Power and Grounding For Audio and Video Systems Part 1

Jim Brown

Andy Benton

Course Outline

- The Jargon
- Audio/Video System Power Requirements
- Power System Architectures
- Neutral Currents
- Grounding for Safety
  - Earth Connections
  - Equipment Bonding

Course Outline

- Audio/Video Signal Wiring
  - Balanced Wiring
  - Unbalanced Wiring
- Voltage on "Ground"
  - Leakage Currents
- Noise Coupling
  - IR Drop on Shields
  - Pin 1 Problems
  - Magnetic Coupling
  - Capacitive Coupling

Course Outline

- Technical Ground Systems
  - Must Conform to Safety Requirements
  - Minimize Noise
  - Prevent Shield Current
- Shielding and Grounding are Different
- Conduit
  - Protects wiring
  - Shielding
  - Spacing

Course Outline

- Power Quality
  - Regulation
  - Surge Protection
  - Interruptions (Blackouts and “Brownouts”)
  - Power Factor
  - Harmonics
  - Noise
  - Power “Conditioning”

Course Outline

- Power Quality
  - Line Filters
  - Uninterruptible Power Supplies
  - Surge Suppression
- Ground Fault Interrupters
- Grounding for Antennas

Course Outline

- Troubleshooting Tools
  - Outlet Testers
  - Current Probes
  - Magnetic Field Probes
  - Volt-Ohm Meters
  - Scope, Spectrum Analyzer
  - Radio Receiver
- Recommended Reading

Course Outline

- Snake Oil (and Other Bad Medicine)
  - Balanced Power
  - Power Conditioners
  - Special Power Cables
  - Exotic Cables
  - Ground Isolators
  - AC Power Ground Lifts
  - Isolation Transformers

The Jargon

- ***Authority Having Jurisdiction (AHJ)*** **– The local government agency having legal authority for establishing building codes and verifying compliance.**
- ***National Electric Code (NEC)*** **– A model electrical code of good practice developed by a consortium of electrical engineers, intended to be adopted by local Authorities Having Jurisdiction.**

The Jargon

- *Service, service entrance* – the connection of a building or other facility to the power company's wiring
- *Separately derived source* – a separate power source that is not directly connected to the power company's transformer – for example, the secondary of a transformer or the output of a generator

The Jargon

- *Means of disconnection* – Circuit breaker or fuse
- *Branch circuit* – All wiring between the last *means of disconnection* and the load (outlets)
- *Feeders* – All wiring between the service and the last means of disconnection – in other words, the wiring between the service and various breaker panels

The Jargon

- *Panel* – An electrical enclosure
- *Panelboard* – an electrical enclosure with circuit breakers

The Jargon

- *Equipment* – Materials, fittings, fixtures, appliances, raceway, conduit, apparatus
- *Load Equipment* – Equipment that draws power from the electrical system

The Jargon

- *Grounding Electrode* – The conductor that makes contact with the earth
- *Solidly grounded* – The neutral and earth ground electrodes are directly connected with no impedance intentionally placed between them. Thus, the word solid implies a d.c. connection – i.e., nothing more than a straight wire.

The Jargon

- *Bonding* – The permanent joining of metallic parts to form an electrically conductive path that will insure continuity and the capacity to carry any current likely to be imposed. This definition implies a connection having very high reliability and very low impedance, and that is physically robust. (BIG, SHORT, RUGGED)

The Jargon

- *Bonding jumper* – A reliable conductor used to ensure the the required electrical conductivity between metallic parts that are required to be connected
- *Main bonding jumper* – The connection between the grounded circuit (neutral) and equipment grounding bus at the service

The Jargon

- ***Phase conductor* – the *ungrounded* (hot) power conductor**
- ***Neutral* – the *grounded* conductor that carries load current (the white wire)**

The Jargon

- ***Safety Agency*** **– An independent testing body, not affiliated with government, whose business is to test the <u>safety</u> of equipment, fittings, and hardware in their intended use. The focus of these agencies is the protection of life and property. They are not concerned with the effectiveness of equipment, except to the extent that it relates to safety.**

The Jargon

- Safety agencies test primarily to make sure that a product
  - will not start a fire
  - will not contribute to flame spread
  - will not create noxious fumes if it burns
  - will not create a shock hazard

The Jargon

- ***Listed* – Equipment, fittings, and hardware recognized by the Authority Having Jurisdiction as acceptable for use in electrical systems. Most AHJ's in North America require that all elements of electrical systems (including most audio and video systems) be listed, and delegate responsibility for listing and testing to Underwriters Laboratory (UL), Canadian Safety Agency (CSA), and Electronic Testing Laboratory (ETL).**

Equipment Power Requirements

- **How Much Power Do We Need?**

Equipment Power Requirements

- Small Signal Equipment
  - Mixers, Signal Processing, Switching, etc.
  - Low Power (2-200 watts/box typical)
  - Constant Current (after turn-on)
  - 120 volts, single phase
  - One 20A circuit can often run a 6 ft rack
    - Always ask for 20A circuits – the cost is 95% labor!
  - All of the power heats the rack (and the room)

Equipment Power Requirements

- Large Signal Equipment
  - Power Amps, Video Display, Big Mixers
  - High Power (100 – 4,000 watts)
  - Constant Current (Idle Current)
  - Variable Current (with loudness, brightness)
  - 240VAC for <u>very</u> large amps and projectors
  - Can require one circuit / chassis
    - Always ask for 20A circuits – the cost is 95% labor!
  - Most of the power heats the rack (and room)

Equipment Power Requirements

- Small Signal Equipment
  - Add up the nameplate power or current
  - Current equals (Power) / 120V
- Video Displays, Mix Desks
  - Add up the nameplate power or current

Equipment Power Requirements

- Power Amplifiers
  - Power (and current) varies with audio power
  - (But <u>much</u> less than you think)
- Audio Power
  - Audio is dynamic
  - Average power typically 1/1000 of rated
  - 1/5 of rated when it's LOUD

Equipment Power Requirements

- Audio Power
  - Audio is dynamic
  - Average power typically 1/500 of rated
  - 1/5 of rated when it's LOUD
- How much AC Power?
  - Idle power 20-50W/ch typical
  - 2X-4X idle power for typical program
  - Rated audio power when it's LOUD

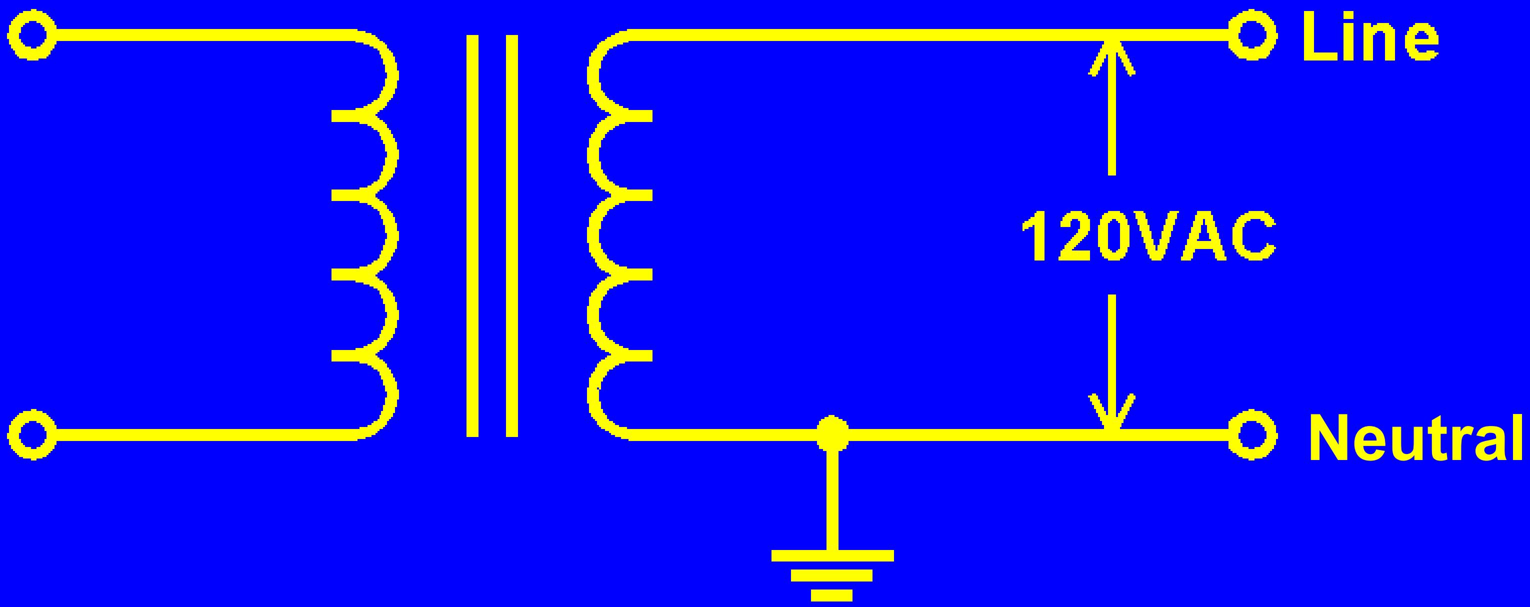
Flavors of Mains Power

- **Mains Power Frequency**
  - **60 Hz in North America**
  - **50 or 60 Hz in Europe**
- **One conductor is grounded for lightning protection**
  - **The "*grounded conductor*" (North America)**
  - **The "*neutral*" (Europe and North America)**
  - **<u>Details</u> of the earth connection vary from one country to another**

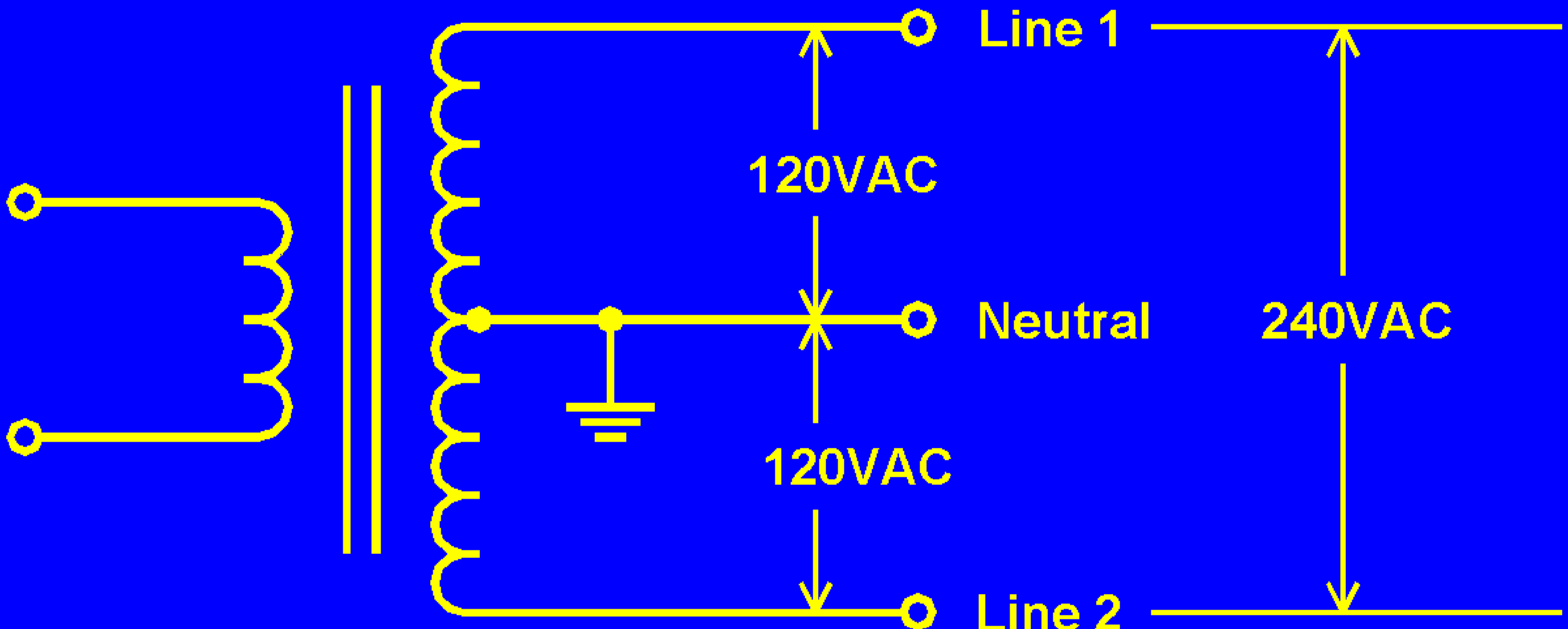
Flavors of Mains Power

- Single Phase
  - 120V in North America
  - 220V/240V in Europe
- Center-Tapped Single Phase
  - 120V-0-120V in North America
  - 240-0-240V in Europe
- Three Phase
  - 120/208 V in North America
  - 240/415V or 230/400 V in Europe

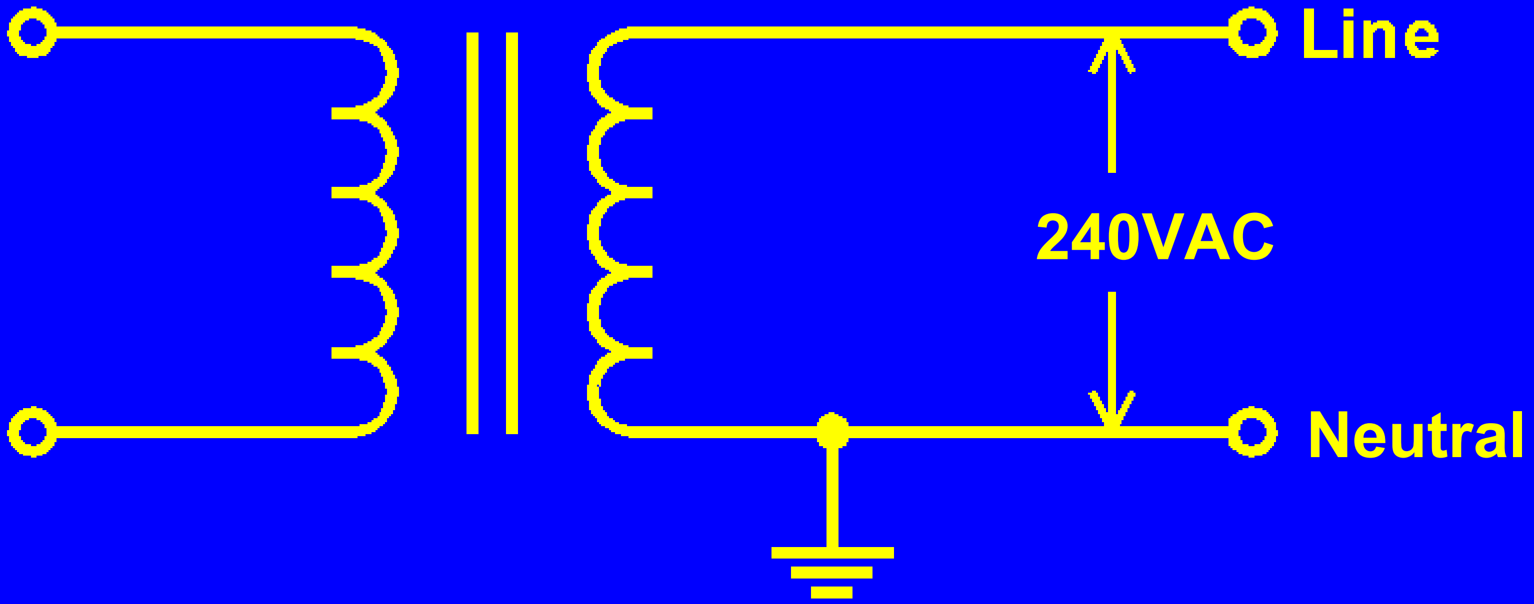
Single Phase Power (North America)



