Optimizing Mains Impedance: Real World Examples

PowerLines

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Power Quality Monitoring

❖ Voltage

- RMS Level, Sags, and Swells
- Voltage Harmonics, Voltage Transients
- Minimum PQ Metering

❖ Current

- Secondary Parameter
- Useful in Diagnosis and Resolution
- Has Become Standard Parameter

❖ Impedance

- Rarely Measured Directly
- Occasionally Assessed Indirectly

Impedance Impact on Power Quality

- Intermittent, Cycling, or Pulsing Load
- High Inrush Current to the Load
- High Power / High Current
- Load Current is Non-sinusoidal
  - Single-phase rectified load
  - Three-phase power converter with minimal input filtering.
  - High harmonic currents, often team up with high impedance to cause significant voltage problems.

Marketing and Selling Impedance

- Impedance is an Important Concept
- Not Well Understood
- Not Easily Packaged and Sold
  - Impedance optimized transformers
  - Premium price
  - Copper Development Association
- Power Conditioning is Sexier
  - TVSS / UPS / Voltage Regulators
  - Harmonics

Optimizing vs. Minimizing Impedance

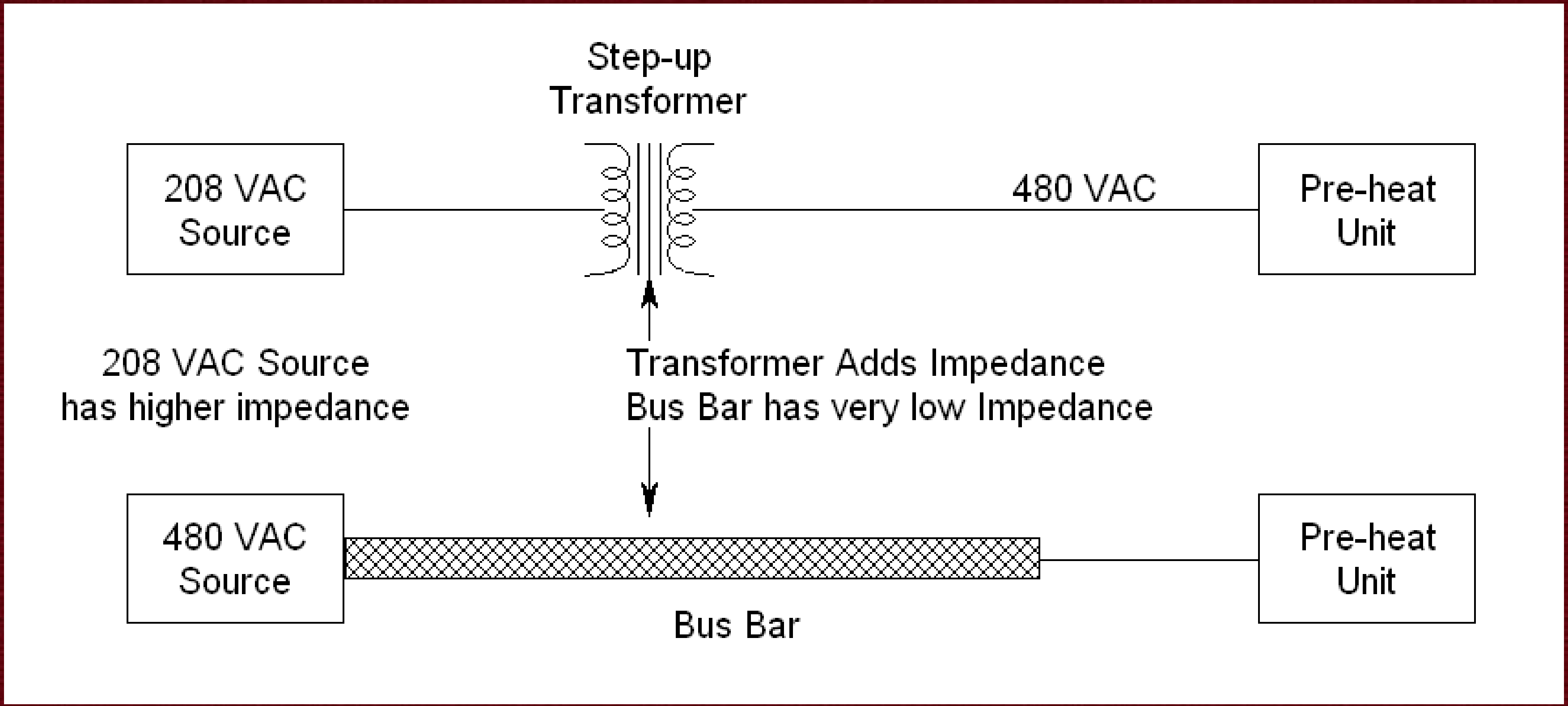
- **Minimizing**
  - Lower Impedance is Always Better
  - Majority of PQ Issues are related to excessive impedance
- **Optimizing**
  - Impedance can be too high, or too low
  - Occasionally, a low impedance issue occurs
- **Tools and Techniques are Similar**

- **Three "Real World" Low Impedance Issues . . .**

Low Impedance Case #1:
Wire Manufacturing Facility

- Inductive Pre-heating Unit
- 480 VAC, Single Phase Power
  - Originally, 208 VAC to 480 VAC via transformer
  - Moved to 480 VAC bus
- Cable “Slapping” at Switch-On
- Disconcerting to User
- Potentially Damaging to Cable / Conduit

Low Impedance Case #1:
Wire Manufacturing Facility



Solution:

Add Impedance to Limit Inrush Currents

Low Impedance Case #2:
Medical X-Ray System

❖ Tube Arcs

- Normal, end of life events for X-Ray Tube
- X-Ray Generator (power converter) should be designed to survive

❖ Low Impedance Source

- Power electronic device failures during tube arcs

Solution:

