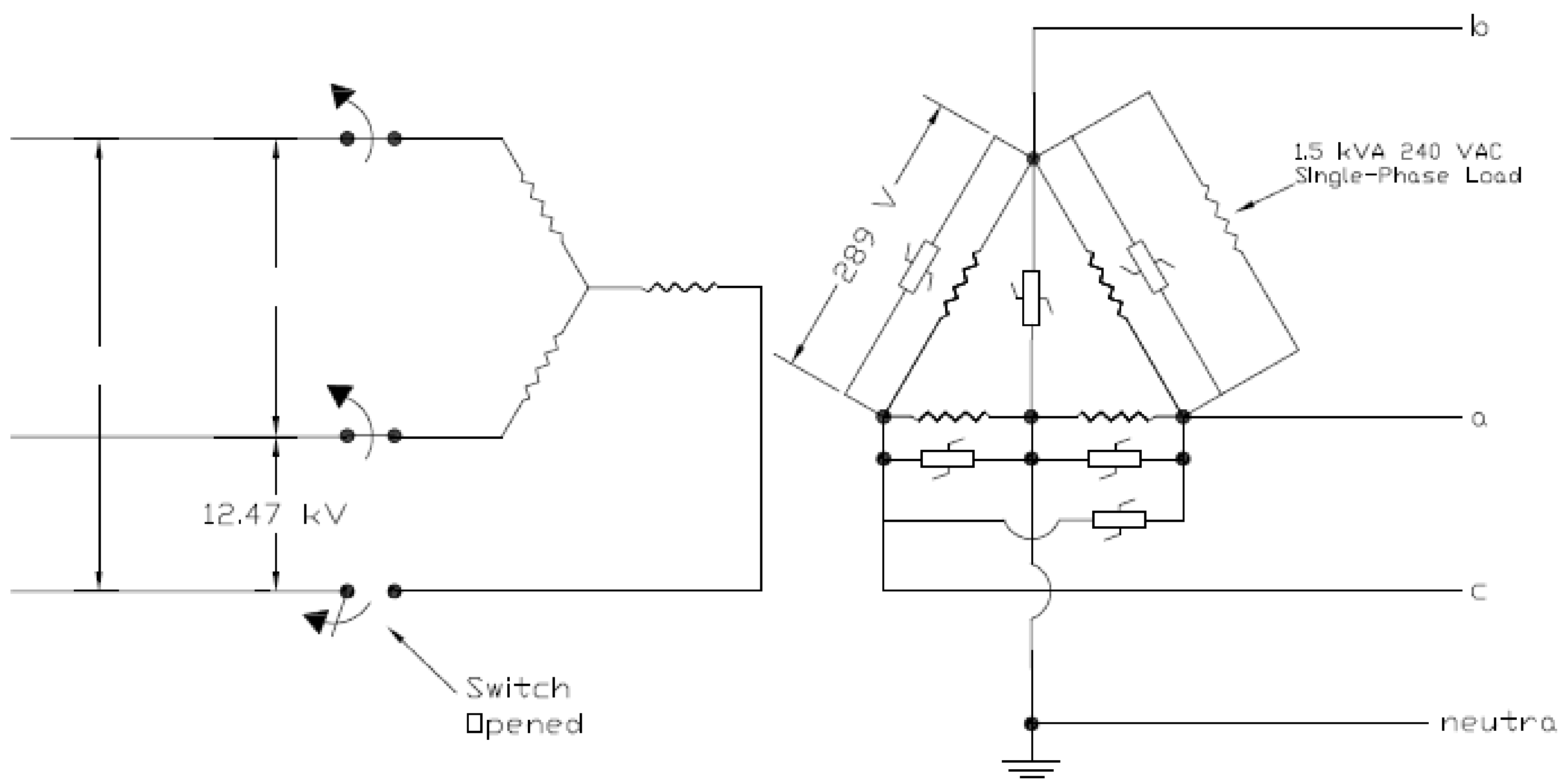
Primary Simulation #2 - A phase cutout opened