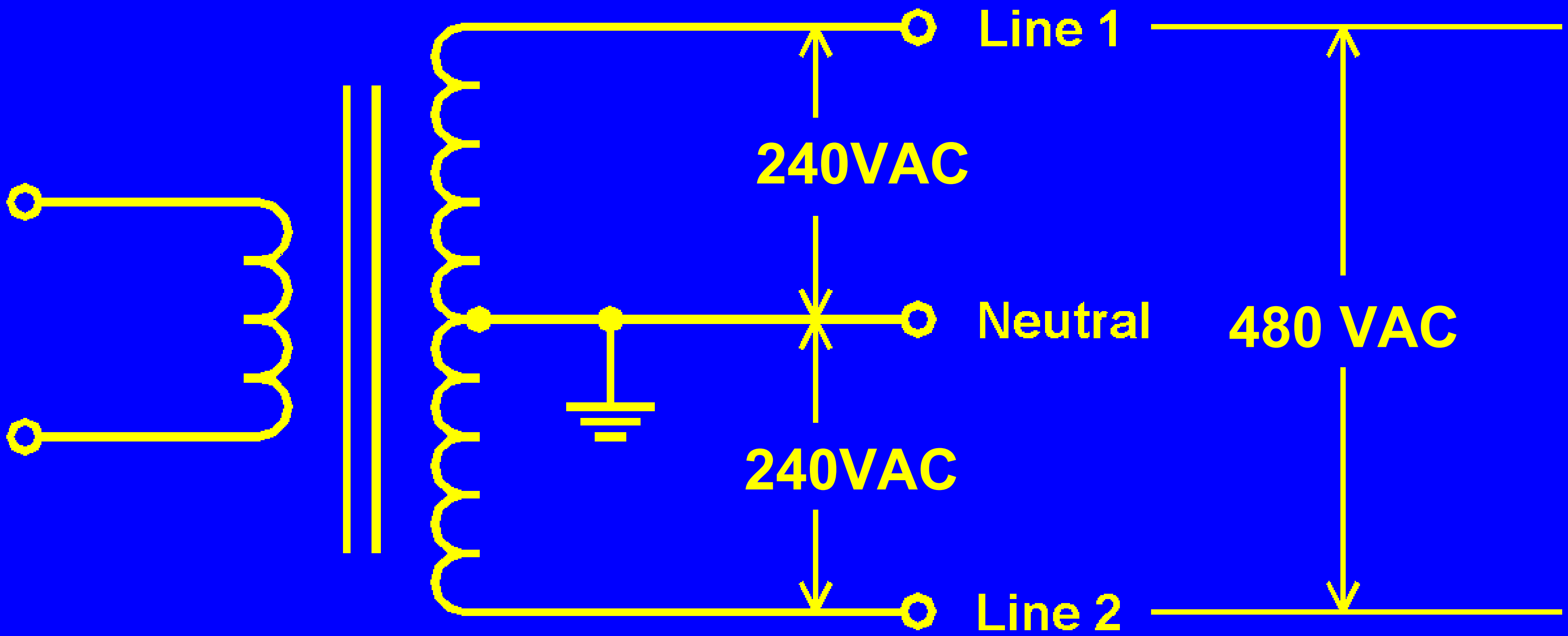
Single Phase Power (North America)



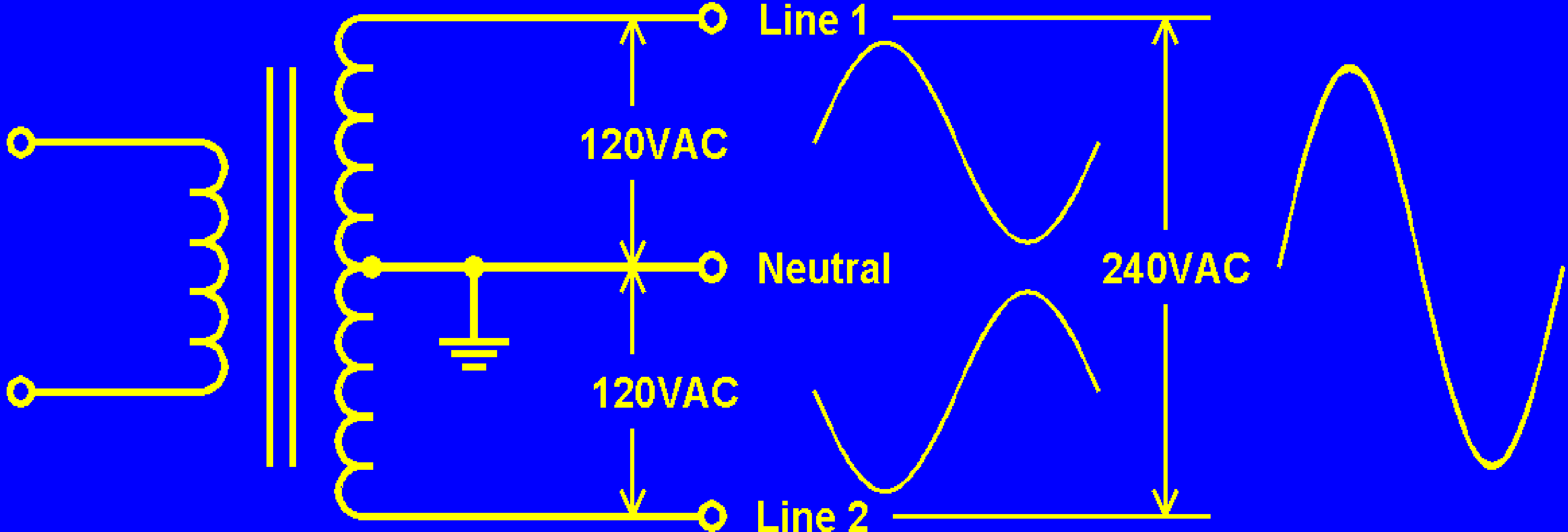
Single Phase Power (Europe)



Single Phase Power (Europe)

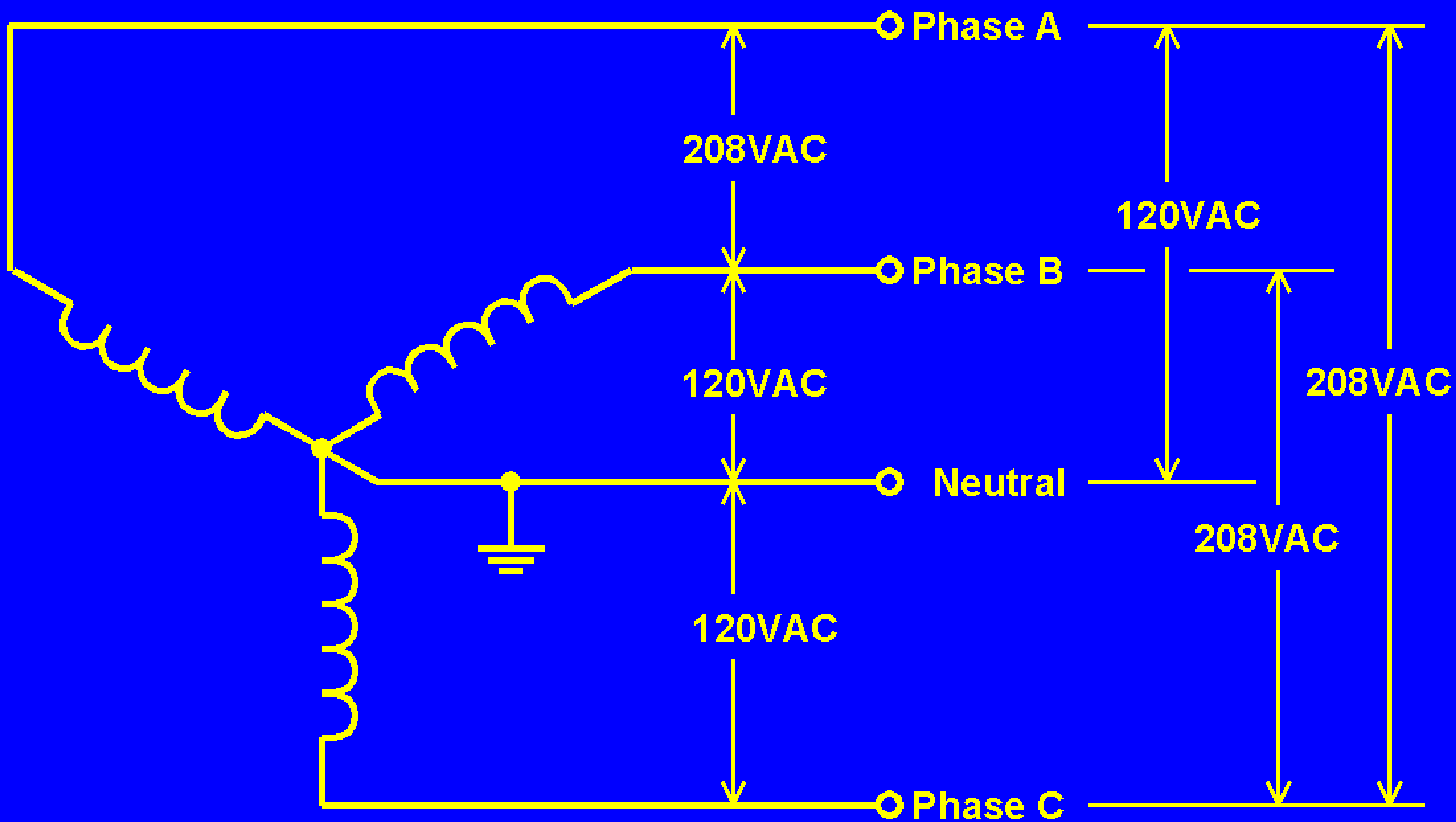


Single Phase Power Waveforms

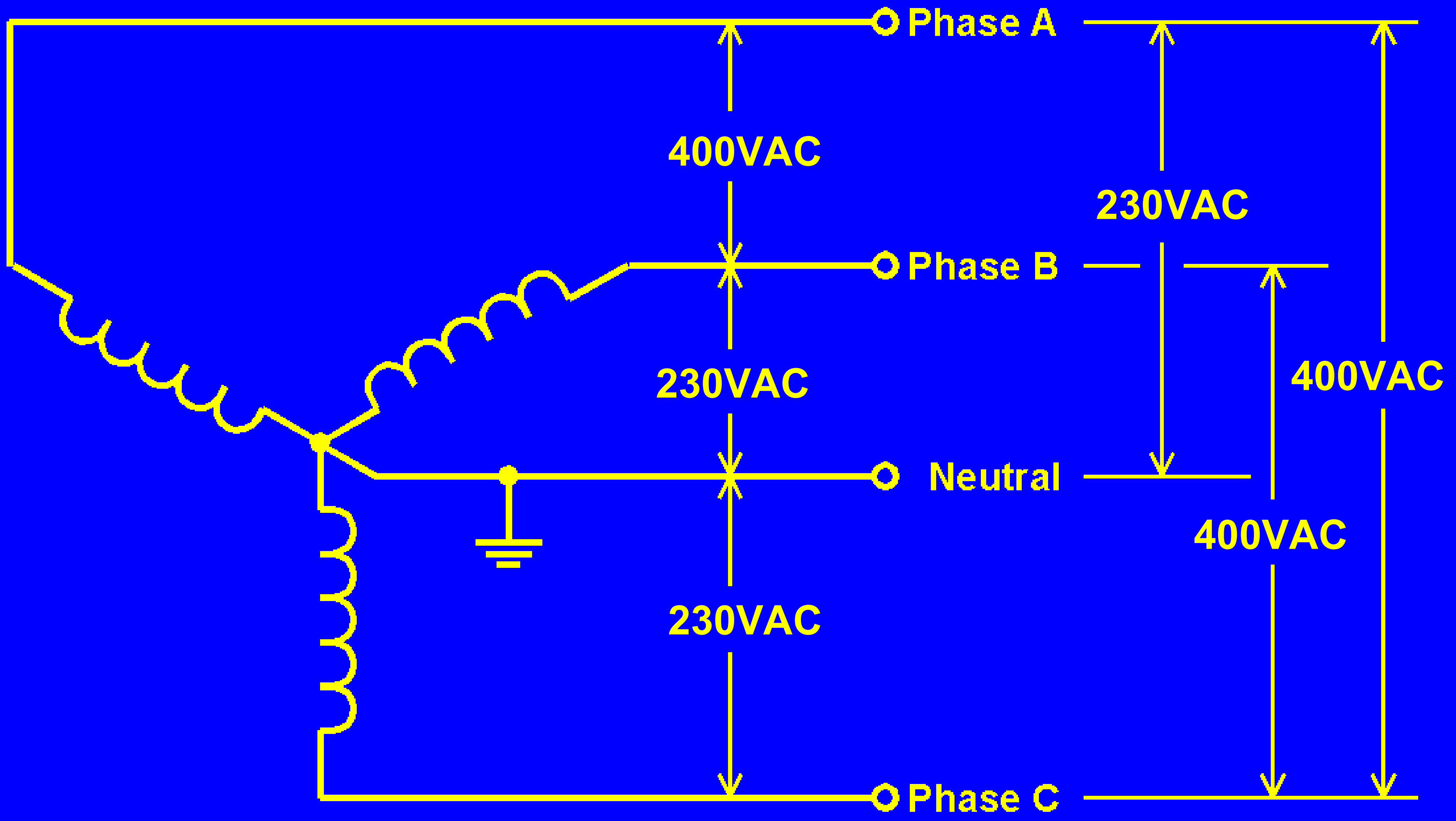


If Currents on Line 1 and Line 2 are equal, neutral current is zero

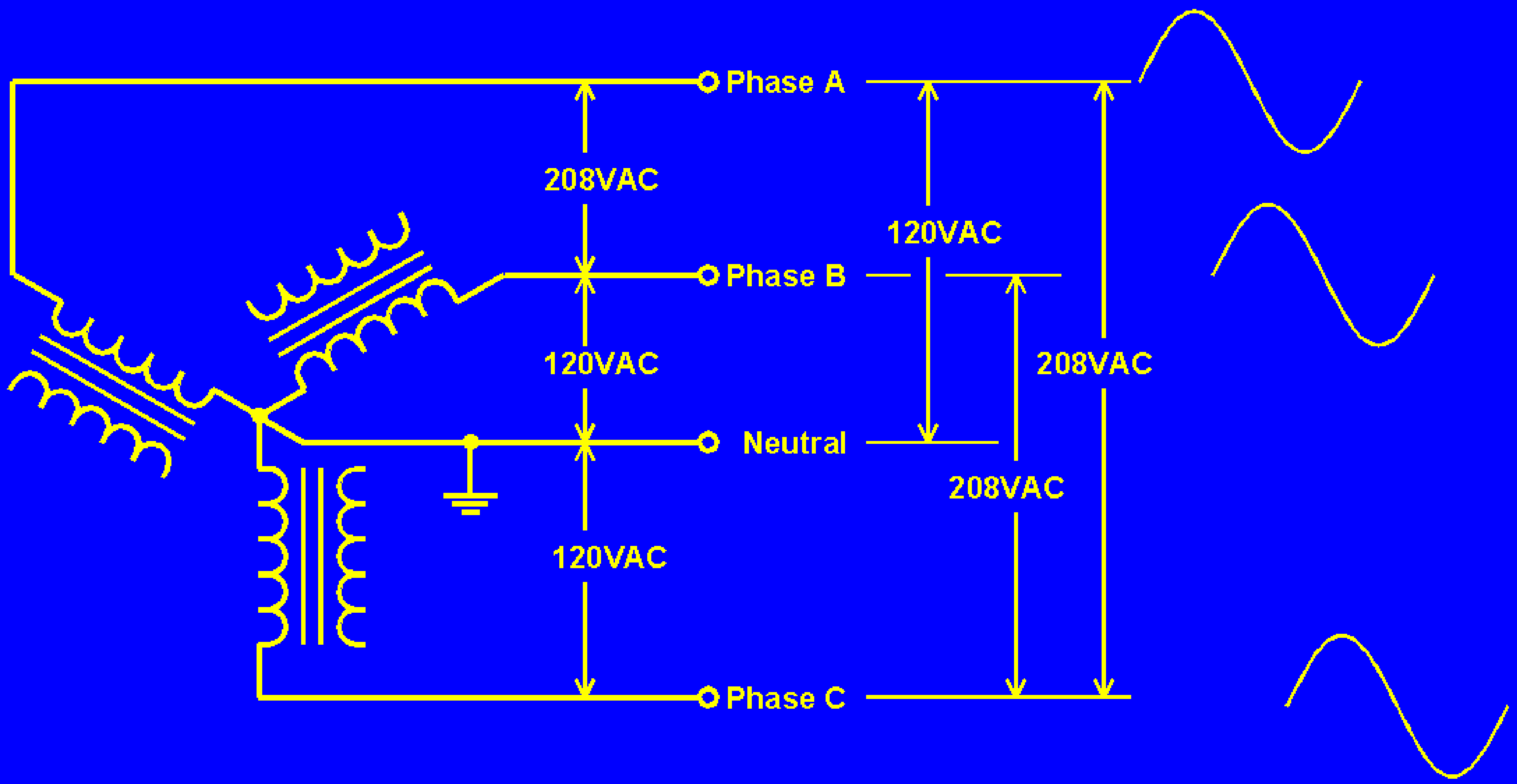
Three Phase Wye (North America)