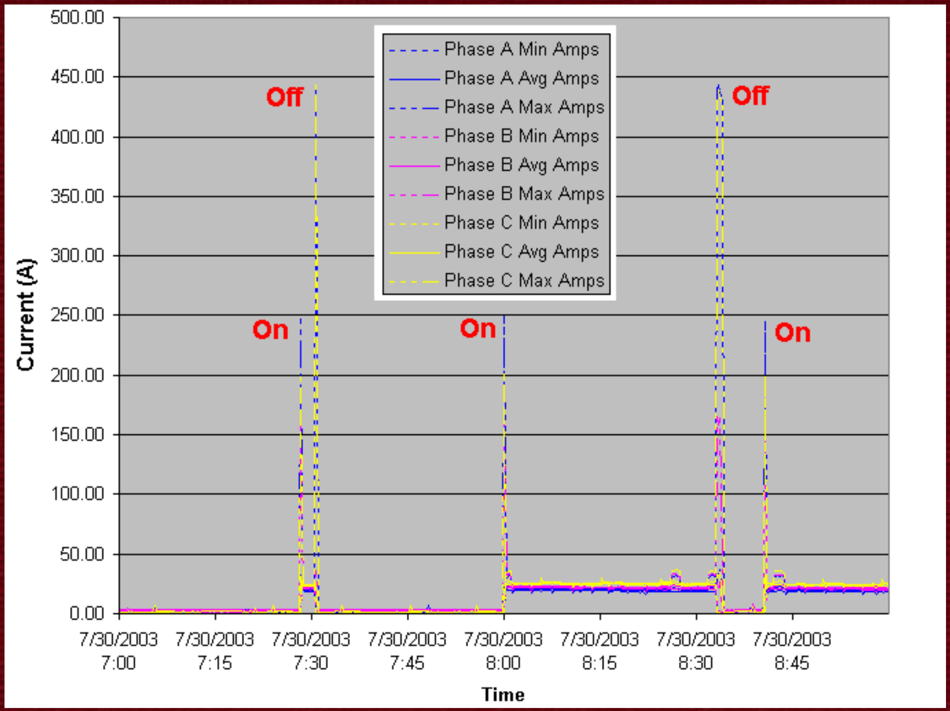
Adding Impedance via a Transformer to Limit Fault Current

Low Impedance Case #3: Press Brake / Metal Bender

- Industrial Facility
- Circuit Breaker Tripping During Operation (Cycle Off)
- On-Board Computer
  - Reboot
  - Loss of Data

Low Impedance Case #3: Press Brake / Metal Bender

- ❖ **High Current Swells**
  - **Switch-On**
  - **Switch-Off**
- ❖ **Low Impedance**



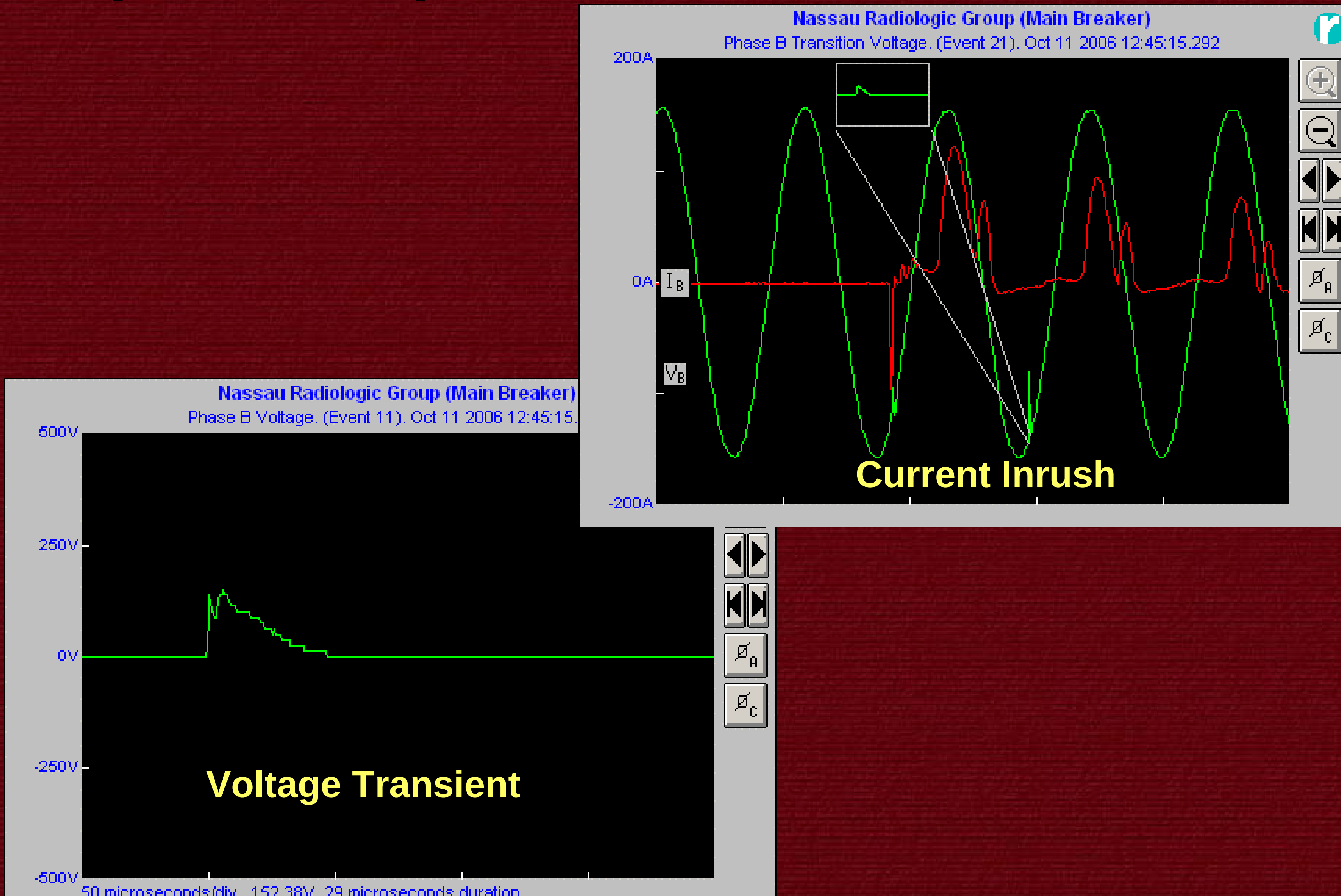
Solution:

Replace circuit breaker with higher magnetic trip

Power Quality Impact of Impedance

- ❖ **Load current swells or inrush**
  - **Transients**
  - **Sags**
- ❖ **Non-linear loads**
  - **Voltage harmonics**
- ❖ **Pulsing or intermittent loads**
  - **Sags, voltage drops**

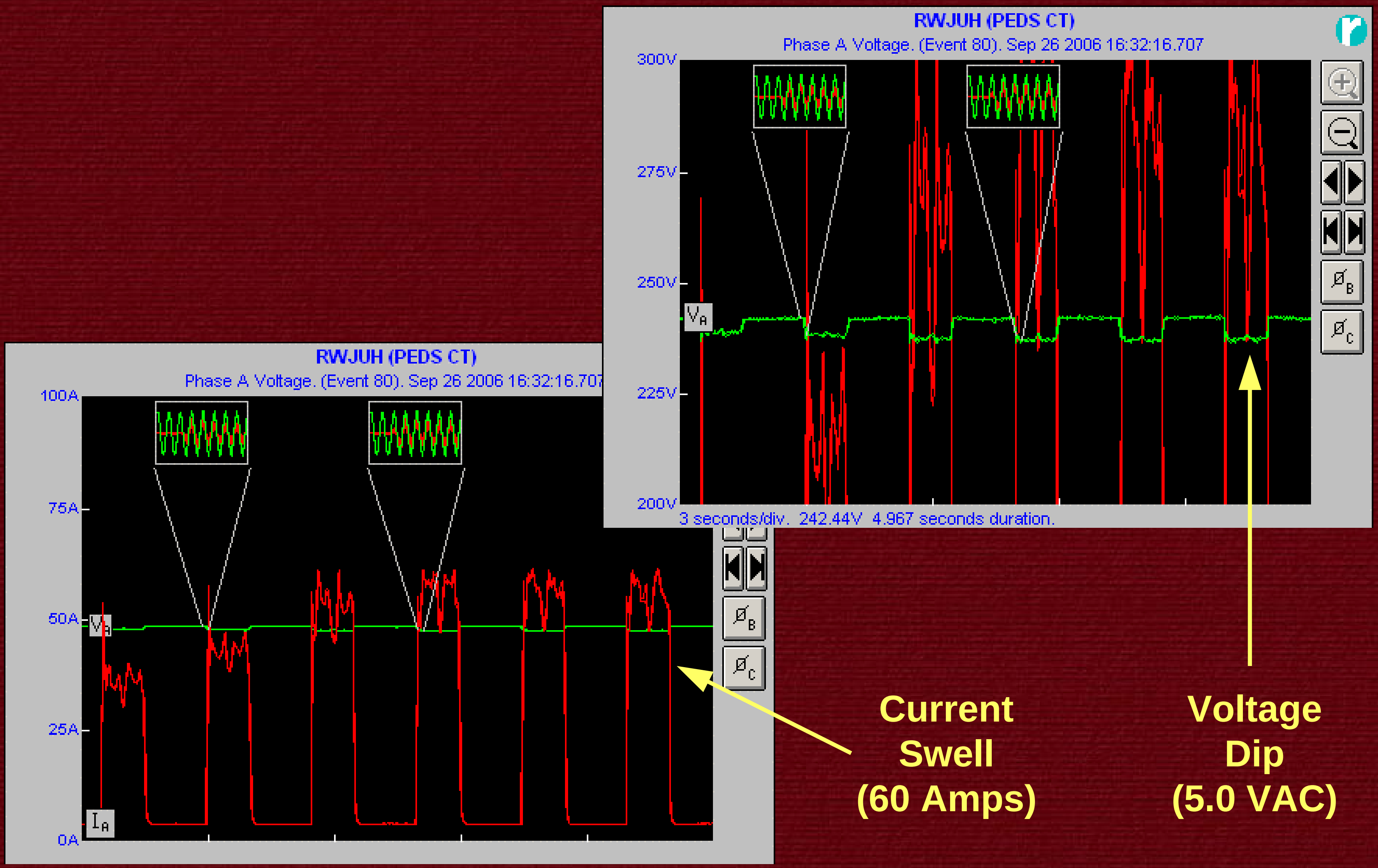
Impact of Impedance: Inrush Currents



Transients

- Generated by Rapid Changes in Current
  - V = L x di/dt
- Primarily Subtractive
- Higher Impedance = Higher Impulses
- *Load Generated Disturbances*