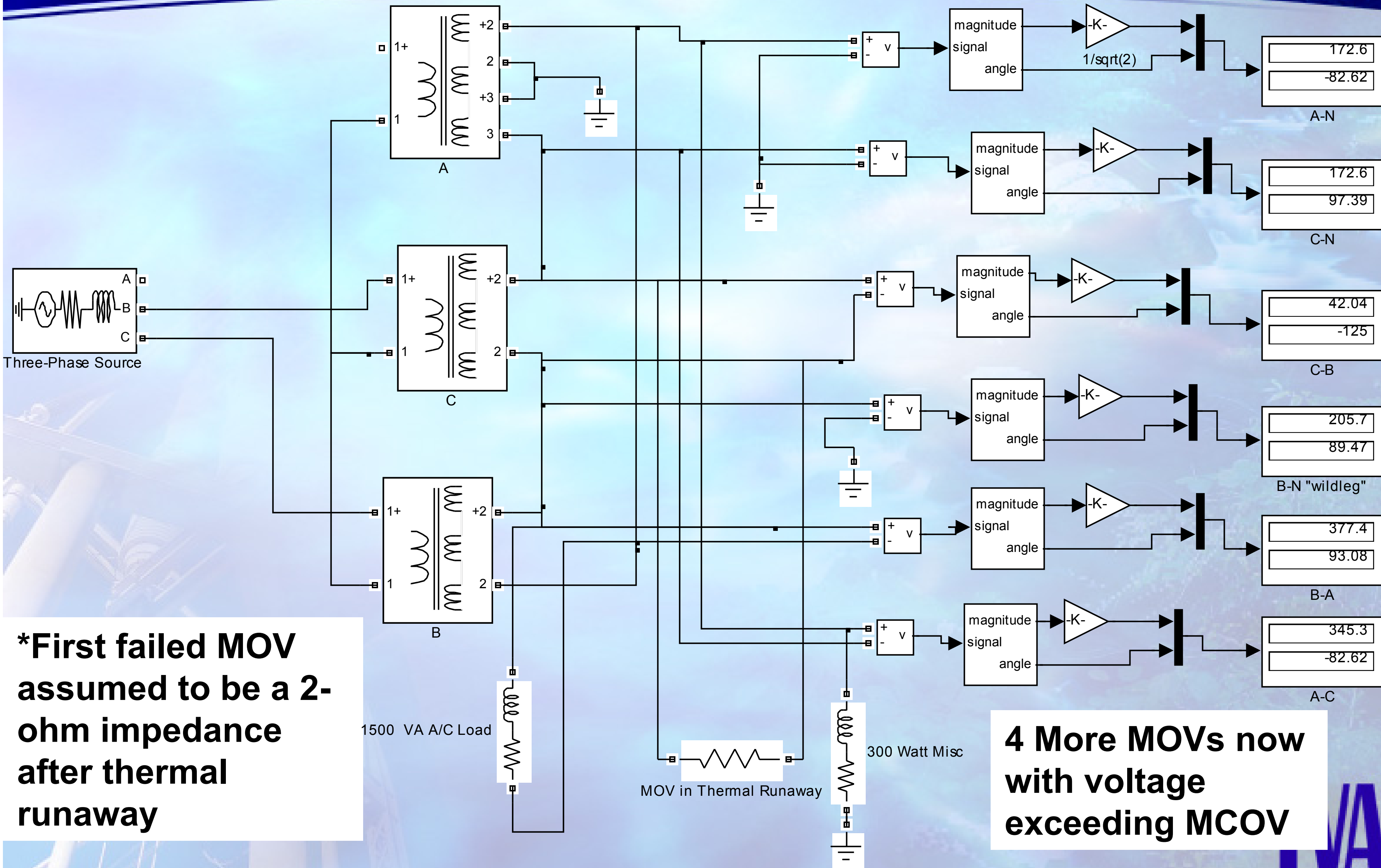
1 Phase to phase MOV with MCOV exceeded

Voltage magnitudes for simulation #2– 1st Cutout opened

Figure 3 - Simulation Conditions Immediately after 1st Switch Opened



Primary Simulation #3 – After 1st MOV Failure results in low impedance between B and C phases

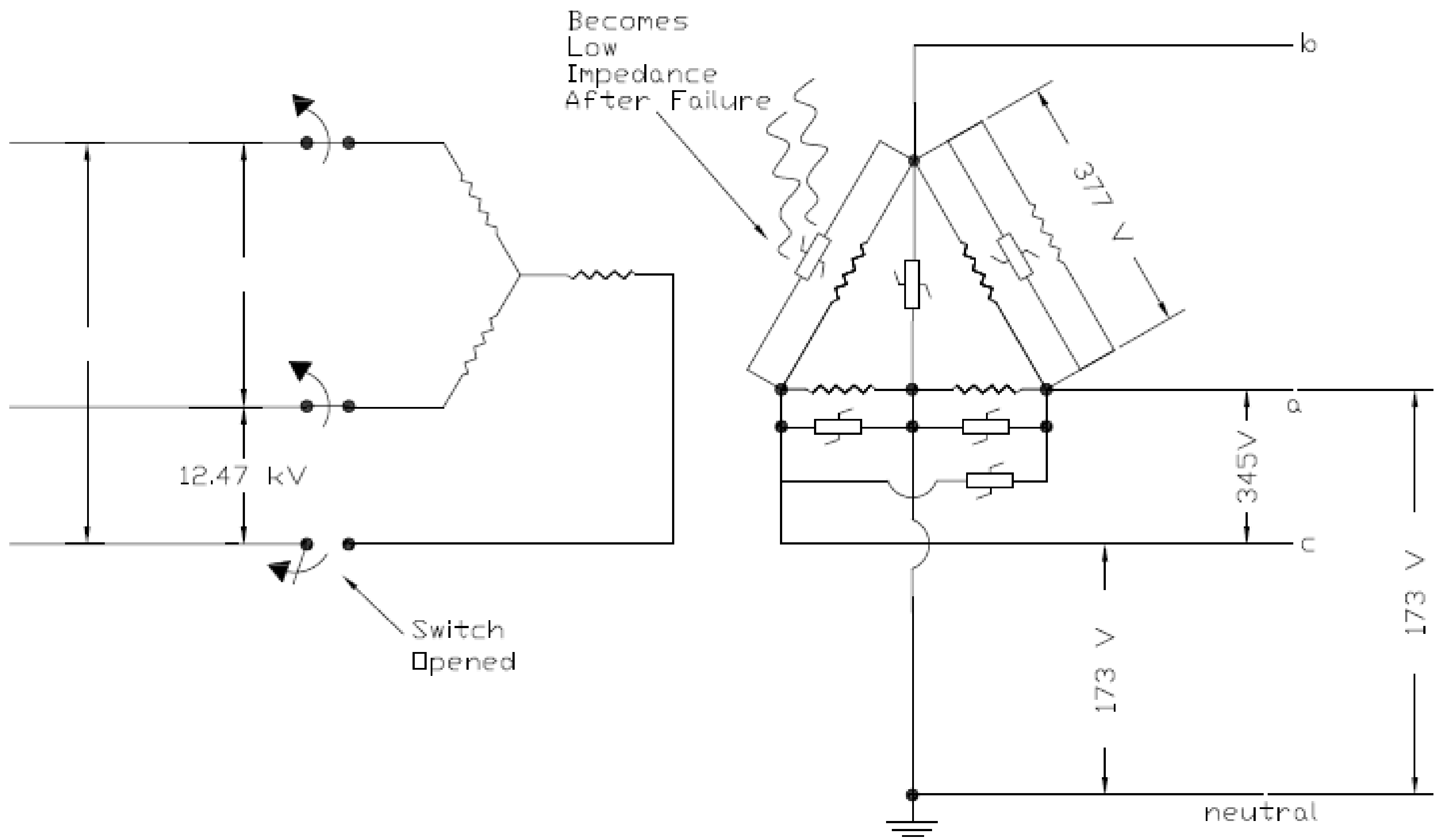


***First failed MOV assumed to be a 2-ohm impedance after thermal runaway**

4 More MOVs now with voltage exceeding MCOV

Voltage magnitudes for simulation #3– 1st Cutout opened

Figure 4 – Simulation Conditions Immediately after 1st MOV Failure



Actual Causes of MOV Failures

- First MOV failure due to the high current and extensive duration of flow resulting from temporary overvoltage.

- Remaining MOV failures due to increased load imbalance on the transformer bank thereby leading to even greater overvoltages on the other phases.

Reason for the overvoltages

- When one phase is opened on an ungrounded wye delta bank, there can be shift of the neutral voltage due to the load imbalance. With the absence of a ground reference at the physically intended neutral point, the neutral is left to float during a phase-loss condition.
- The position of the actual primary neutral point under this circumstance for ungrounded-wye/delta configuration is dependent on the load imbalance on the secondary side.
- During open-circuited conditions, i.e. no load, there is virtually no imbalance; hence no overvoltage occurs.