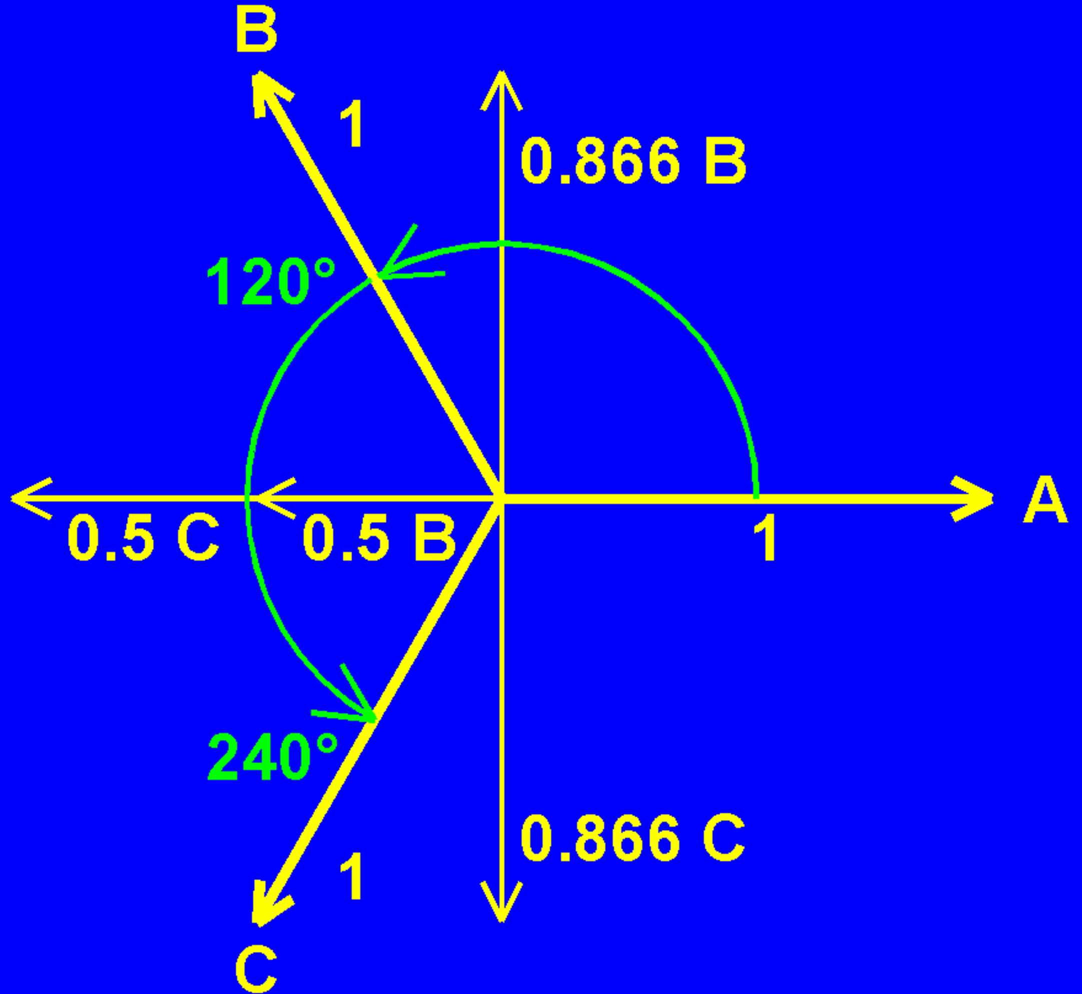
Three Phase Wye (Europe)