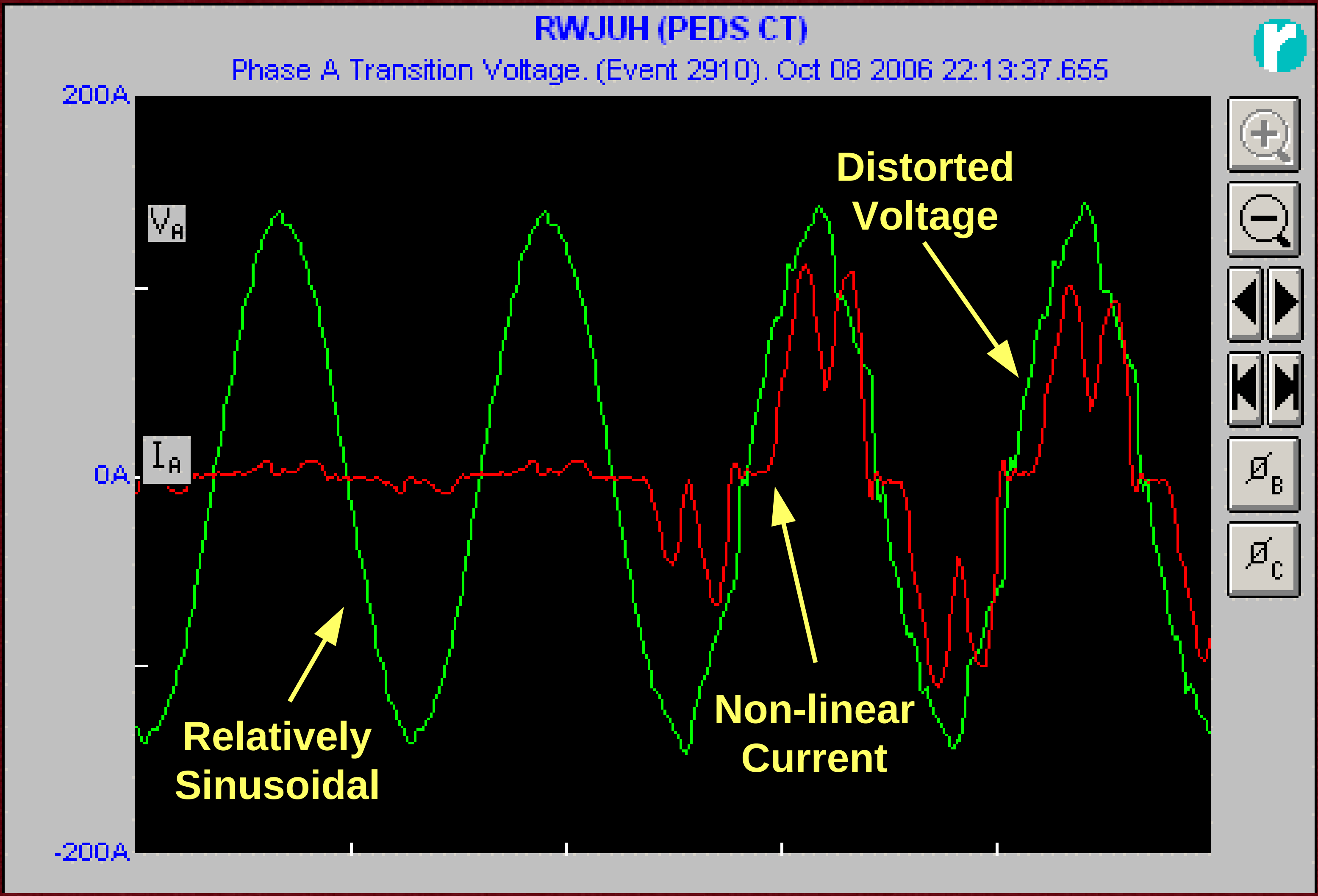
Impact of Impedance: Voltage Fluctuation



Current Swell (60 Amps)

Voltage Dip (5.0 VAC)

Impact of Impedance: Voltage Distortion



Optimizing Impedance: Nominal Voltage Level

- Select the best nominal voltage for the applied load
- Higher Load = Higher Voltage / Lower Current
  - 480 VAC or 400 VAC
- Lower Load = Lower Voltage / Higher Current
  - 220 VAC, 208 VAC, or 120 VAC

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RGB Display Sign

- 800 kW Demand
- 1.5 MVA Service
- Image Quality Problems (Stair-step artifact)
- 13.6 KV Feeder
- 208Y/120 VAC Secondary

- Load Generated Distortion (Phase Controlled SCR)
- Excessive Transformer Impedance
- Excessive Secondary Conductor Impedance (208 VAC Bus Bar)

Optimizing Impedance: System Type

❖ Single Phase vs. Three Phase

❖ Medical Imaging Systems (X-Ray)

- Typically 3 Phase Equipment
- 100 – 200 KVA
- 480 VAC / 3∅ = 100 Amp Circuit

❖ Single Phase Generator

- Small offices or clinics
- 240 VAC / 1∅ = 300 Amp Circuit

Optimizing Impedance: Conductor Size vs. Run Length

- **Consider impact of conductor size and run length on impedance**
  - Thermal Performance and Safety
  - Electrical code is bare minimum
- **Warning Signs**
  - Intermittent or pulsing load
  - High inrush current or current swell
  - Source derating permitted by codes

Optimizing Impedance: Conductor Size vs. Run Length

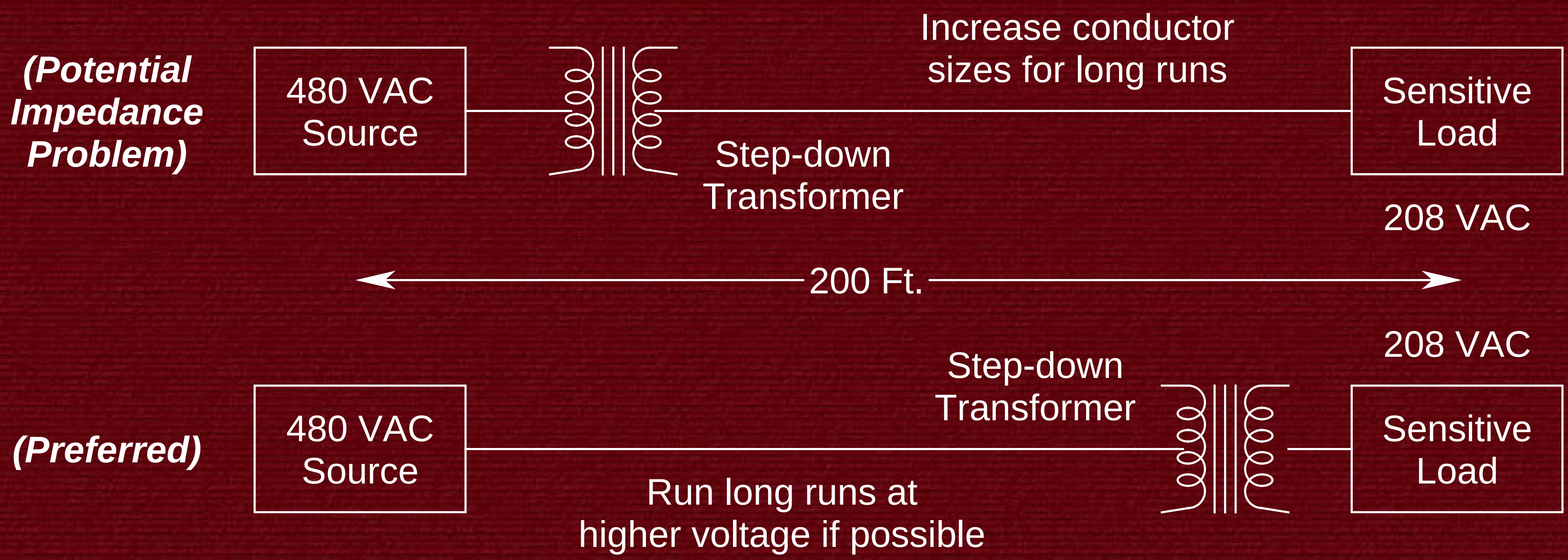
- Smaller Conductors = Higher Impedance
  - #12 - #2 AWG = Resistance is Dominant
  - #2/0 AWG and ⇧ = Inductance is Dominant
- Copper vs. Aluminum
  - Impedance of Copper is Lower for Same Size Conductor
- Operating Temperature
  - Higher Temperature = Increased Impedance
- Conductor Orientation
  - Tightly Coupled Lowers Inductance
- Conduit Material
  - Ferrous Conduit increases Inductance