Recommended solutions

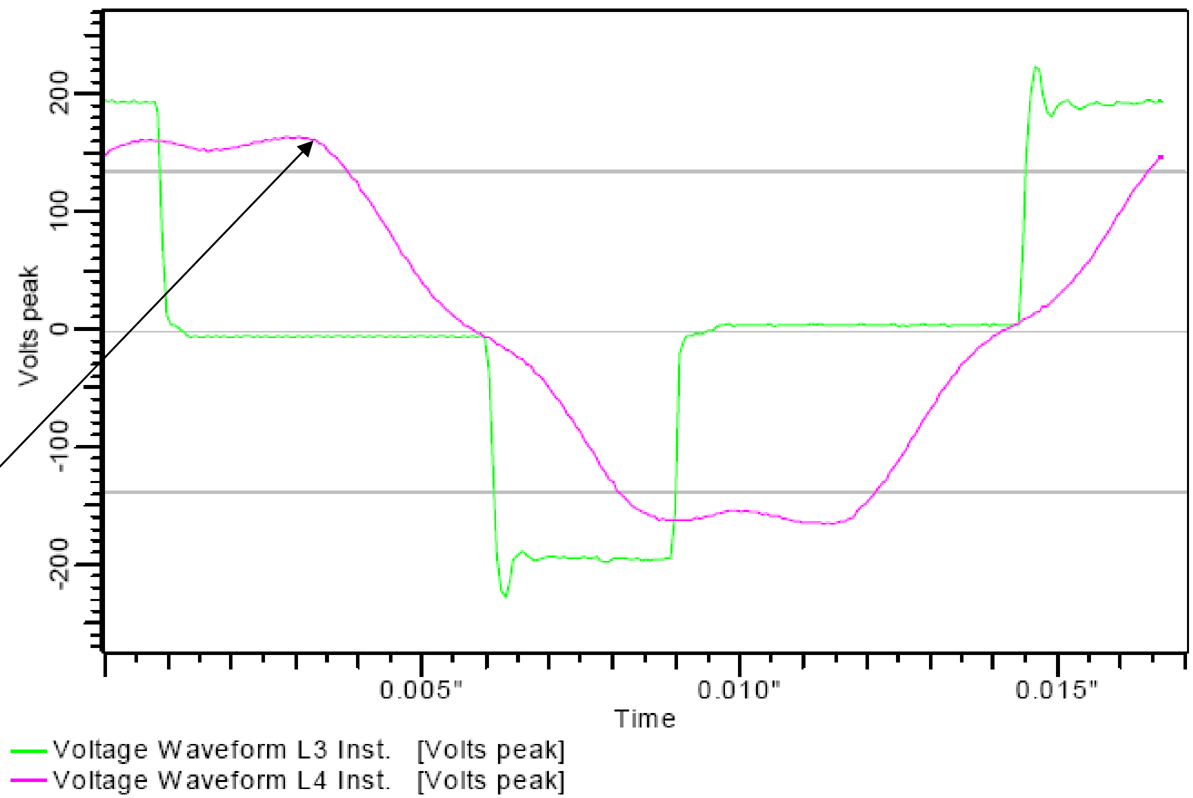
- Avoiding temporary overvoltages during switching
  1. Turn off all load prior to transformer de-energizing.
  2. Temporarily ground neutral through a fused cutout prior to transformer de-energizing.
- Preventing MOV-related fire hazard during loss of phase
  1. Use UL 2nd Ed. Listed surge-protective device
  2. Fuse according to manufacturer's requirements
  3. Provide plenty of margin between MCOV rating and actual system voltage.
  4. Adhere to NEC 280 if arrester or NEC 285 if TVSS

Harmonic Distortion and Nuisance UPS Transfer to Battery Backup

Case #1 – Attorney's Office Desktop UPS

Measurements Taken At: May 05, 2004 00:59:31.824
Record each: Real Time

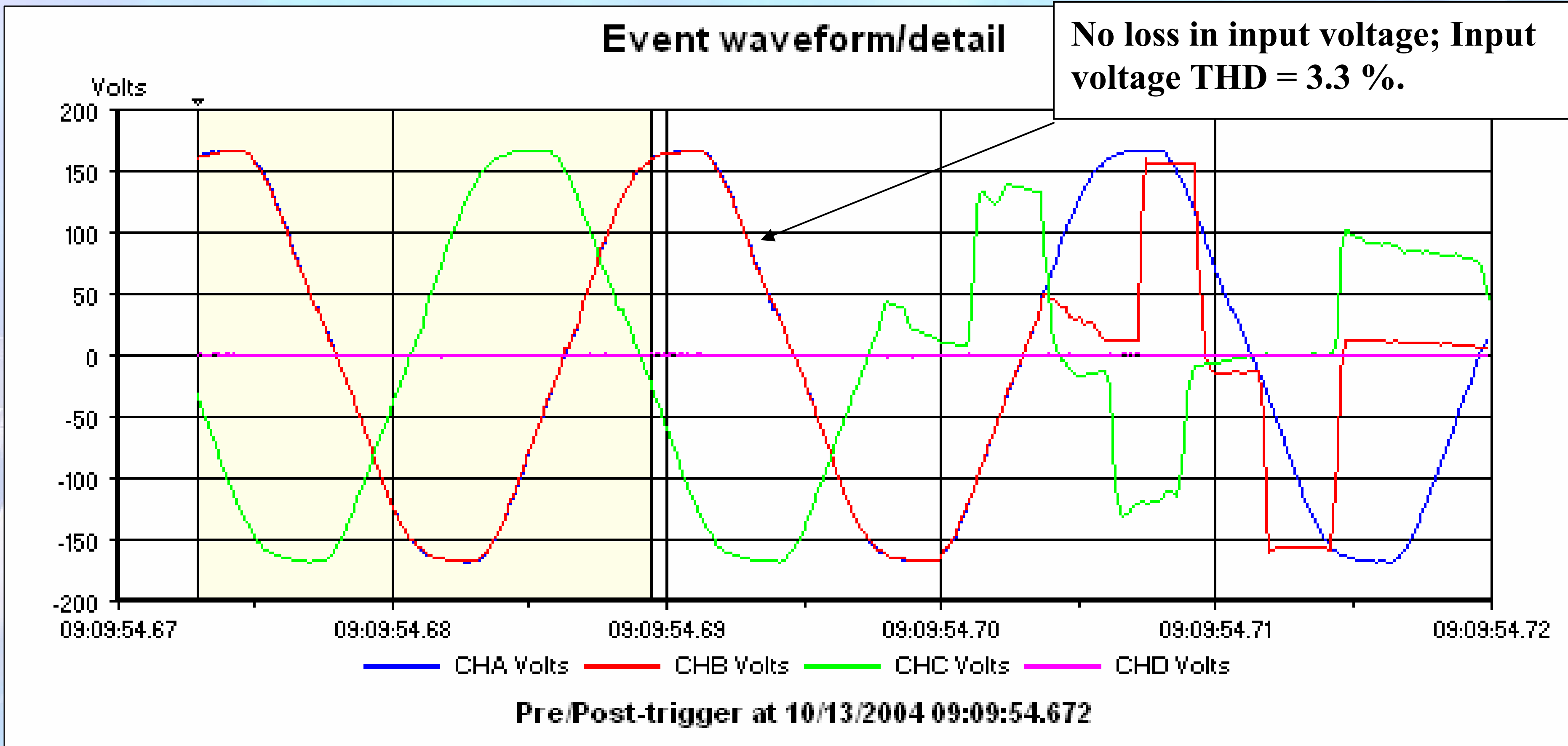
Description:



Voltage THD
~ 11 %

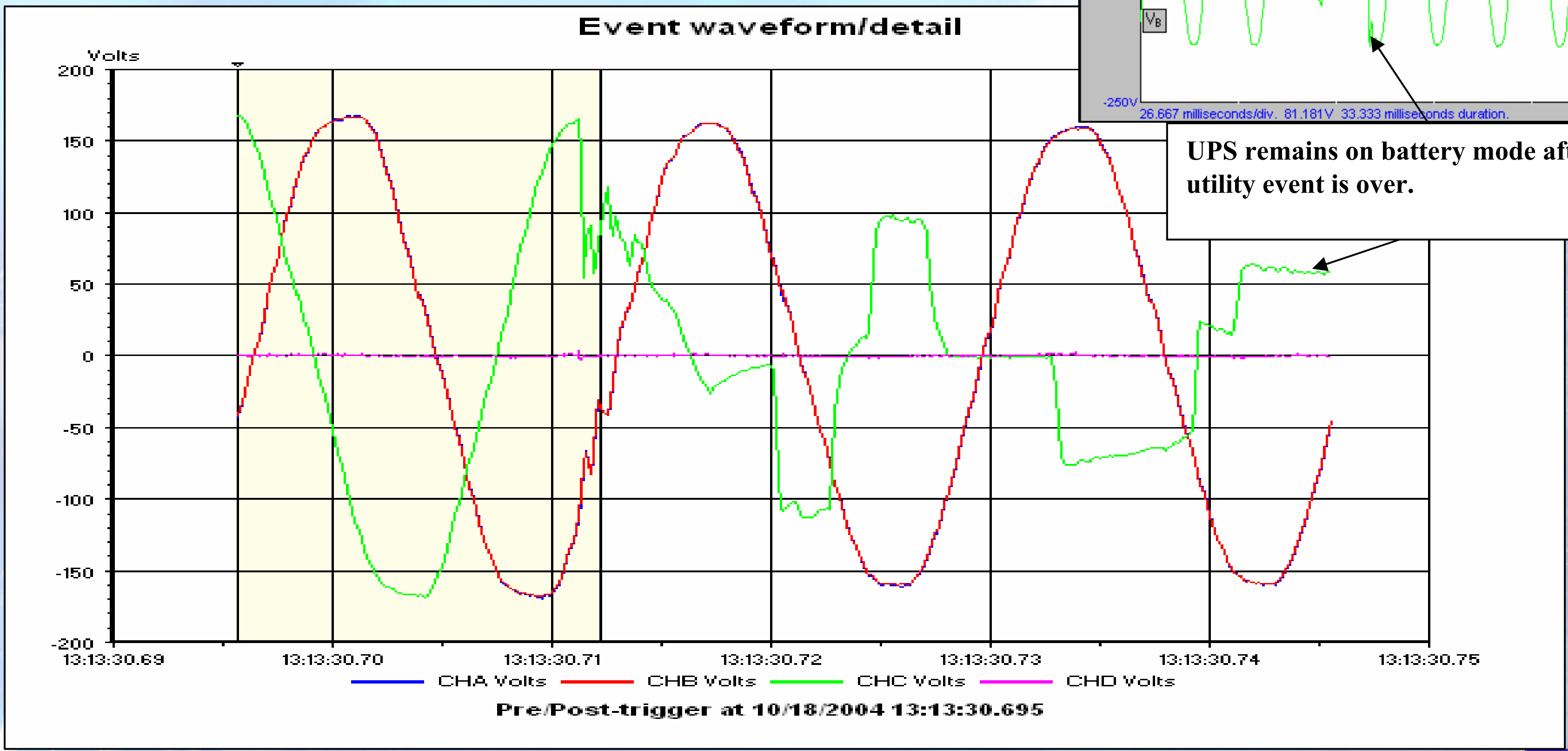
Measurement	Lo Peak	Hi Peak	RMS value
Voltage Waveform L3 Inst.	-227.8Vpk	224.2Vpk	116.3V
Voltage Waveform L4 Inst.	-165.8Vpk	163.5Vpk	120.7V

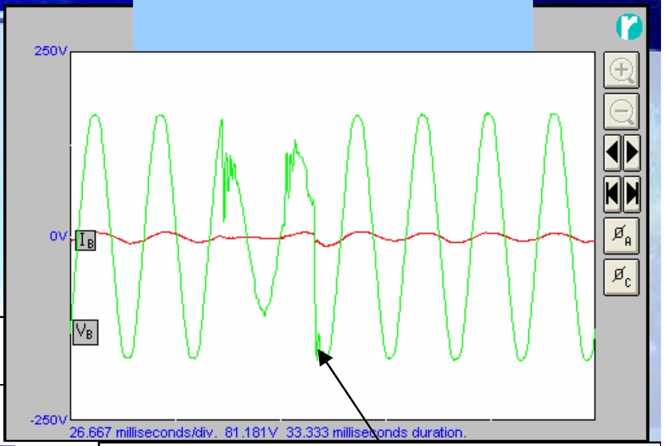
Case #2 – Medical Office Server UPS



No loss in input voltage; Input voltage THD = 3.3 %.

Case #2 - Same UPS when actual voltage sag occurs



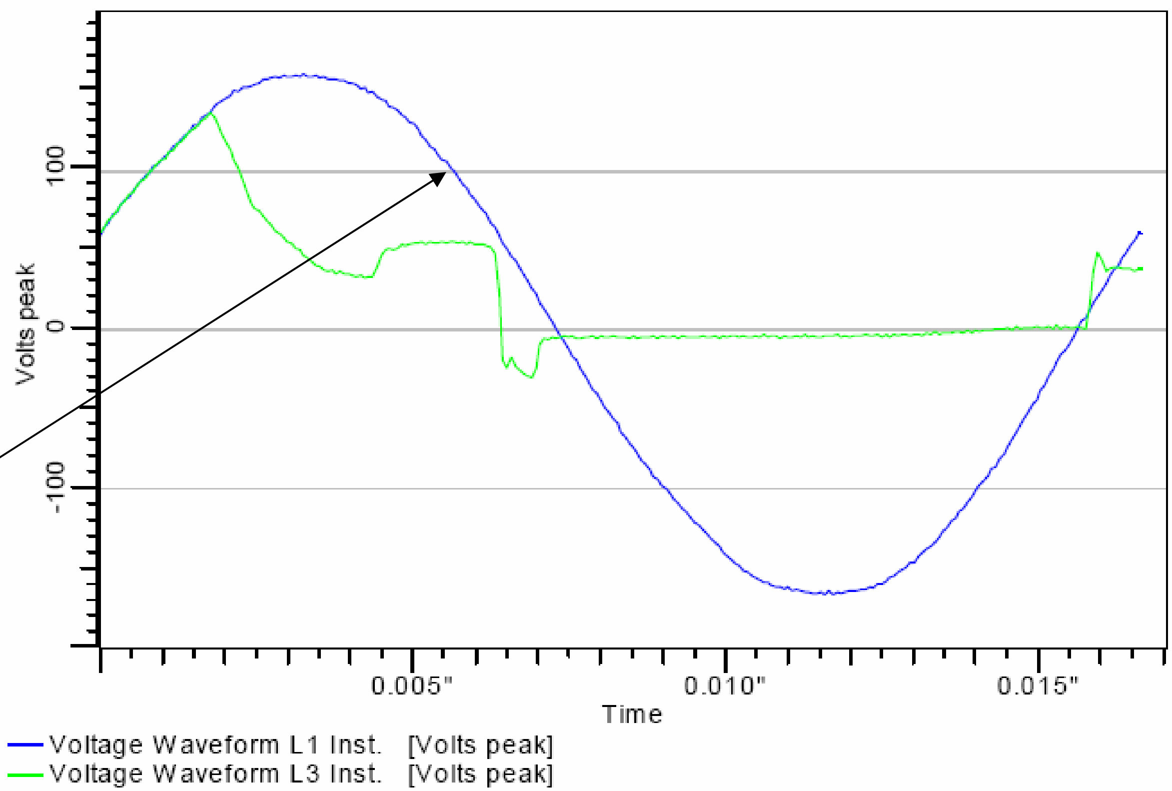


UPS remains on battery mode after utility event is over.