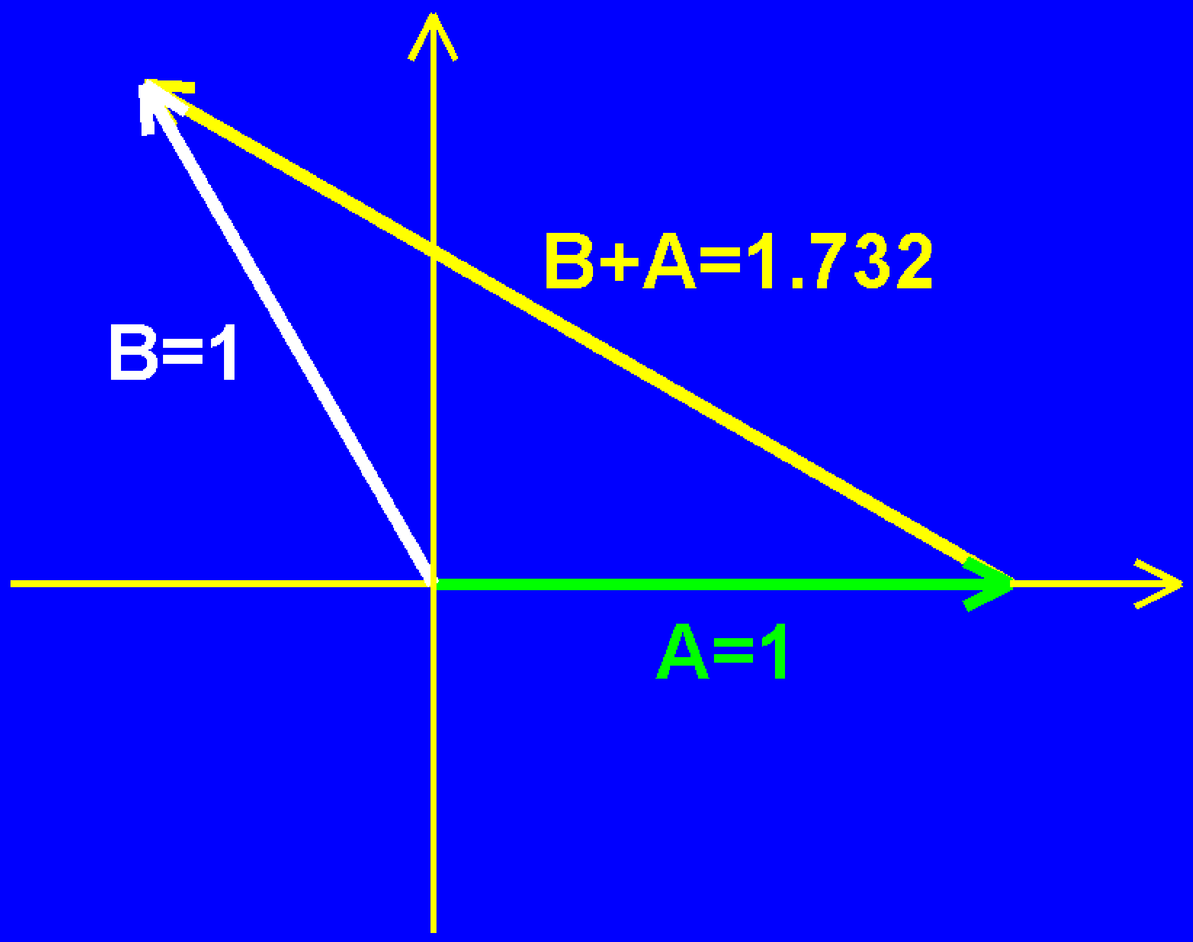
Three Phase Power Waveforms



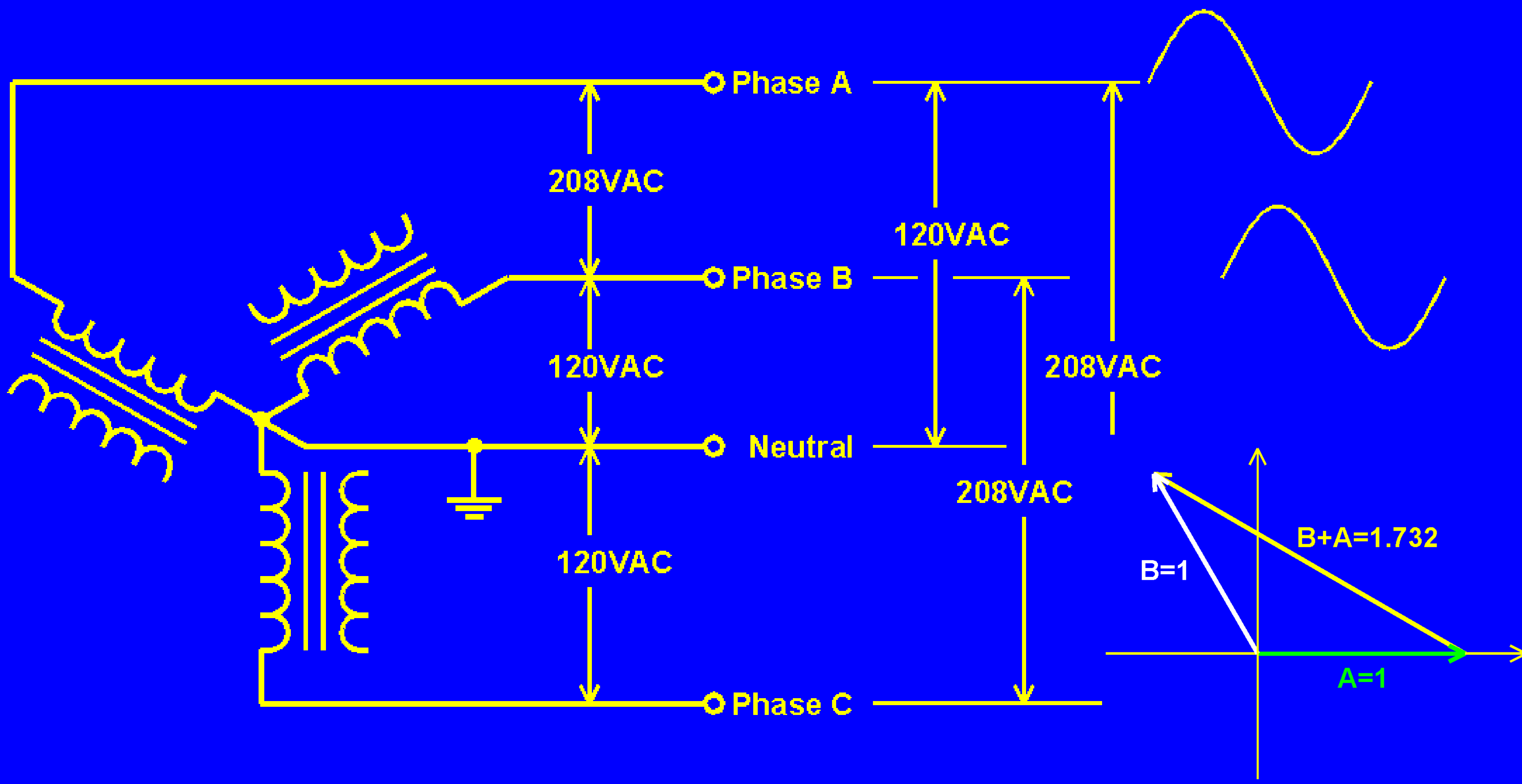
Three Phase Power Waveforms



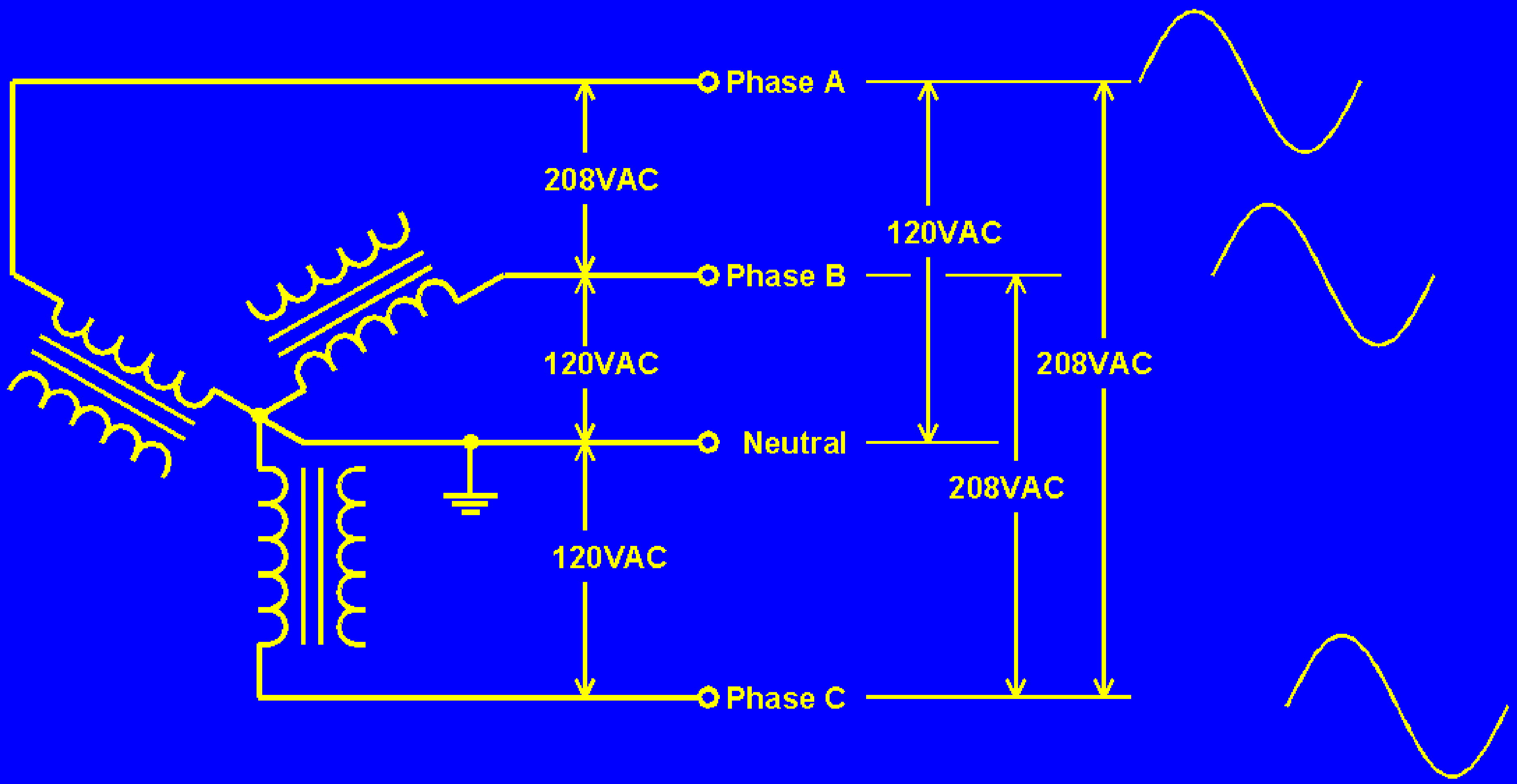
Three Phase Power Relationships



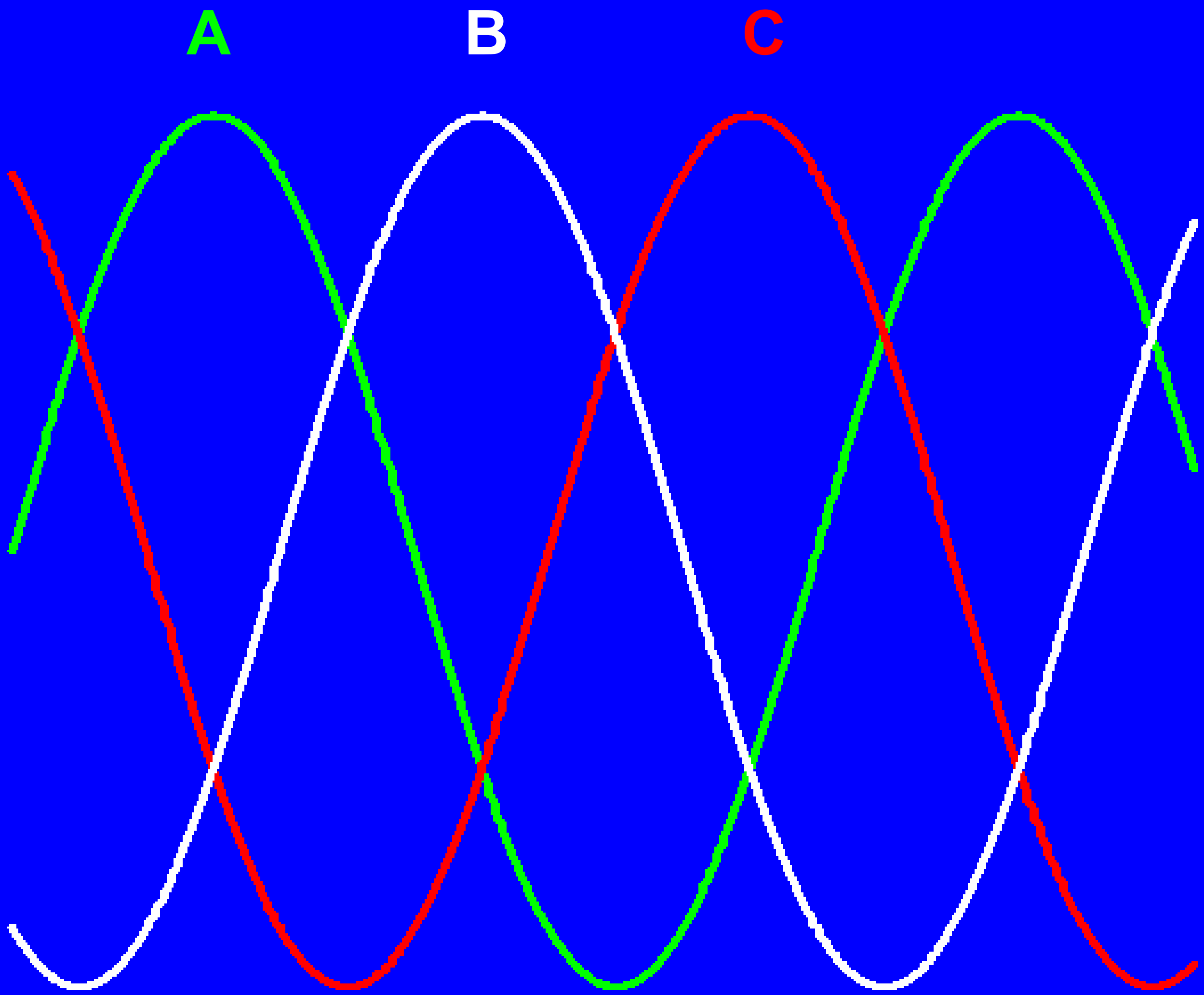
Three Phase Power Waveforms



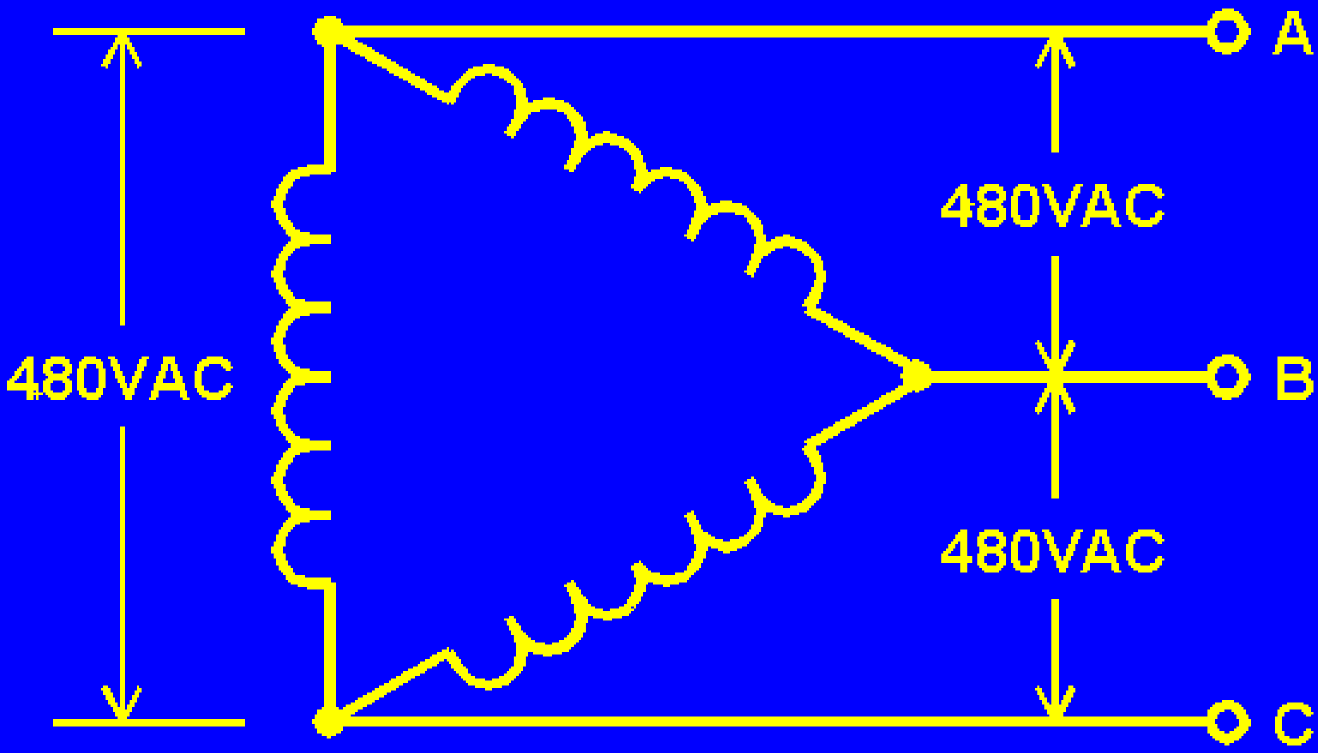
Three Phase Power Waveforms



Three Phase Power Waveforms

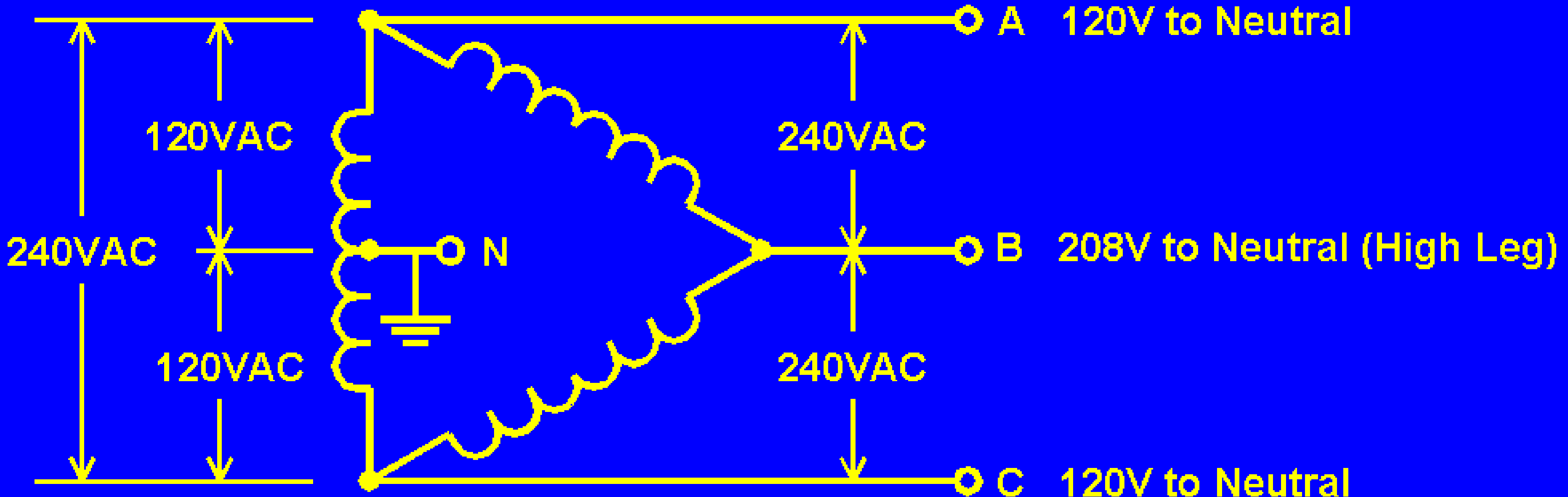


Three Phase Delta



No Grounded Conductor, not used for premises wiring

"High Leg" Delta



And now, Andy Benton will talk about Power Quality and Power Conditioning!

POWER CONDITIONING

What Is Power Conditioning?

Alternative question:

What are the problems that occur on AC branch circuits?

AC BRANCH CIRCUIT PROBLEMS

For each problem we will look at:

- Characterization of the problem (if needed)
- What causes the problem
- The effect on equipment
- Available solutions

AC BRANCH CIRCUIT PROBLEMS

- Power outages
- Waveform distortion
- Sustained under-voltage
- Sustained over-voltage
- Surges and transients

POWER OUTAGES – CAUSES

- Power company disconnect
  - Varying duration from as short as one cycle
- Local circuit breaker blows

POWER OUTAGES – EFFECTS

- Equipment can no longer operate
- Programmable equipment looses settings and status
- Computer and DSP-based equipment often takes significant time to reboot

POWER OUTAGES – SOLUTIONS

- Generator
- Uninterruptible Power Supply (UPS)
- Inrush current limiting
(Prevents circuit breaker blowing due to a large inrush at turn-on)

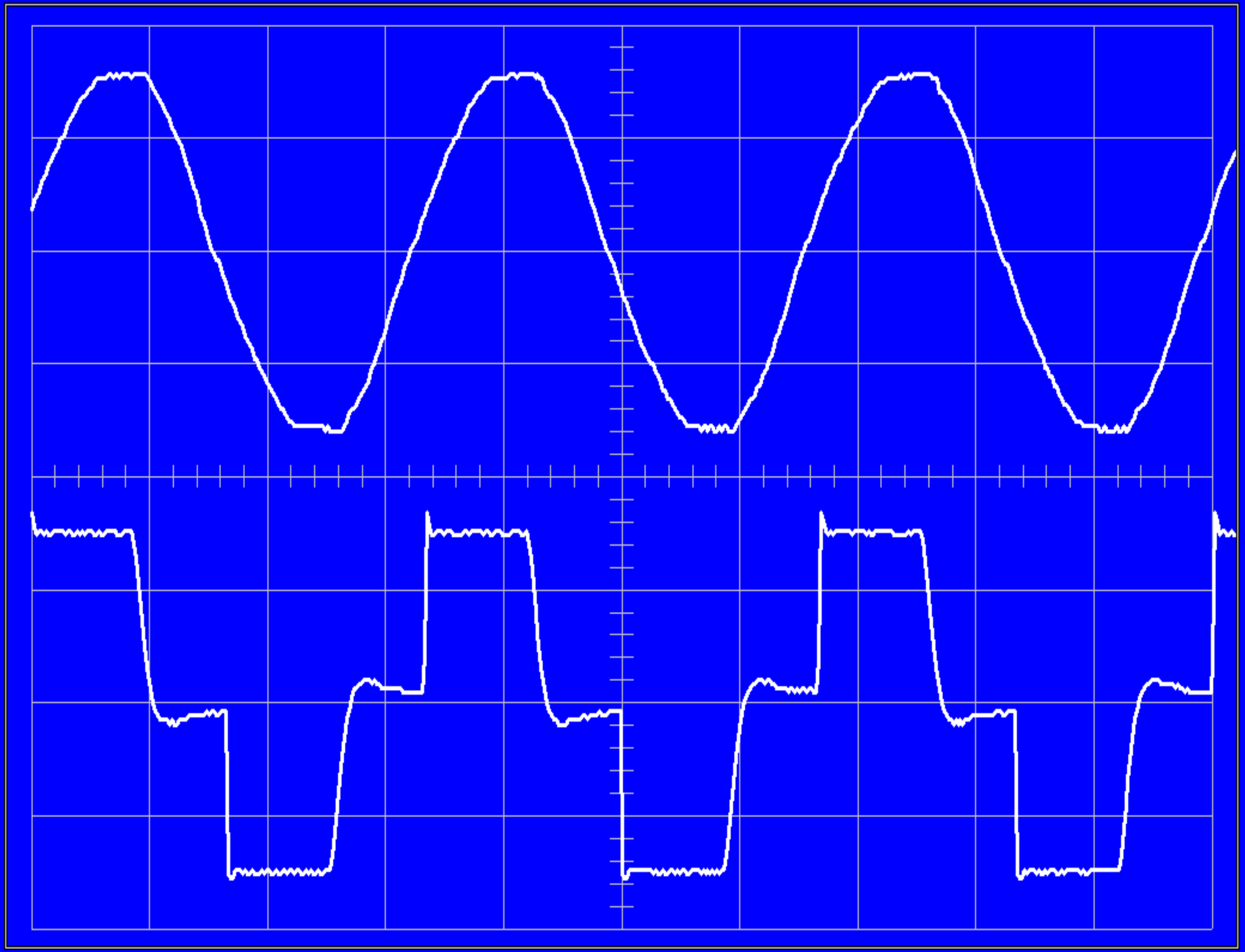
UPS (Battery backup)

- Off Line
  - Normally passes AC and switches to battery only when AC drops out
- Line Interactive
  - Has limited regulating ability
- On Line
  - Continuously generates clean AC