Optimizing Impedance: Conductor Size vs. Run Length

- **Manufacturer Clues**
  - Impedance Specification
  - Conductor Size Chart (Size vs. Length)
  - Overcurrent Protection: Rating, Trip Characteristics, Time Delay
  - Separate or Dedicated Circuit
- **Real Life Situation #1**
  - Contractors “rough in” conduit, conductors, etc. based on breaker size
  - No consideration of impedance
- **Real Life Situation #2**
  - Location step-up or step-down transformers to minimize runs at lower voltages

Long Conductor Runs

- Consider impedance / voltage drop, not just thermal performance
- Increase conductor size to reduce impedance / voltage drop
- Long conductor runs at highest voltage possible



Impedance Impact of Isolation Transformers

- Typically the Highest Impedance Component / Element
- KW / KVA is usual sizing criteria
- Impedance is often ignored
- Impedance rises with temperature
  - Loading
  - Harmonics
- Materials and winding techniques are critical to impedance characteristics
- Off-the-Shelf: 4 - 7% Impedance is typical

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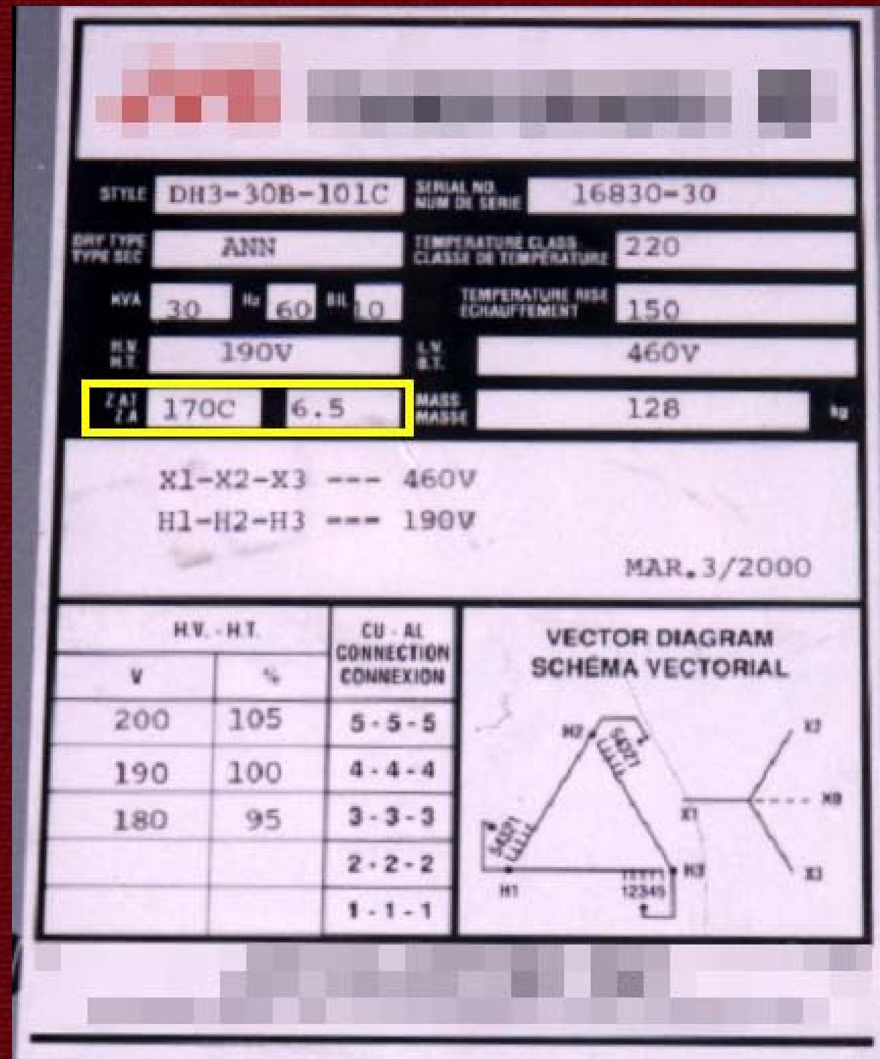
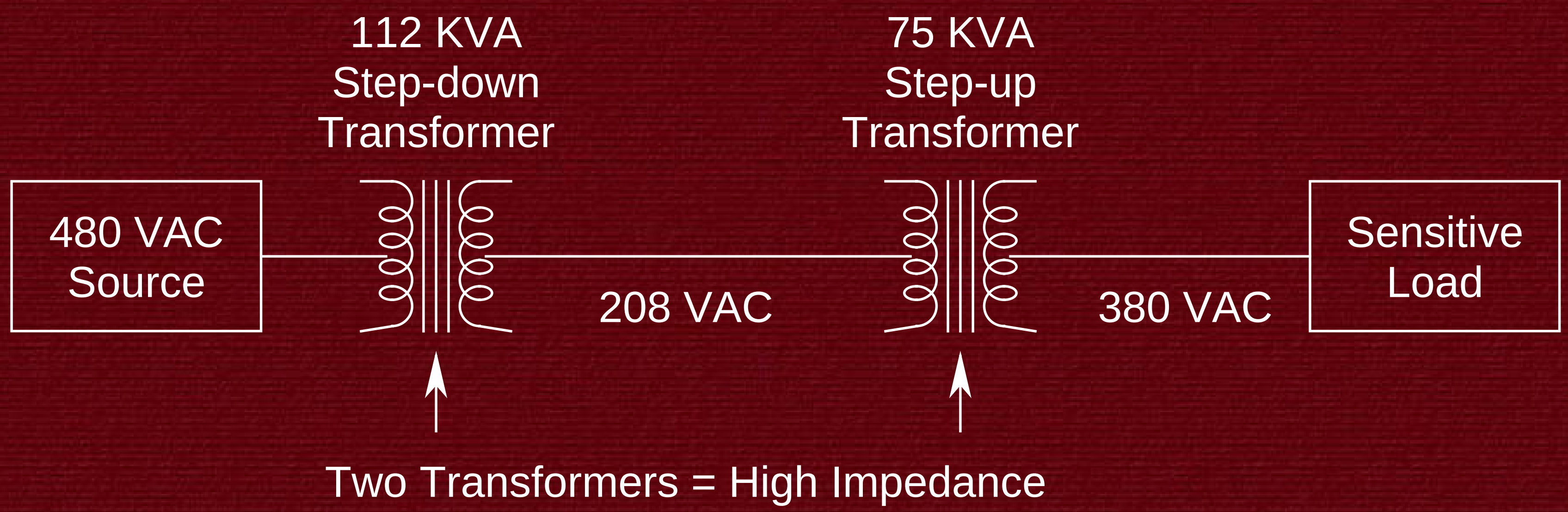
Transformer Nameplate