Case #3 – Jail Office Server UPS

Measurements Taken At: June 27, 2006 14:39:23.631
Record each: Real Time

Description:



Voltage THD ~ 2 %

Measurement	Lo Peak	Hi Peak	RMS value
Voltage Waveform L1 Inst.	-166.4Vpk	158.5Vpk	116.2V
Voltage Waveform L3 Inst.	-30.57Vpk	134.6Vpk	47.64V

TVA

Recommendations

- De-sensitize units by setting thresholds as low as equipment to be protected can handle.
- Use the right UPS for the job. Example - don't use a home-use model to backup a server
- Change batteries at least per manufacturer's recommendations. Be aware of system conditions that may necessitate more frequent battery replacement.

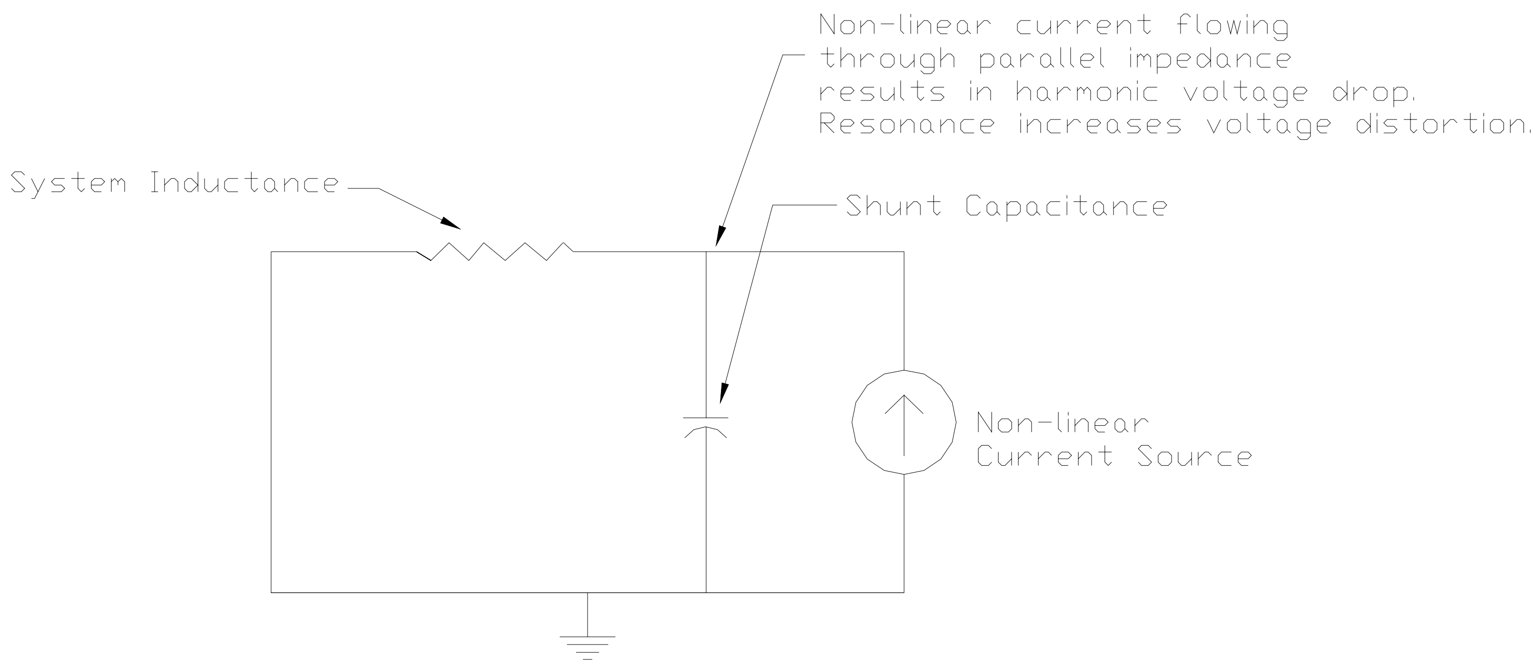
Detuned Capacitor Bank/ Harmonic Filter Non-Characteristic Harmonic Considerations

TVA

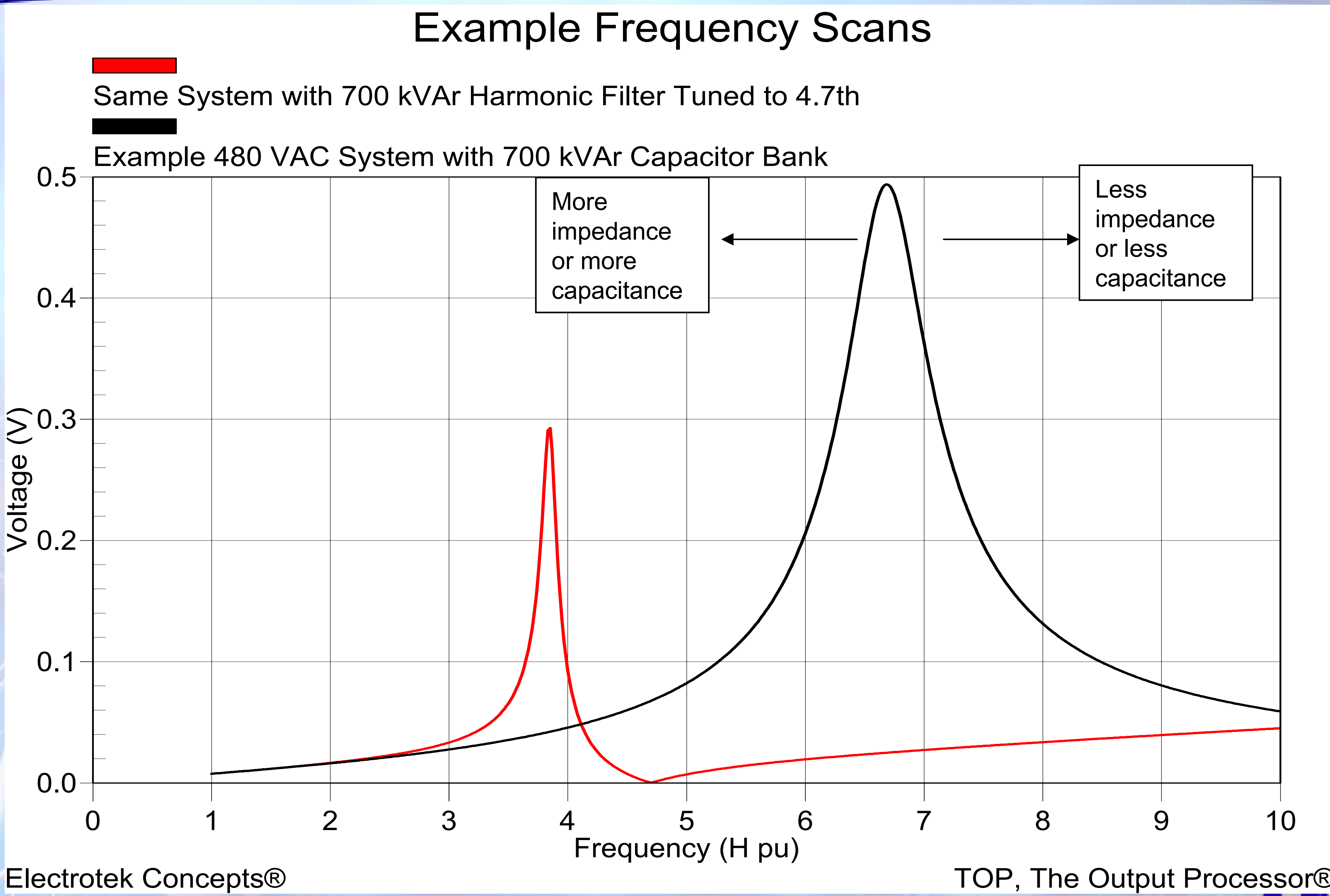
Harmonic and Power Factor Correction Capacitors