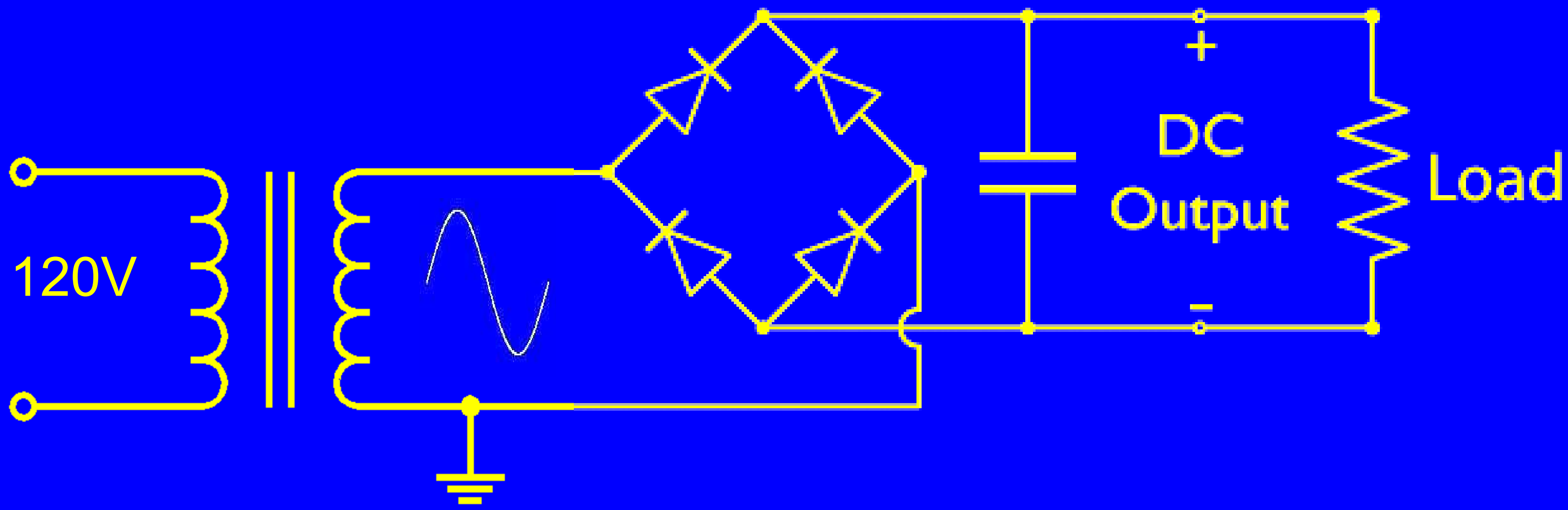
UPS (Battery backup) Waveform

Passing AC

On Battery



Waveform Distortion

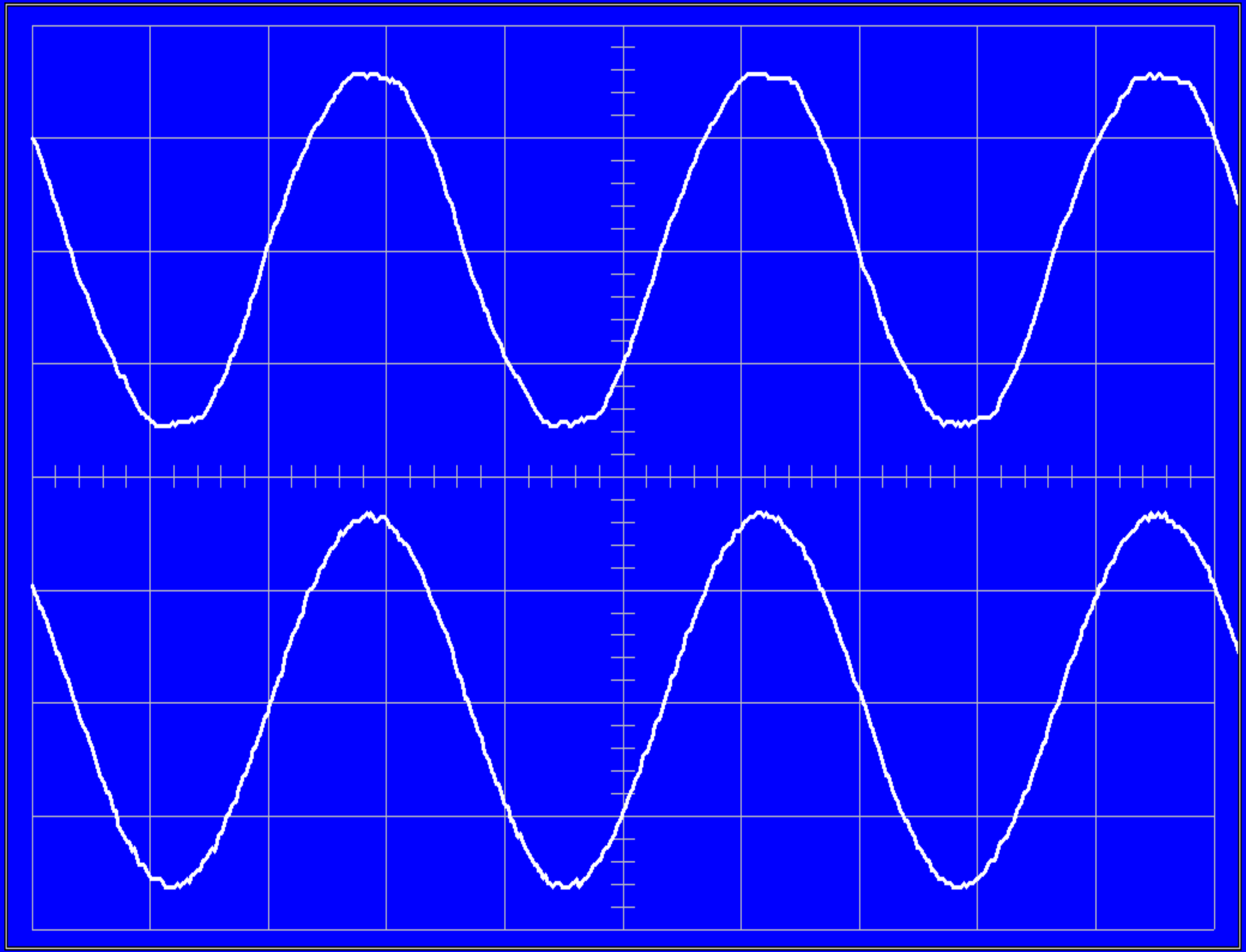


- Current flows only at peaks of AC cycle

WAVEFORM DISTORTION

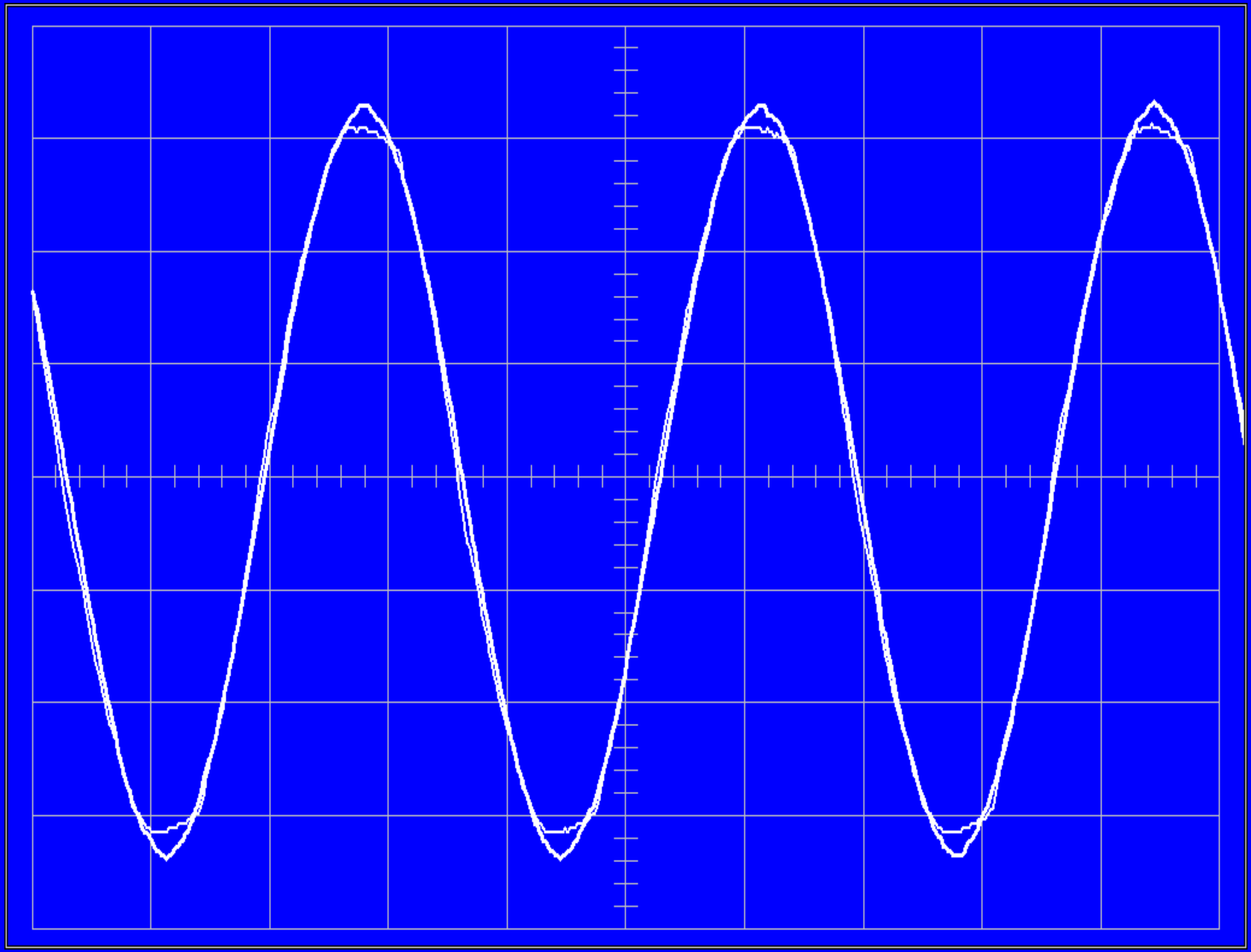
Branch
Circuit

Pure
Sine
Wave



WAVEFORM DISTORTION

Wave-
forms
over-
lapped



WAVEFORM DISTORTION – CAUSES

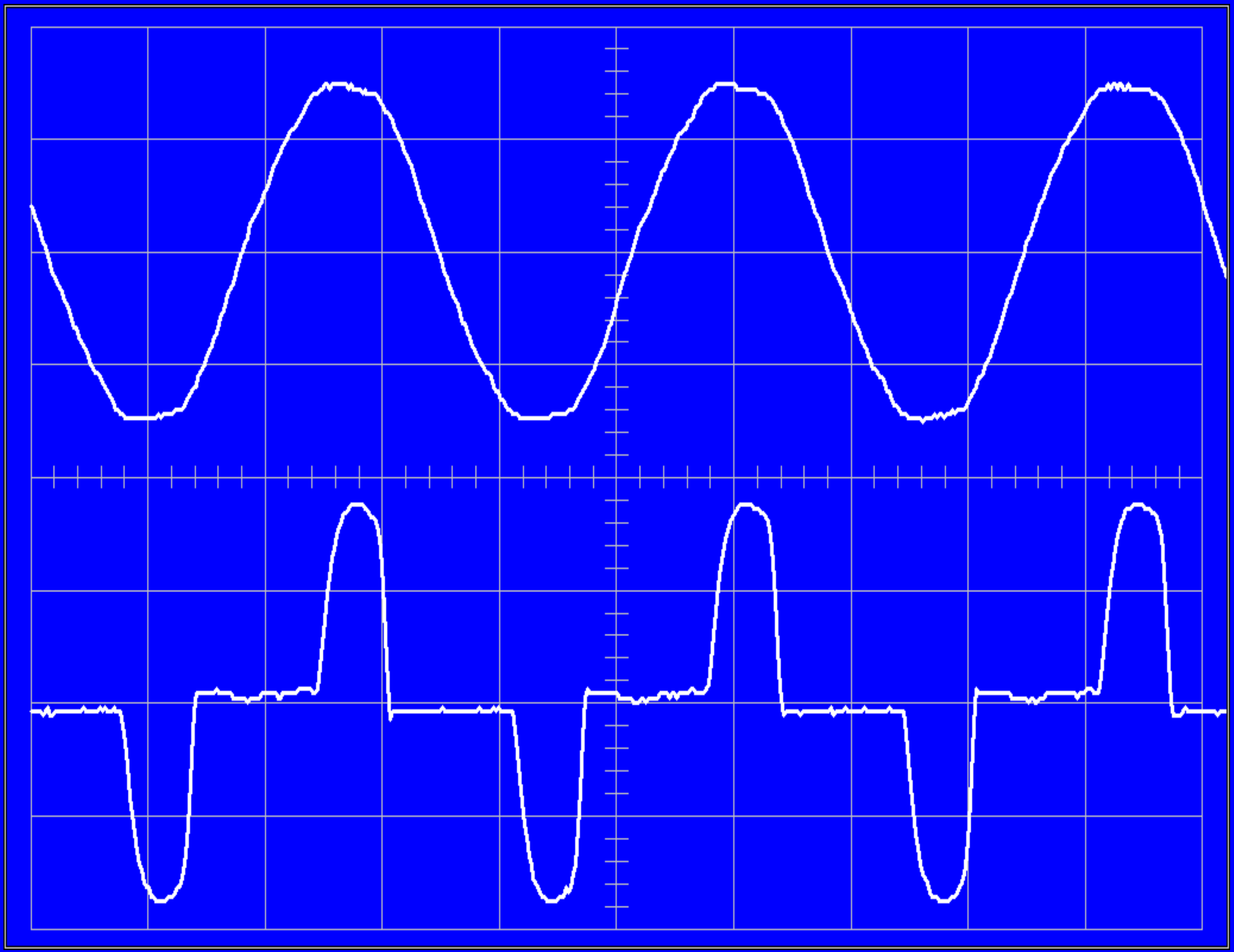
- Caused by non-linear loads.
  What is a “non-linear” load?
  In the A/V industry, it is usually an electronic power supply that is not power-factor corrected, and which draws current only during the AC peaks.
  The result is that the peaks get flattened.

WAVEFORM DISTORTION – CAUSES

QSC
RMX850
AC Current
Draw

Running at:
1KHz In
100W Out

4.4A RMS
9.1A Peak



WAVEFORM DISTORTION – EFFECTS

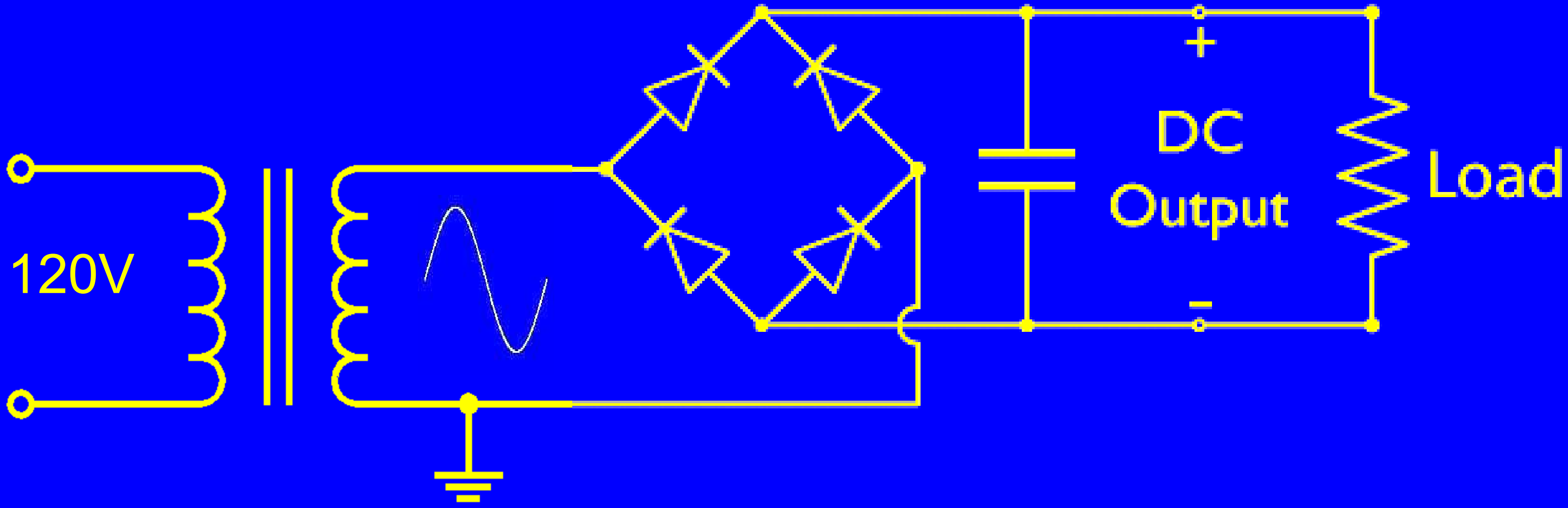
- Hurts voltage regulation
  - #12 gauge wire reacts more like #14 gauge
- Increases distribution losses (I^2R losses)
- Amplifiers do not quite have full headroom because the peak voltage is lower
- Increased harmonic content increases noise

WAVEFORM DISTORTION – SOLUTIONS

- Use heavier gauge of copper wire
- On Line UPS or Regulator
  - But, is the regulation and peak current handling capability any better than the branch circuit?
- Beware! Some products claim to reconstruct the AC sine wave but they don’t