- **Impedance is Specified at Maximum Temperature (6.5% @ 170°C)**
- **Real-world Impedance is usually much less (~50%)**
- **Premium Transformers have lower impedance**
  - **50 / 60 Hz**
  - **Higher Frequencies**
  - **Materials**
  - **Winding and Construction Techniques**



Optimizing Impedance at Isolation Transformers



Never combine or daisy chain similarly sizes isolation transformers

Consider worst case loading (maximum load, inrush currents) when sizing transformers

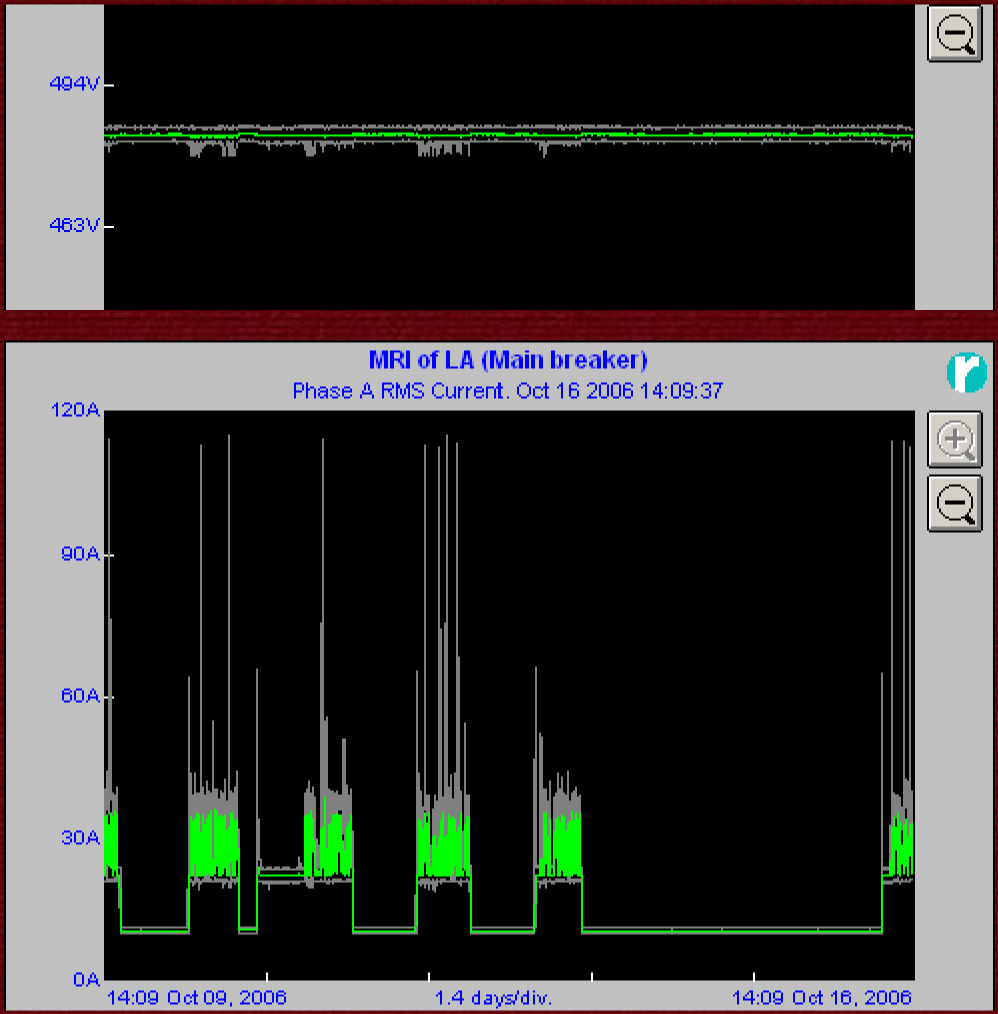
Include impedance in your transformer selection criteria

Derate transformers or consider premium transformer designs

Impedance Impact of Power Conditioners

- Power Conditioners Can be a “Wild Card”
- Double Conversion Systems
  - Create or Synthesize output voltage
  - Output impedance independent of input
- Transformer or Autotransformer Based Regulators
  - Can correct RMS voltage (within some response time)
  - Little impact on transients, distortion, sub-cycle issues
  - Often add impedance (transformer)
- Compatability with the load is critical