- Typical harmonic concerns focus on 3rd, 5th, 7th, 11th, 13th and so on
- Detuned capacitor banks or harmonic filters tuned near/below characteristic harmonic frequencies (e.g. 4.7, 4.2, or 4.08 when primary concern is 5th harmonic)
- Unless harmonic spectrum and duty specified, manufacturer may possibly assume a typical spectrum

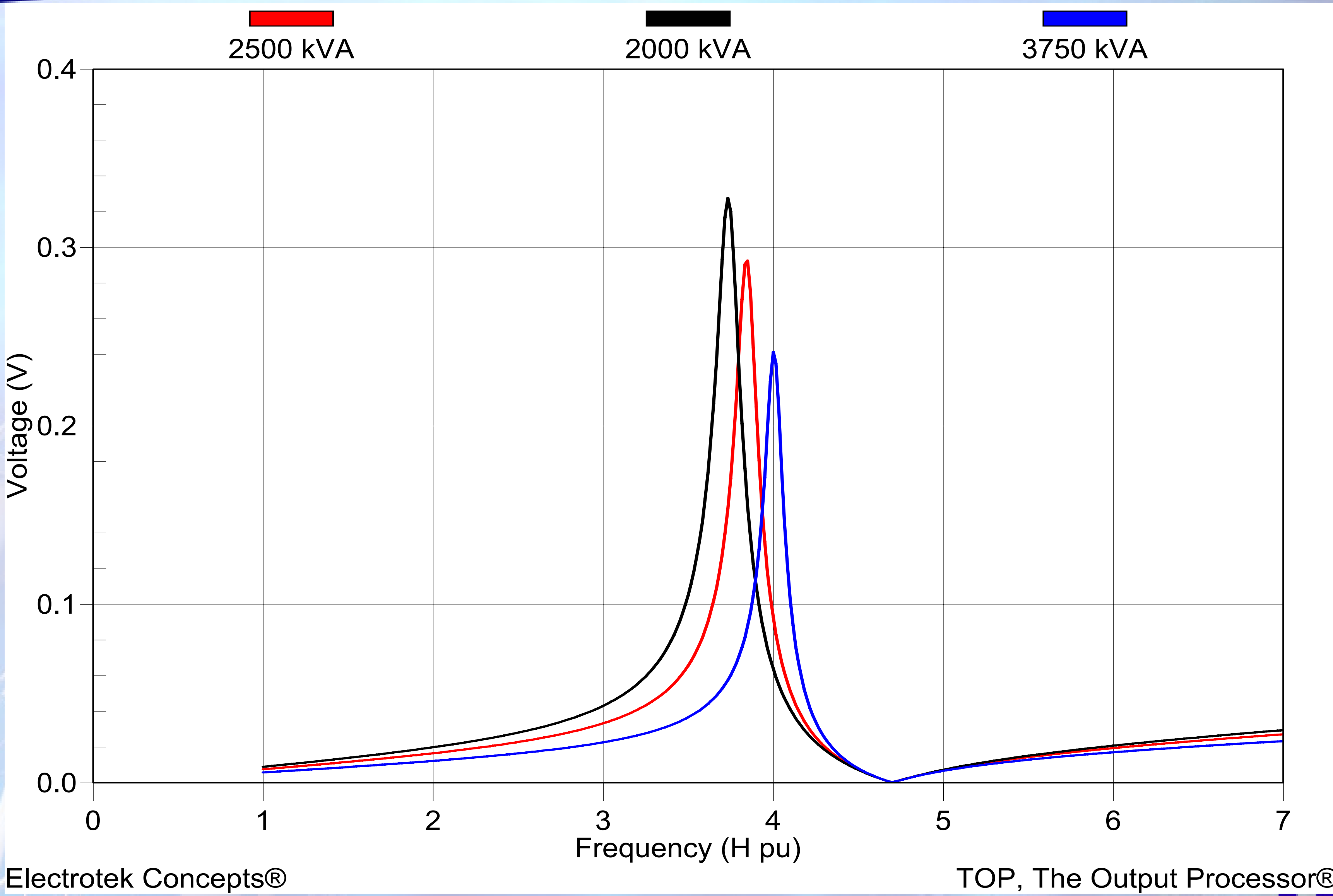
Parallel Resonance