Inrush Current

- The capacitor must charge at turn-on



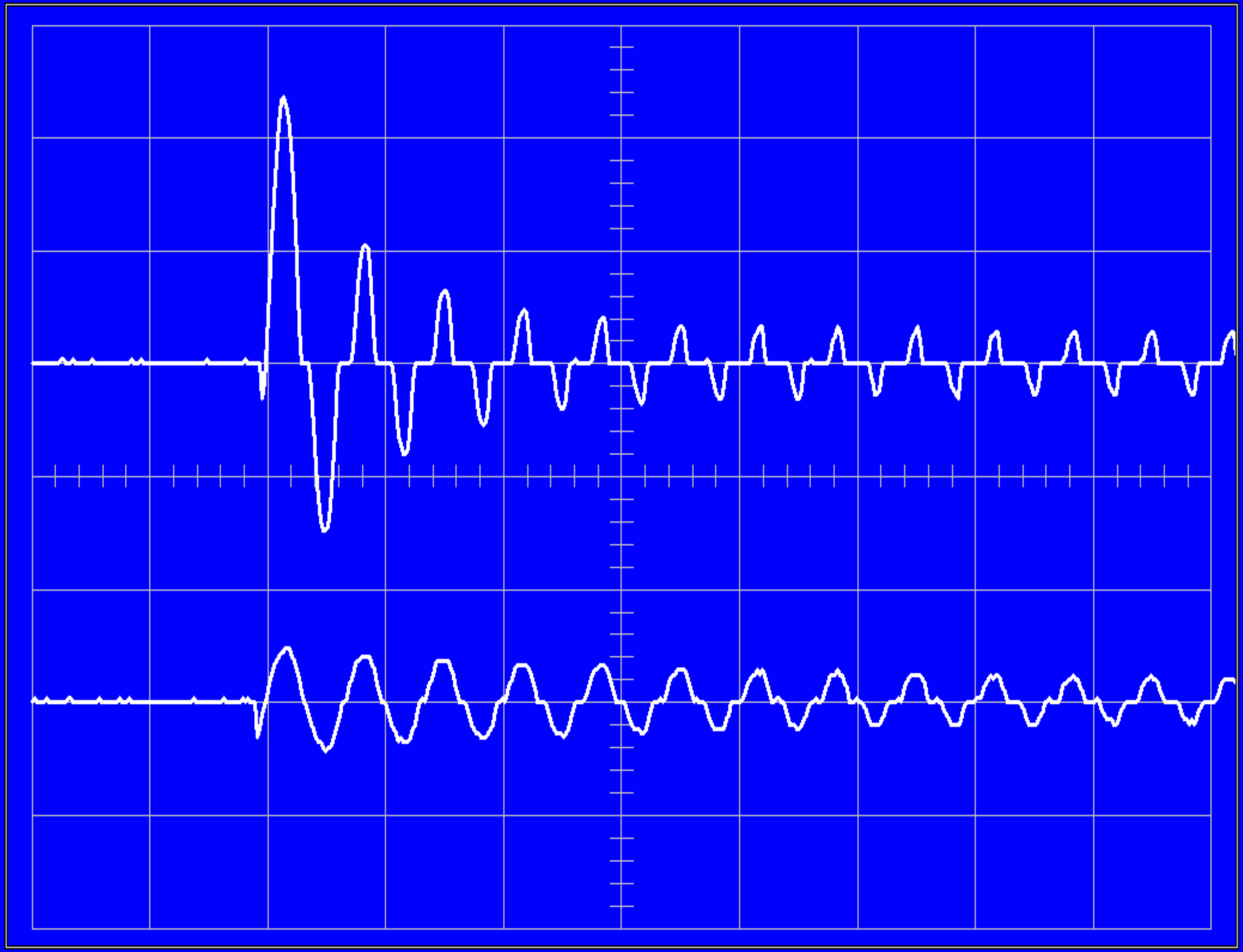
- Largest spike at peak of cycle
- Smallest surge at zero crossing

INRUSH CURRENT LIMITING

Without Limiting

50A/Div

With Limiting



UNDER-VOLTAGE CONDITION

- A sustained condition where the RMS voltage of a branch circuit is much lower than 120V
- Most equipment will function perfectly well down to 105V

OVER-VOLTAGE CONDITION

- A sustained condition where the RMS voltage of a branch circuit is much higher than 120V
- Most equipment will function satisfactorily up to 135V with damage not occurring until around 150V

UNDER- & OVER-VOLTAGE – CAUSES

- Power company fault
- Complete or partial loss of neutral on a three-phase or split-phase service
  - This unbalances the phases

UNDER-VOLTAGE – EFFECTS

- Depending on actual voltage, equipment may:

- Stop working entirely
- Behave erratically
- Hang up or freeze (microprocessor based)
- Loose programming or settings

OVER-VOLTAGE – EFFECTS

- Depending on actual voltage equipment may:

- Overheat
- Malfunction
- Fail Destructively (Blow up)

UNDER- & OVER-VOLTAGE – SOLUTIONS

- Regulator (limited input voltage range from about 90V to 145V)
- Shut down the power to the equipment
  - Shutdown slowly for under-voltage
  - Shutdown within ½ cycle for over-voltage
- Convenience feature:
  - Many products stay off until manually reset
  - Some products automatically turn back on

SURGES & TRANSIENTS

- Surges and transients are very short duration over-voltage events typically lasting from a few micro-seconds to a thousandth of a second – much shorter than ½ cycle of 60Hz AC.

- Surges contain more energy than transients

SURGE ENERGY

- IEEE 62.41 states for a branch circuit:

- Maximum voltage is 6000V
- Maximum current is 3000A
- Maximum energy is 90 Joules

- Does this sound like it can do damage?

SURGE ENERGY & PEAK POWER

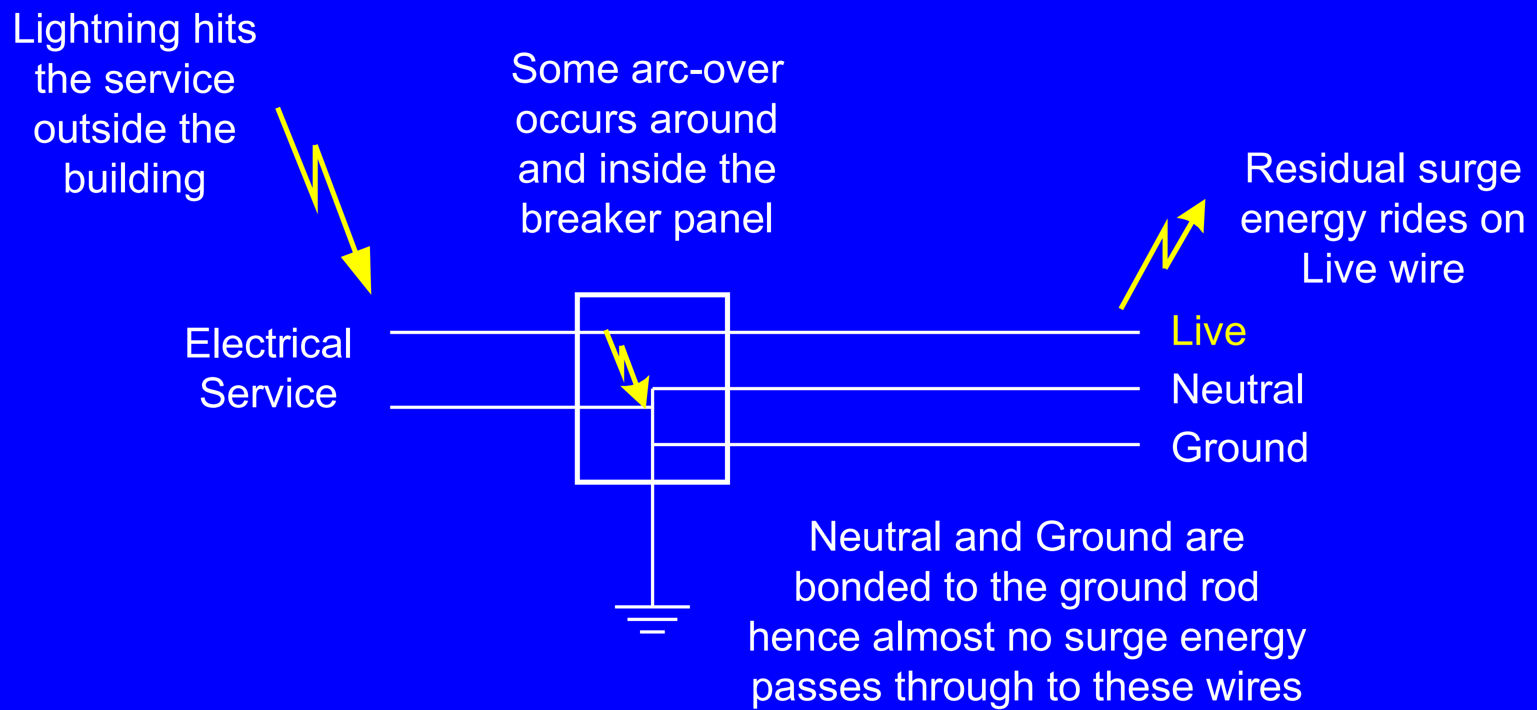
- A 20 microsecond, 90 Joule surge (as defined by IEEE 62.41) has a peak power of…

4.5 Megawatts!!!

SURGES & TRANSIENTS – CAUSES

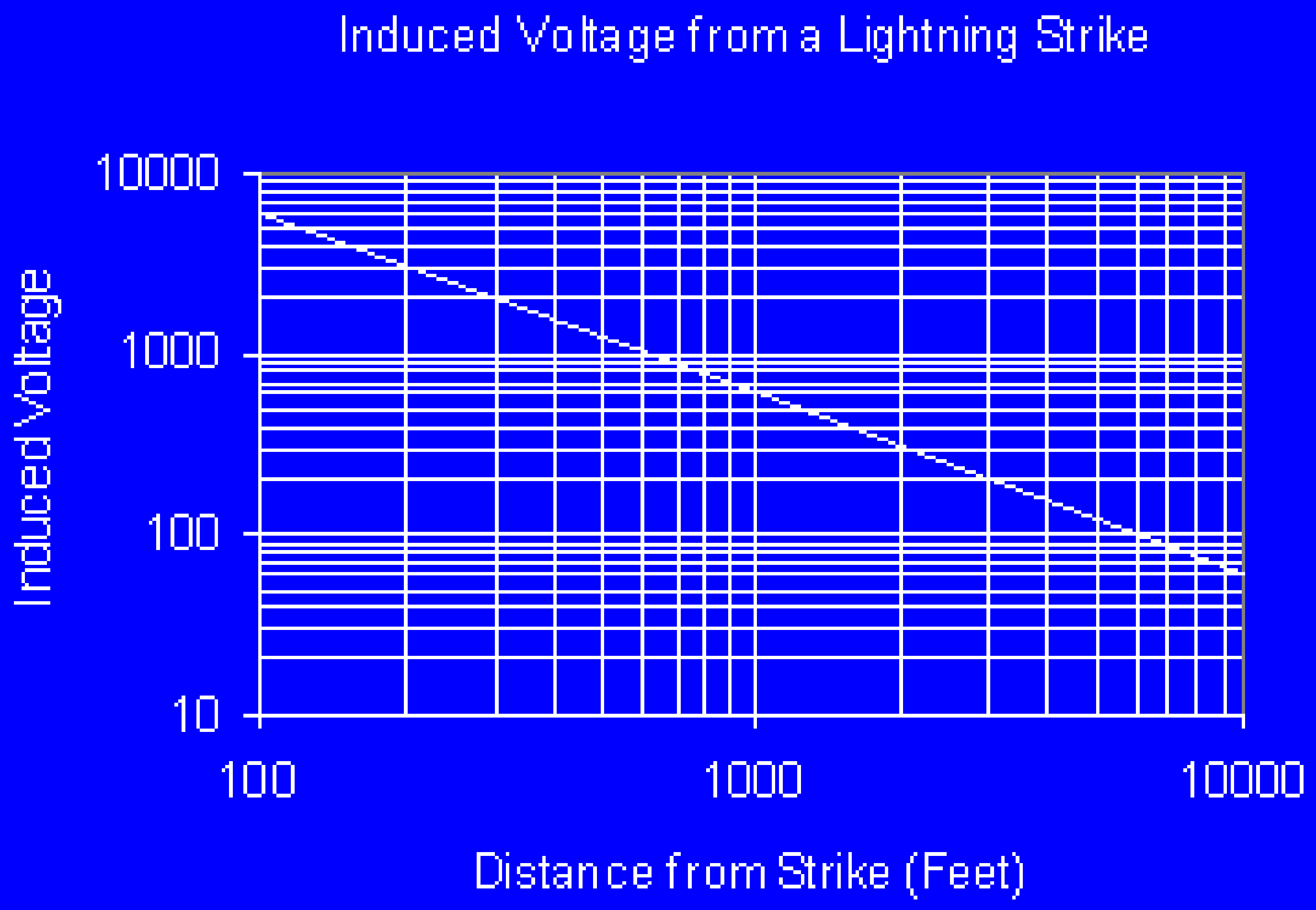
- Direct lightning strike
  - Typical 20,000 Amps; Maximum 200,000 Amps
- Induced lightning
  - Intense electromagnetic fields induce voltages on building wiring and A/V cables
- HVAC turning off & on
- Power company switching

DIRECT LIGHTNING



Lightning Strike Hits Electrical Service

INDUCED LIGHTNING



SURGES & TRANSIENTS – EFFECTS

- Catastrophic damage to equipment
- Degradation of semiconductors resulting in overheating and eventual failure
- Loss of setup information or status
- Equipment crashes or freezes
- Interruption of session or performance
- Clicks or pops in audio

SURGES & TRANSIENTS – SOLUTIONS

- Shunt current to neutral and/or ground
  - Voltage clamp (Diversion technology)

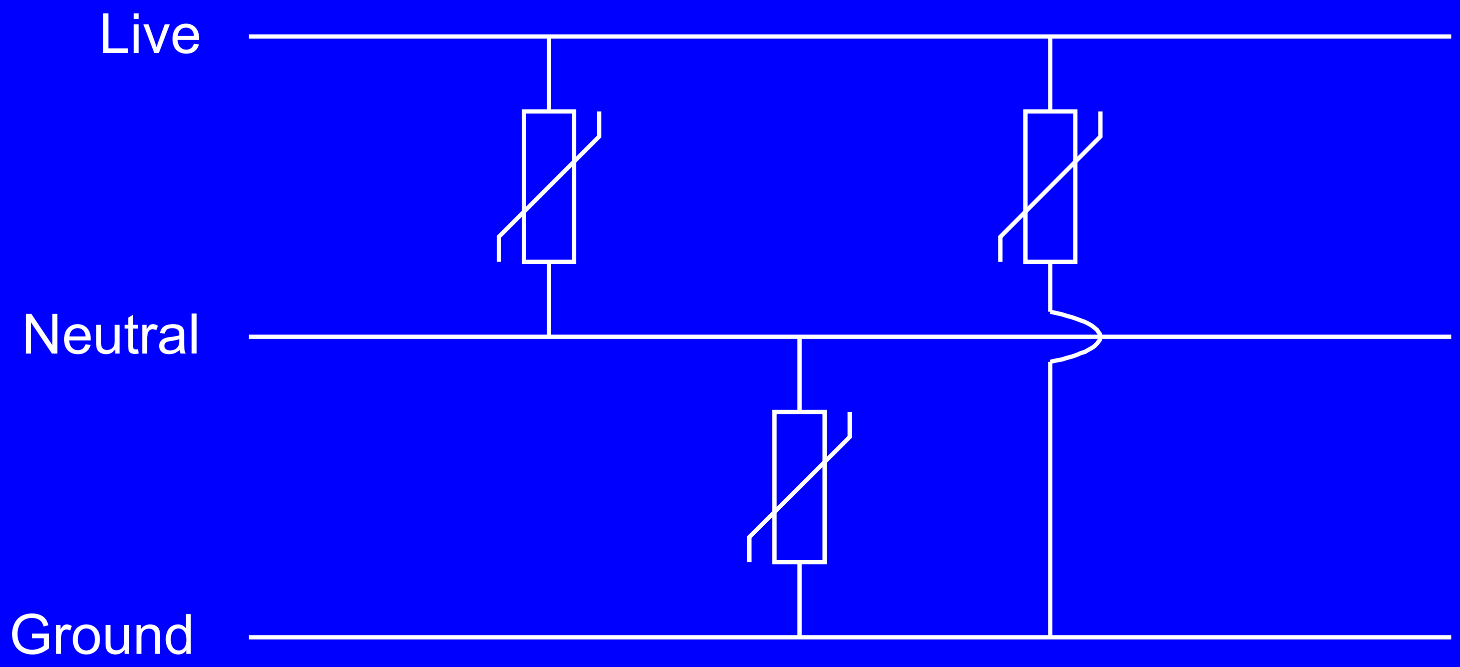
- Block and contain energy
  - Series Mode®

Series Mode® and SurgeX® are registered trademarks of Electronic Systems Protection, Inc.