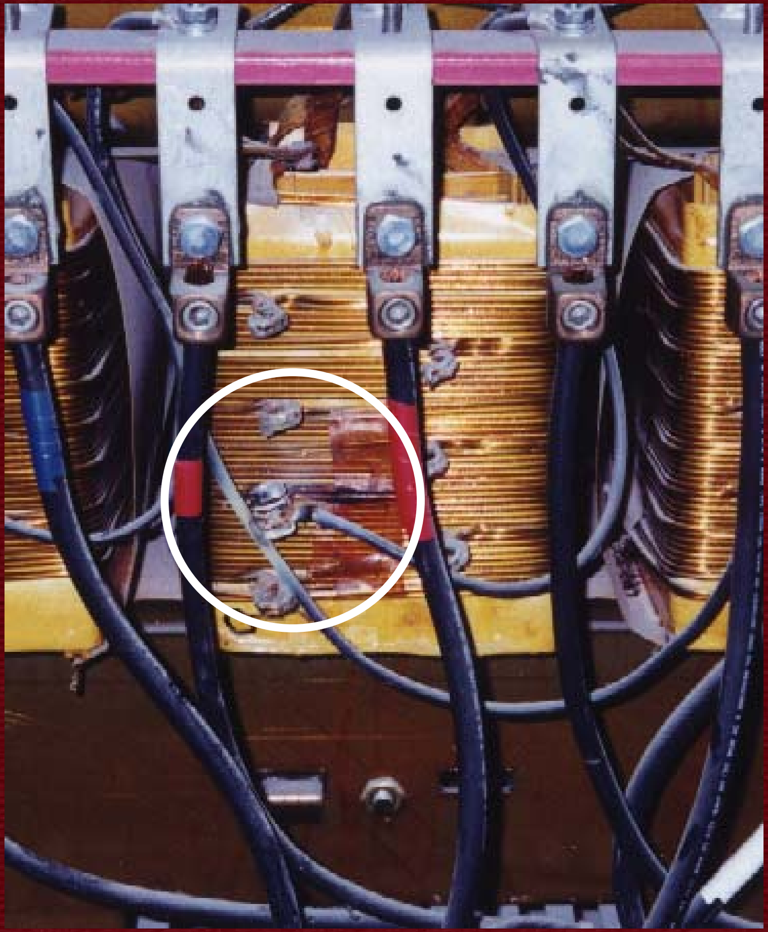
Impedance Impact of Power Conditioners



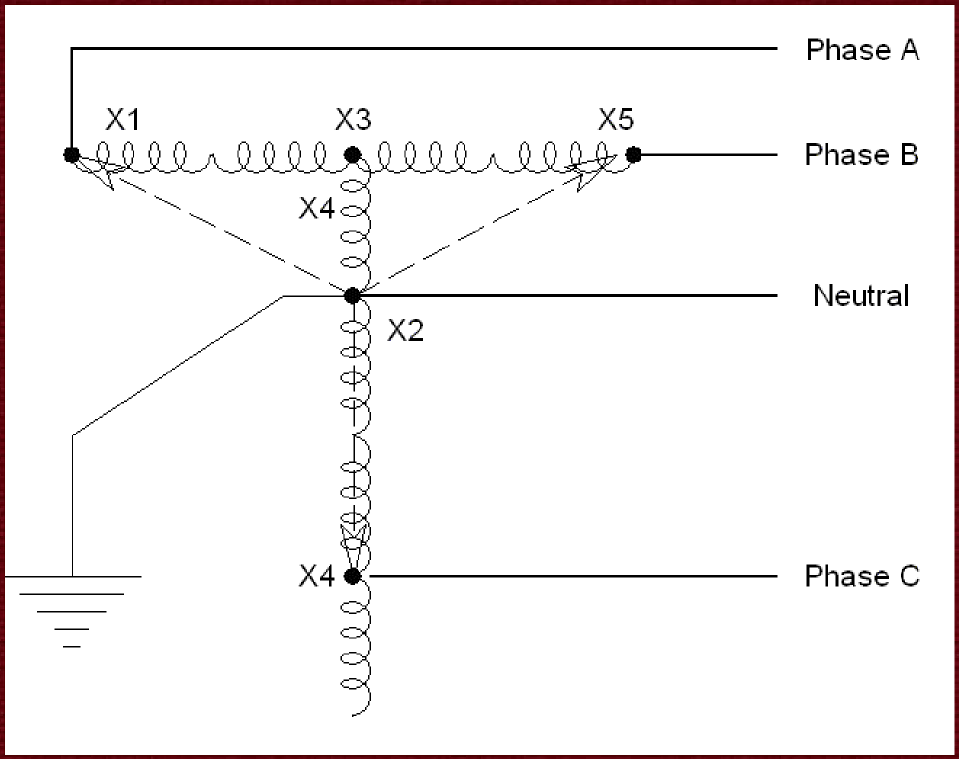
Unbalanced Impedance

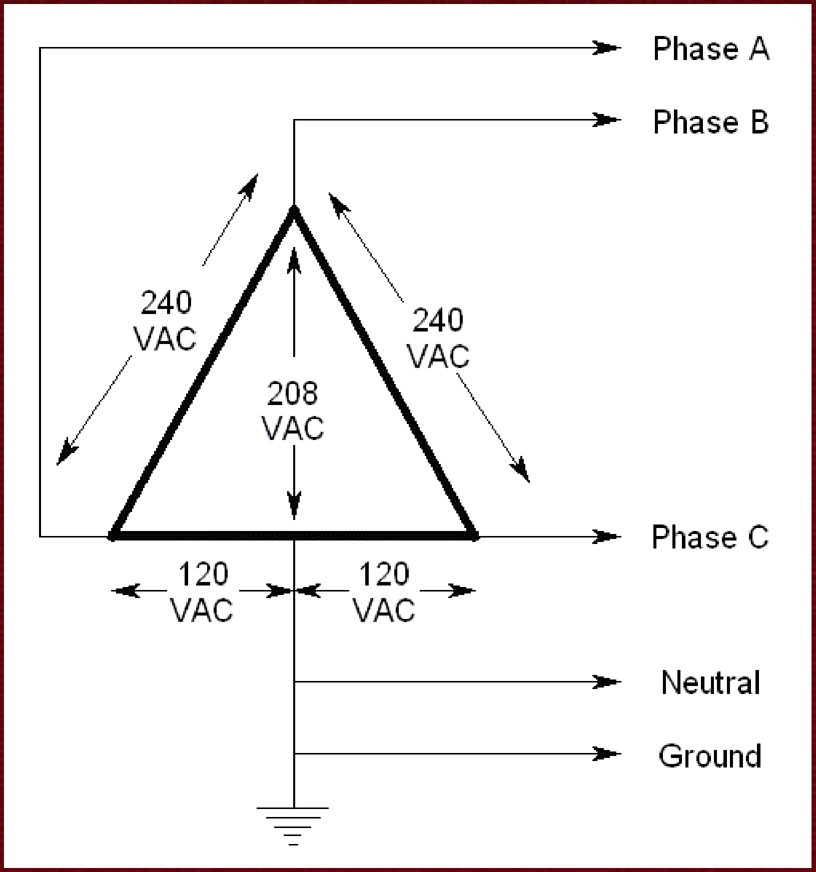
- ❖ Impedance Is Typically Balanced Across Phases
- ❖ Unbalanced Impedance = Problem
- ❖ Loose or corroded connections
  - Internal or external to devices
- ❖ Atypical or non-standard source
  - Open Delta
  - Scott-Tee
  - 240/120 Three phase with center tapped neutral