Frequency scans to identify resonant frequencies



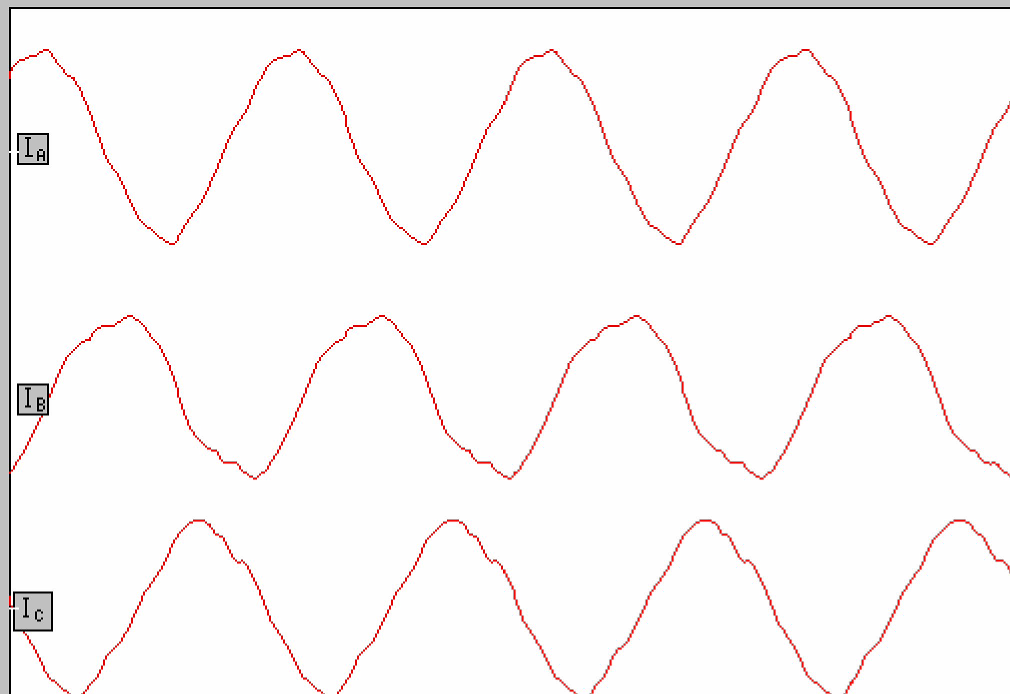
Effects of XFMR Size on Parallel Resonances For an Example 480 VAC System with 4.7th Series-Tuned Filter



Case #1 – 480 VAC System

277/480 VAC XFMR (41850)

Phase C Current Waveform. Jul 12 2006 14:00:02 (K=600)

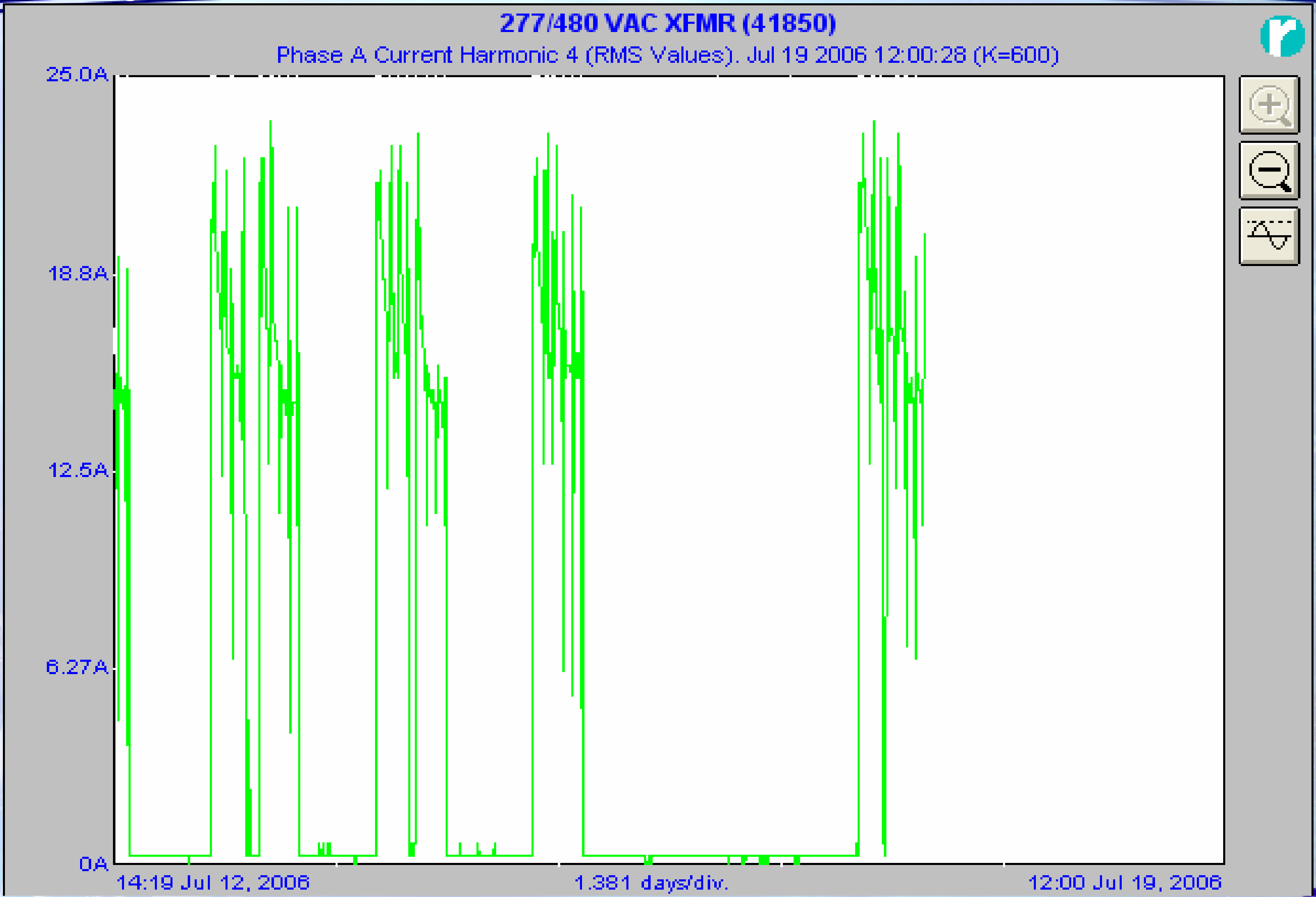


277/480 VAC XFMR (41850)

Phase A Current Harmonics. Jul 12 2006 14:00:02 (K=600)