SHUNT MODE (VOLTAGE CLAMP) – Diversion Technology

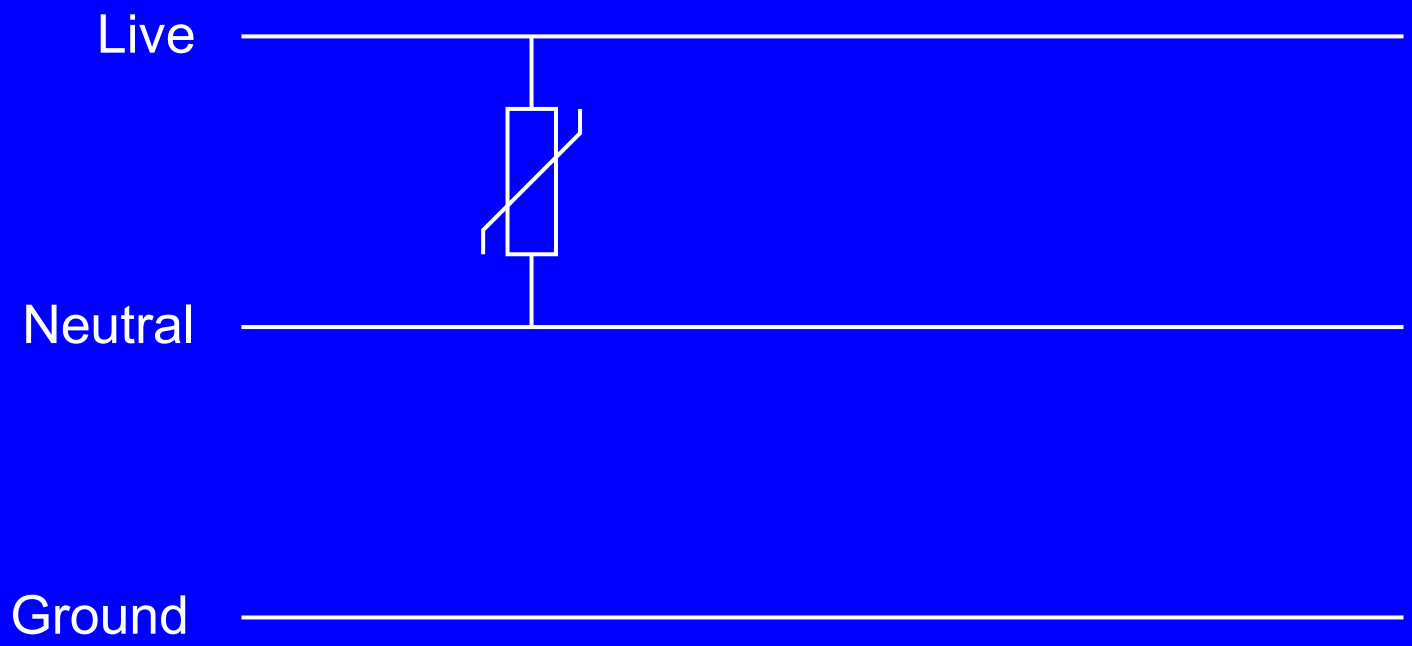
- All modes (L-N-G)
  - Contaminates ground if used on a branch circuit
- Normal mode (L-N)
  - Does not contaminate ground but generates common-mode surges on a branch circuit
- Hybrid (L-N)
  - Does not contaminate ground but generates common-mode surges on a branch circuit

SHUNT MODE SURGE PROTECTION – All Modes



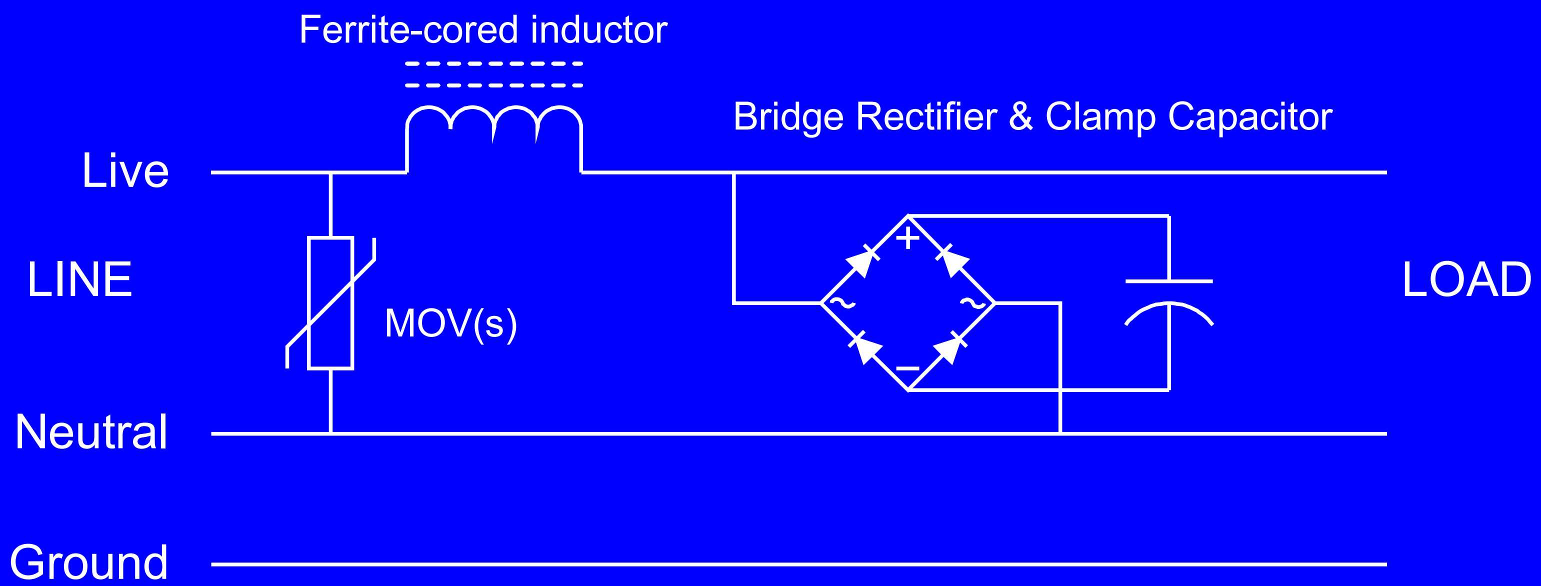
Traditional Shunt Mode Protection Using MOVs

SHUNT MODE SURGE PROTECTION – Normal Mode



Shunt Mode Protection Using MOVs
Only Between Live & Neutral

SHUNT MODE SURGE PROTECTION – Hybrid



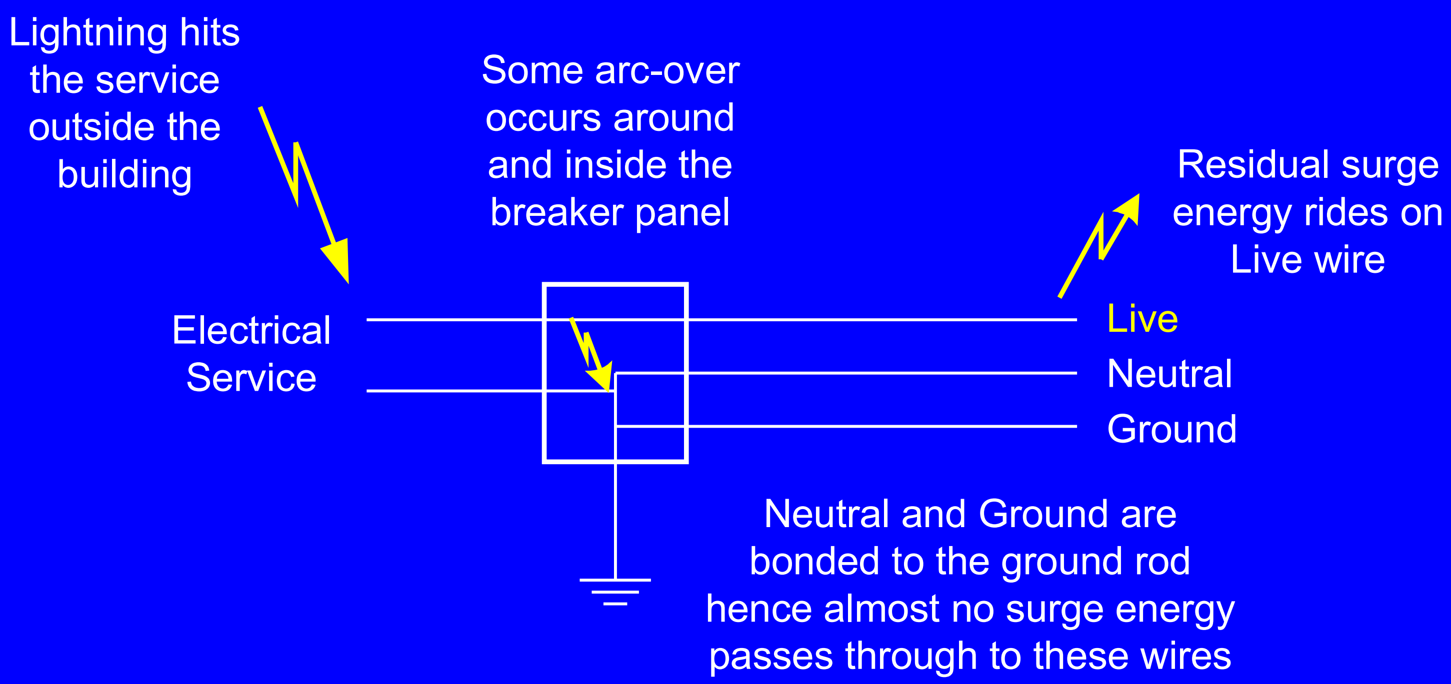
Shunt Mode Hybrid Protection

MOV(s) clamp voltage to around 400V (99% of the surge energy)
Capacitor clamp lowers voltage between L & N but not L & G

SHUNT MODE SURGE PROTECTION – Limitations of Use

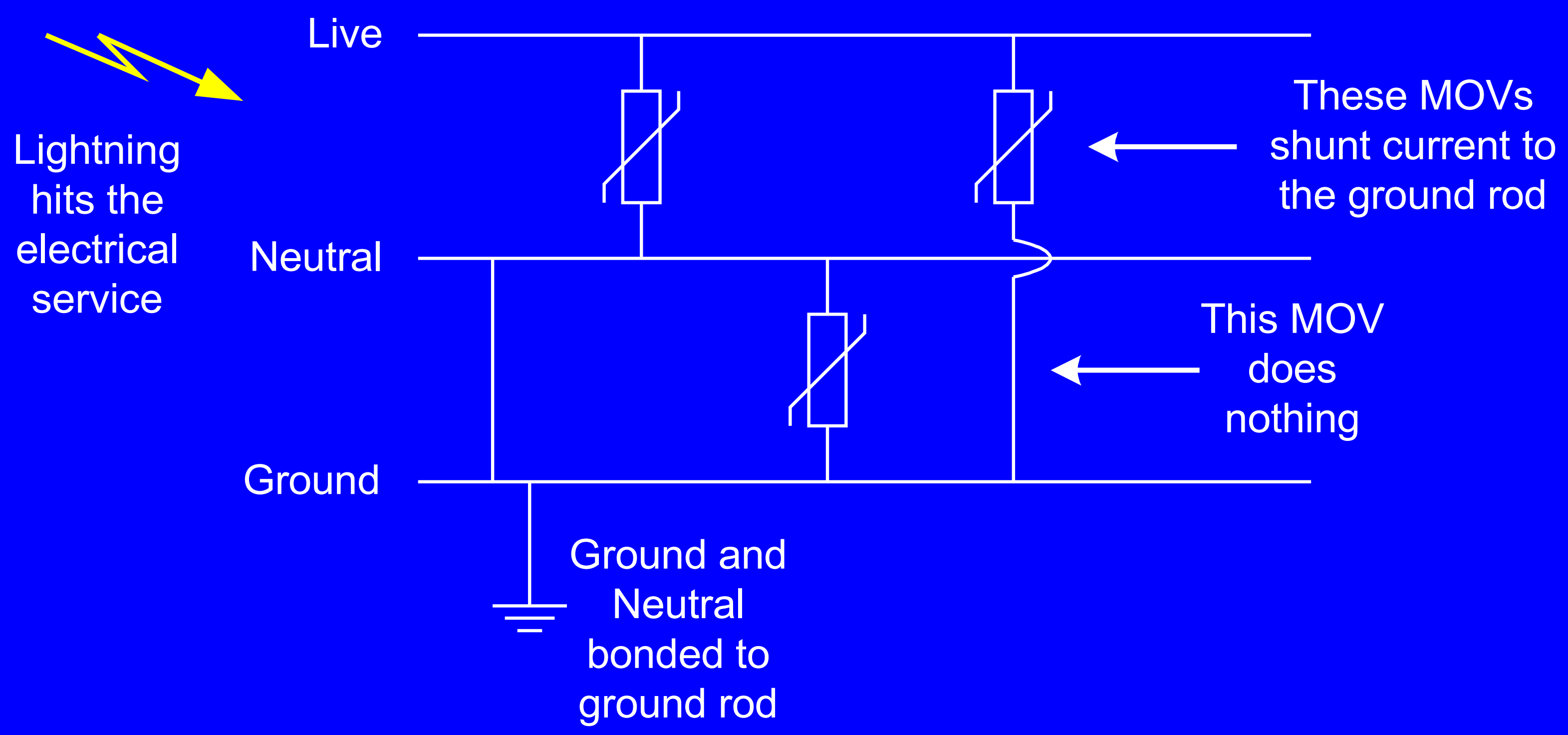
- Can only effectively divert surges to ground when connected at the service entrance
- Depending on mode (all modes or normal mode) either contaminates ground or produces common-mode surges
- Reliability (limited lifetime)
- Leakage to ground
- Unable to withstand over-voltage conditions
  - MOVs conduct a large current and burn up

SHUNT MODE SURGE PROTECTION – Applications



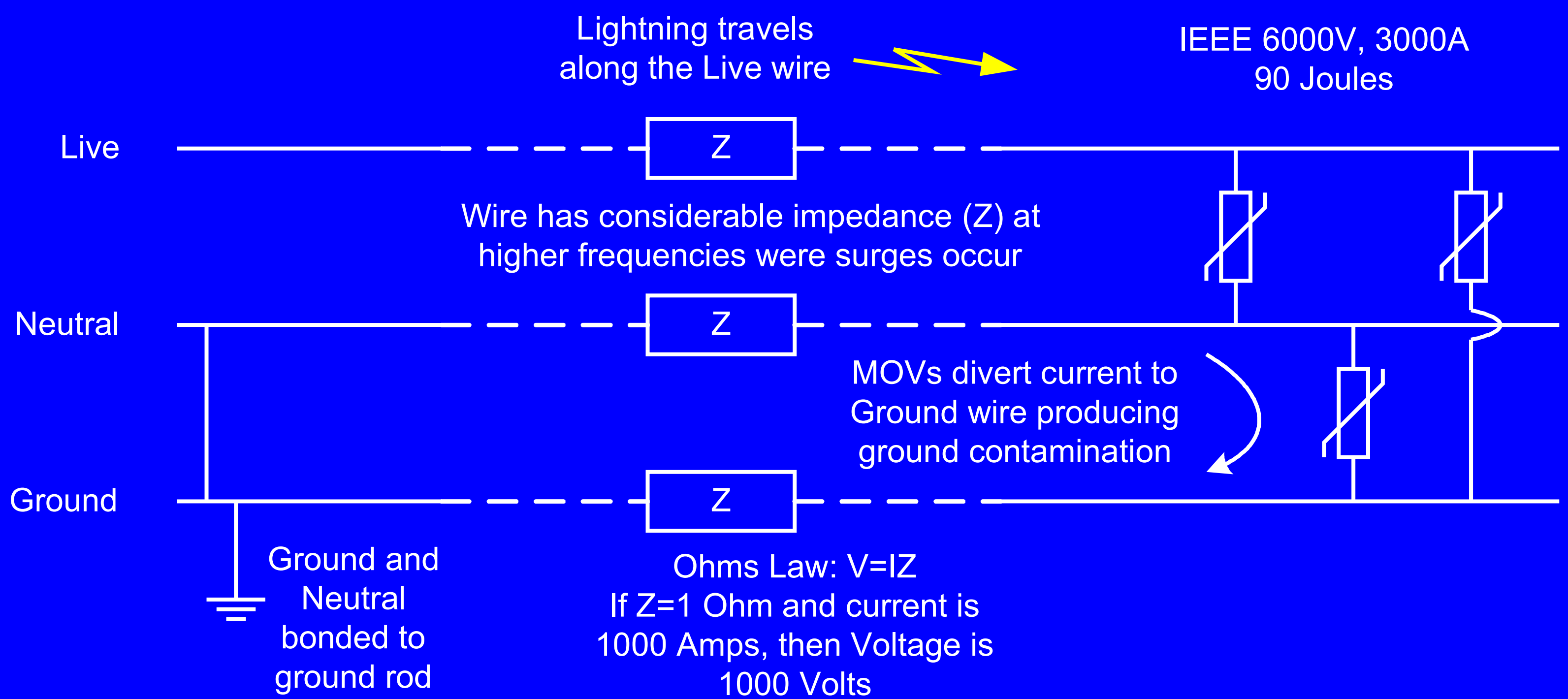
Review of Lightning Striking Electrical Service