Transformer Tap



Unbalanced Source



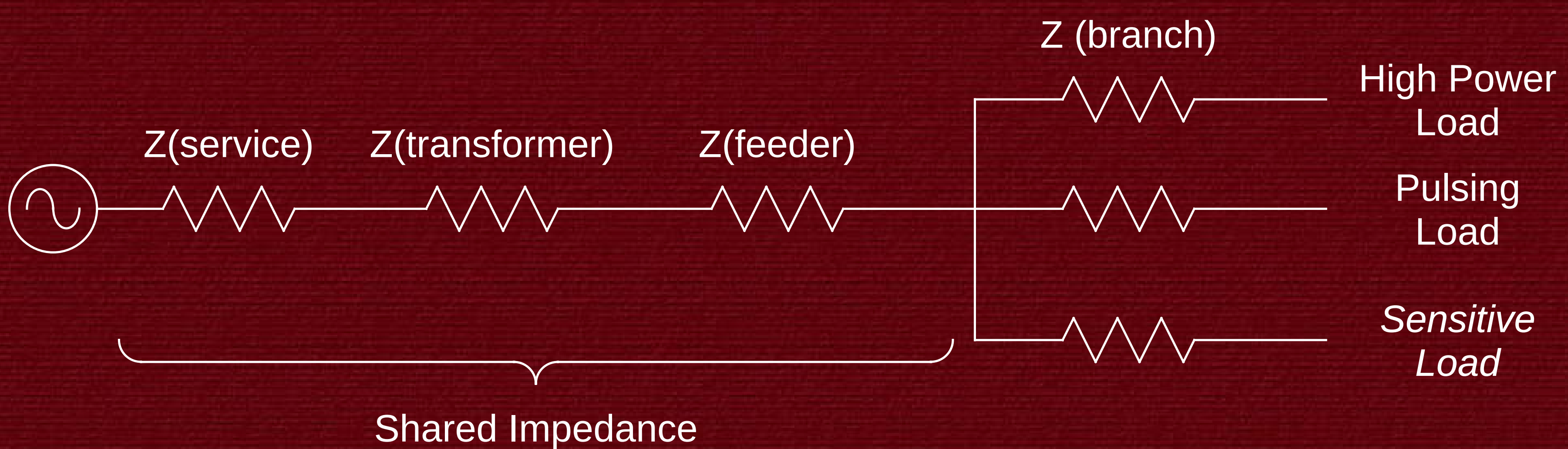


A Scott Tee transformer connection, used to connect a three-phase load to a two-phase source.

A 240 VAC Delta transformer connection, with one phase center tapped to feed 240/120 VAC single-phase loads.

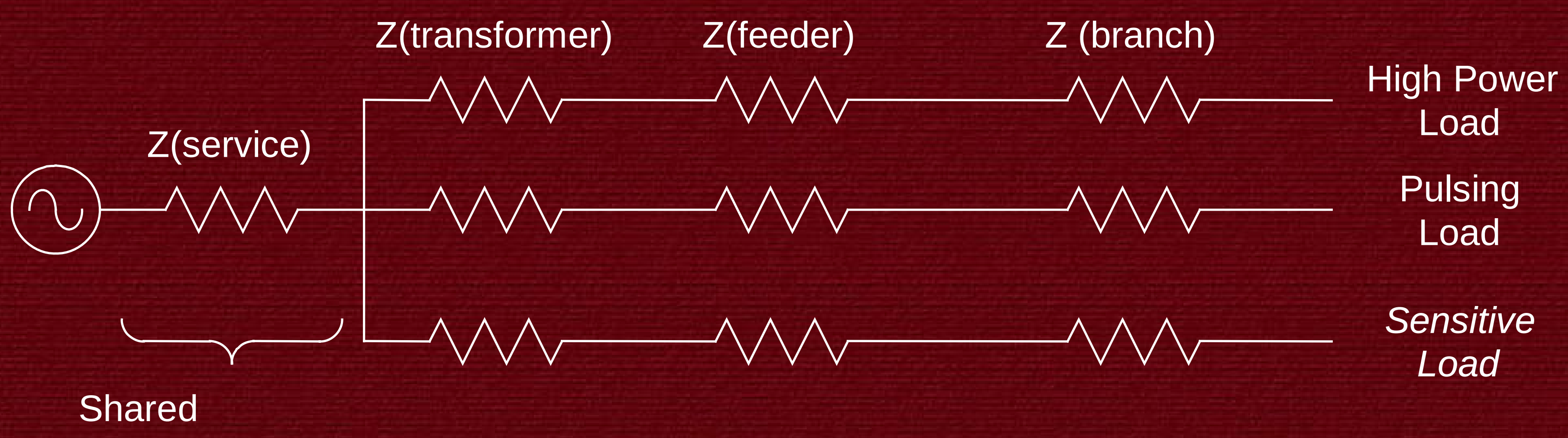
Dedicated Lines

- Often used to optimize power quality
- "Minimize shared impedance"



Dedicated Lines

- ❖ Often used to optimize power quality
- ❖ “Minimize shared impedance”



Dedicated Lines can Increase Impedance

Example #1

- 200 Feet x 200 Amp feeder to a distribution panel
- 50 Feet x 30 Amp circuit to load

Pro:

- Lower impedance

Con:

- Shared impedance
- Electrical proximity to other loads

Example #2

- 250 Feet x 30 Amp circuit to load

Pro:

- No shared impedance
- Isolation from other loads

Con:

- Higher impedance unless oversized

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Power Quality 2006 Conference

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