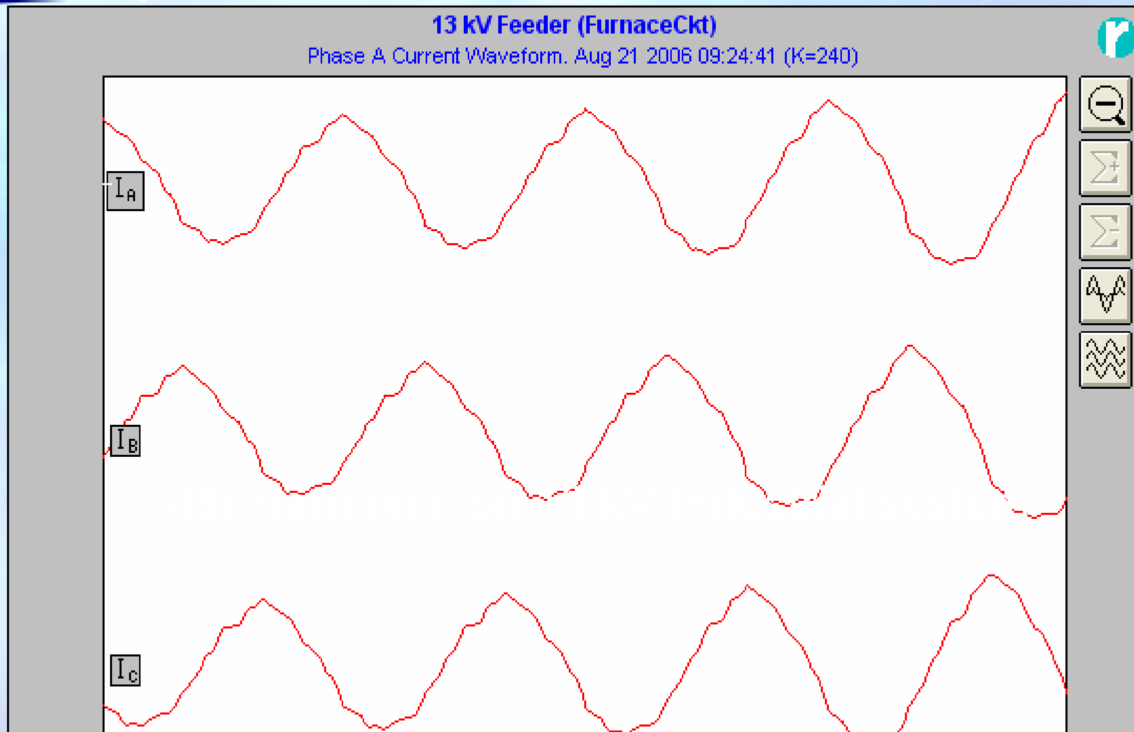
Harmonic	RMS Value	Phase	Percent
0	8.448A	180°	0.972%
1	869.0A	316.3°	100%
2	16.07A	117.7°	1.849%
3	12.87A	178.2°	1.481%
4	14.67A	319.5°	1.688%
5	9.101A	223.4°	1.047%
6	325.7mA	116.5°	0.037%
7	28.10A	332.4°	3.234%
8	3.481A	219.9°	0.400%
9	4.494A	263.7°	0.517%
10	1.823A	131.7°	0.209%
11	6.789A	80.94°	0.781%

Time profile of 4th harmonic on Case #1 480 VAC system



With fundamental 60 Hz load current ranging 1,200-1,500 amps

Case #2 - 4th Harmonic on 13 kV Industrial system snapshot



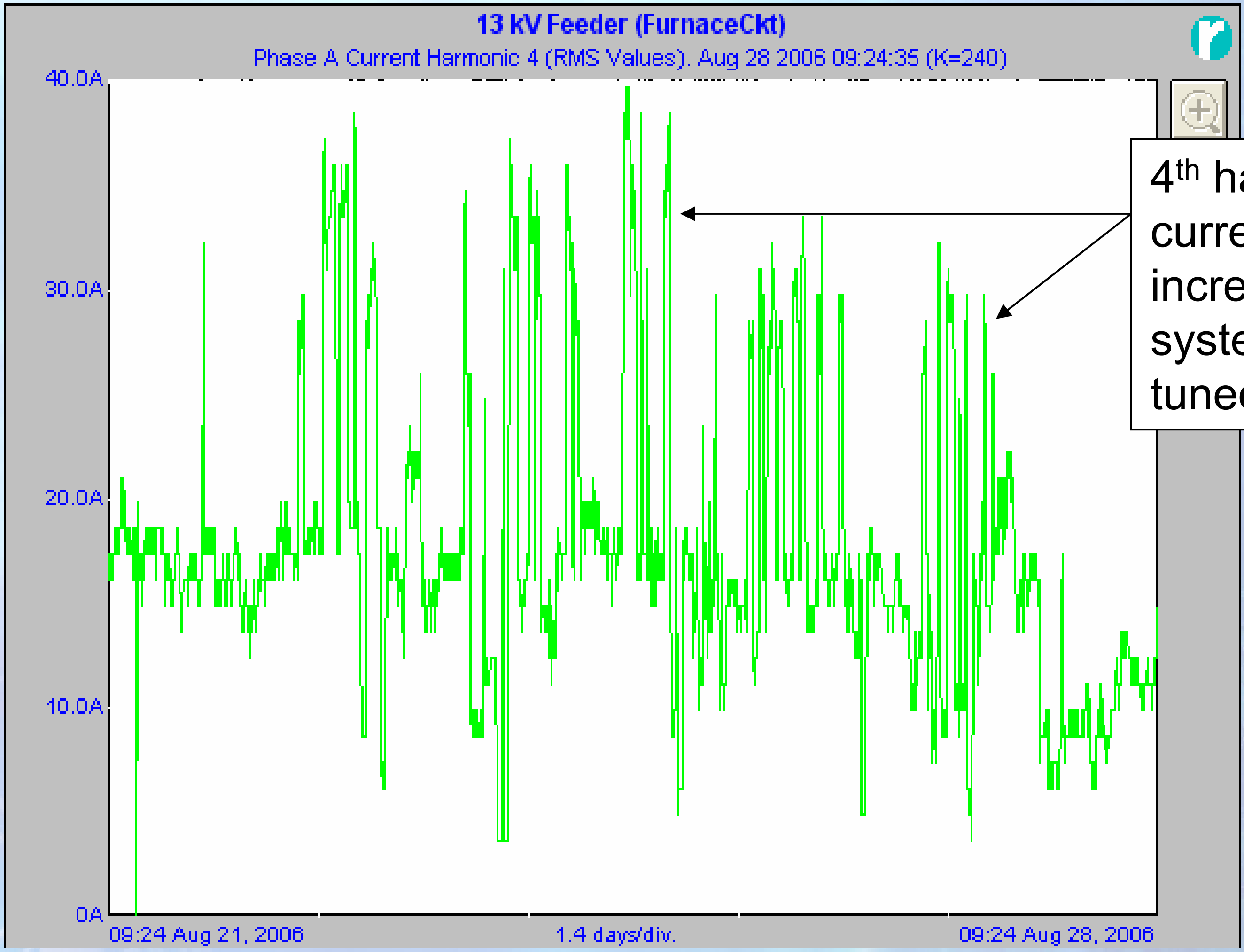
13 kV Feeder (FurnaceCkt)

Phase B Current Harmonics. Aug 21 2006 09:24:41 (K=240)

Harmonic	RMS Value	Phase	Percent
0	24.62A	180°	5.941%
1	414.4A	242.2°	100%
2	3.727A	33.52°	0.899%
3	2.527A	316.2°	0.609%
4	22.49A	228.9°	5.427%
5	6.252A	98.93°	1.508%
6	971.1mA	270°	0.234%
7	17.53A	307.5°	4.231%
8	746.2mA	231.3°	0.18%
9	640.7mA	255.9°	0.154%
10	556.1mA	335.2°	0.134%
11	12.30A	27.05°	2.969%

TVA

Case #2 - 4th Harmonic on 13 kV Industrial system time profile



4th harmonic current increases system parallel tuned to 4th

Recommendations

- Avoid applying capacitors and/or harmonic filters where non-characteristic harmonics appear if other transformer/service entrances are available for application and IEEE 519 limits are not an issue.
- If a harmonic filter or detuned capacitor bank has to be installed, make sure filter manufacturer is aware of harmonic spectrum.