SHUNT MODE SURGE PROTECTION – Use At The Service Entrance



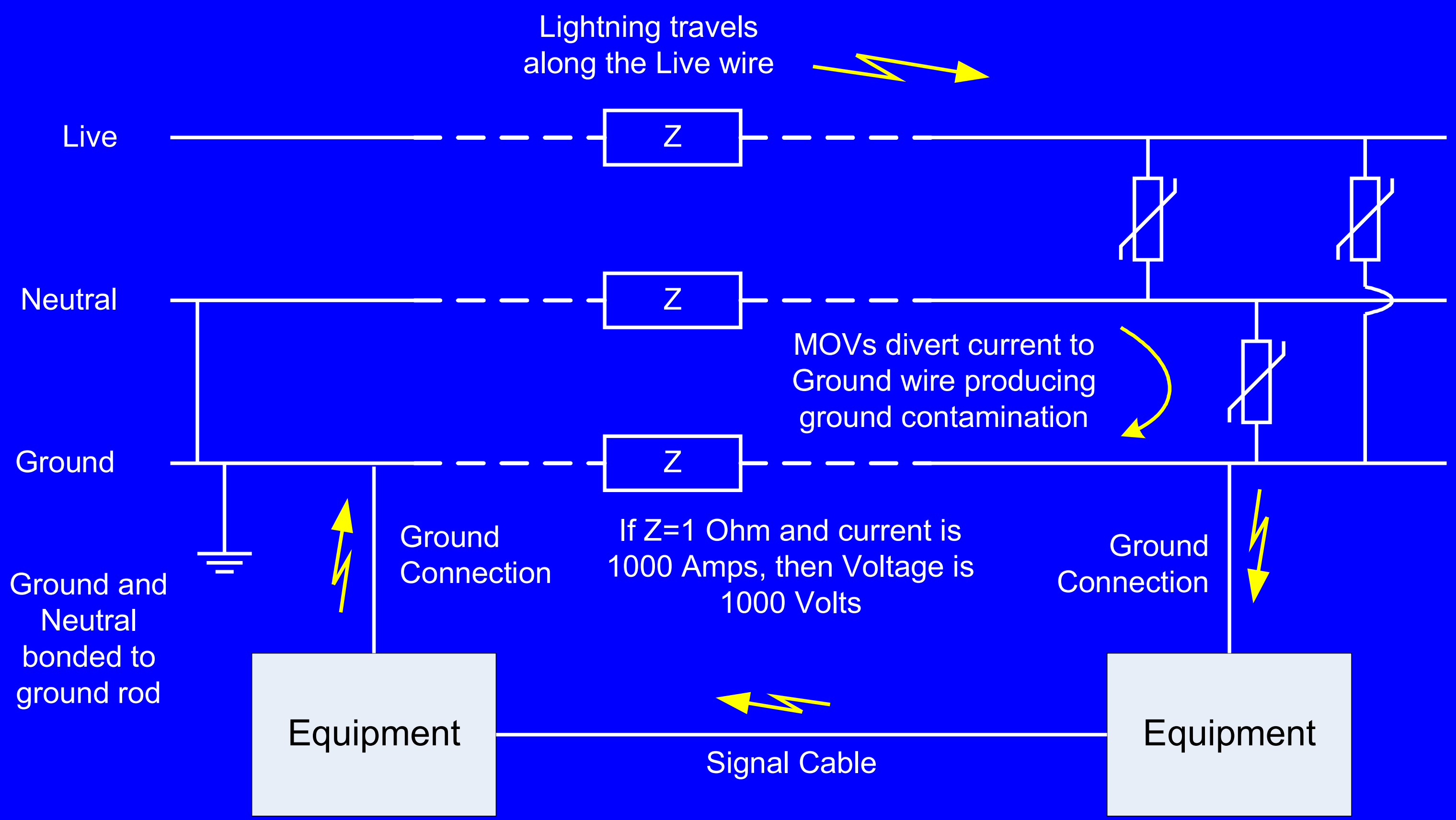
Shunt Mode Protection Using MOVs At Service Entrance

SHUNT MODE SURGE PROTECTION – Use On A Branch Circuit



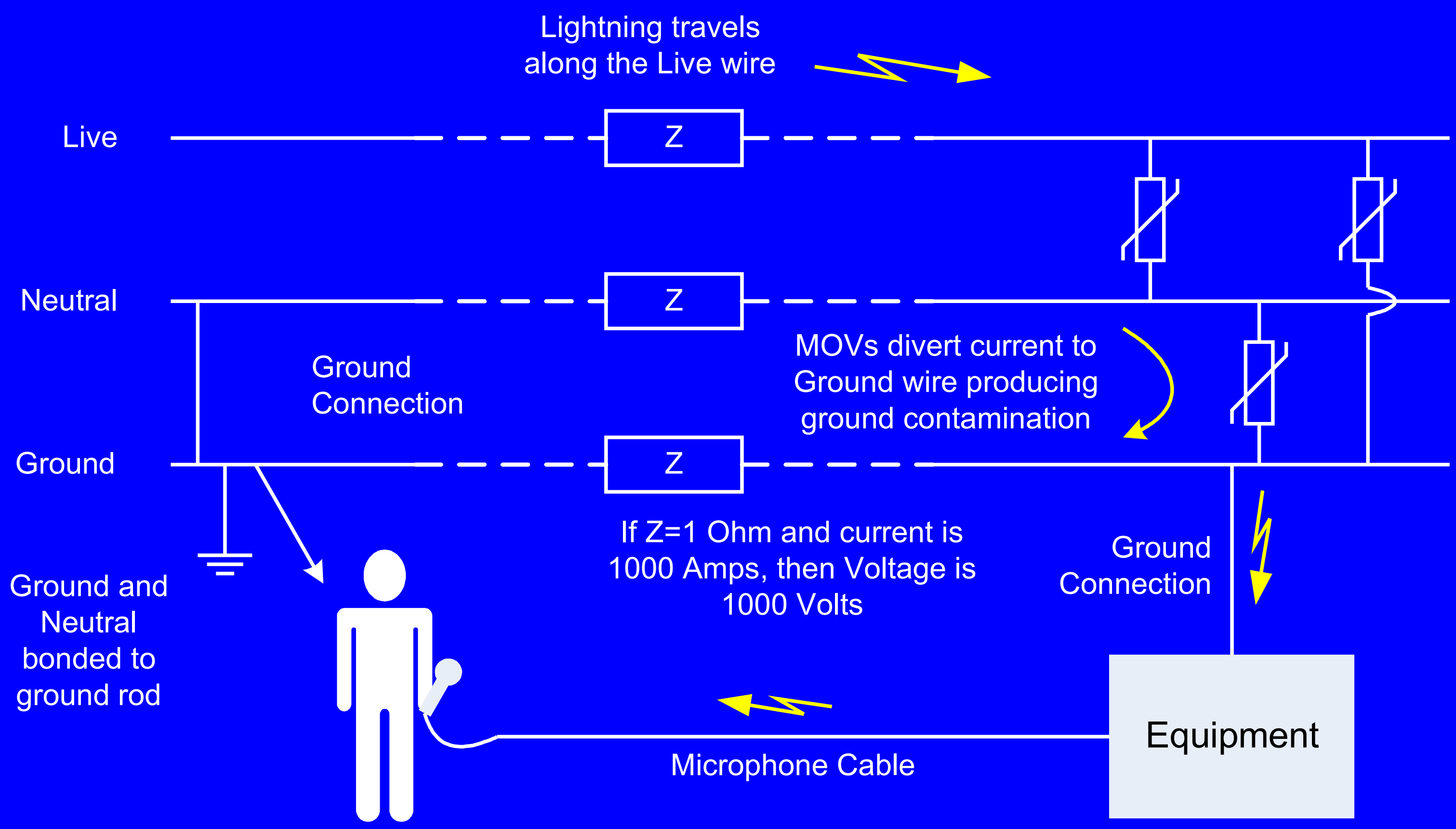
All-Modes Shunt Mode Protection On A Branch Circuit

GROUND CONTAMINATION
– Why it is a problem (Equipment)



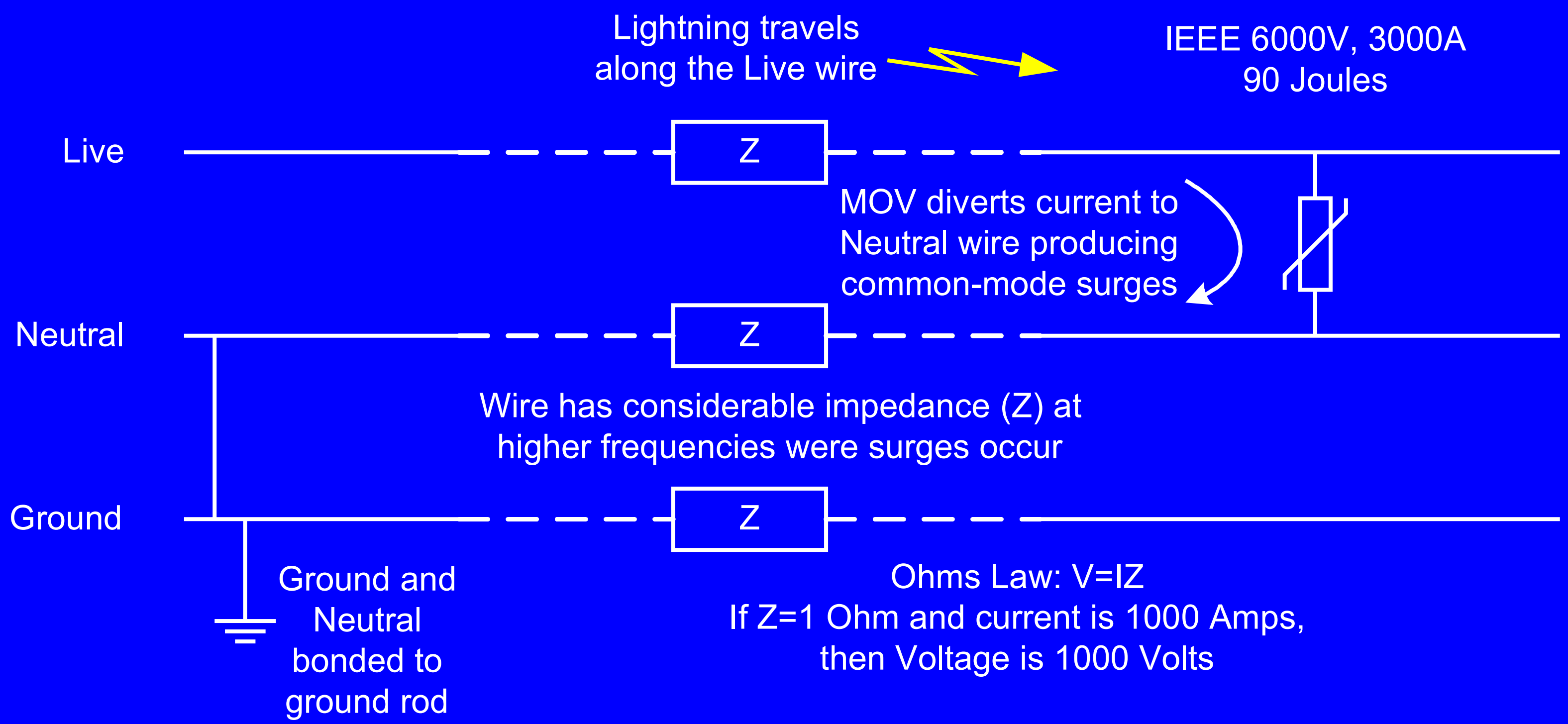
Multiple Paths To Ground Caused By Ground Contamination

GROUND CONTAMINATION – Why it is a problem (Personnel)



Multiple Paths To Ground Caused By Ground Contamination

SHUNT MODE SURGE PROTECTION – Use On A Branch Circuit



Normal-Mode Shunt Mode Protection On A Branch Circuit

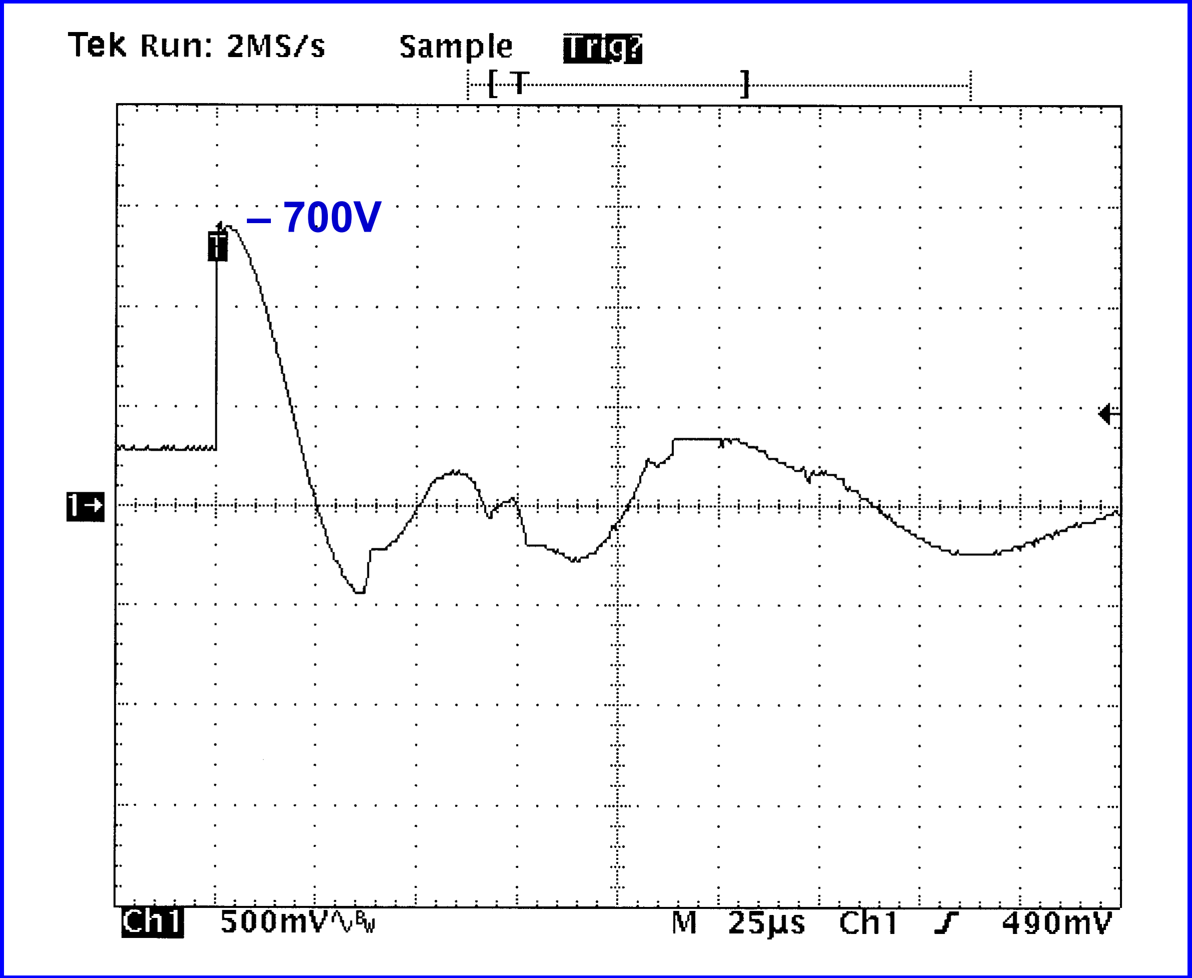
SHUNT MODE SURGE PROTECTION – Common-mode surge voltage

250V/Division

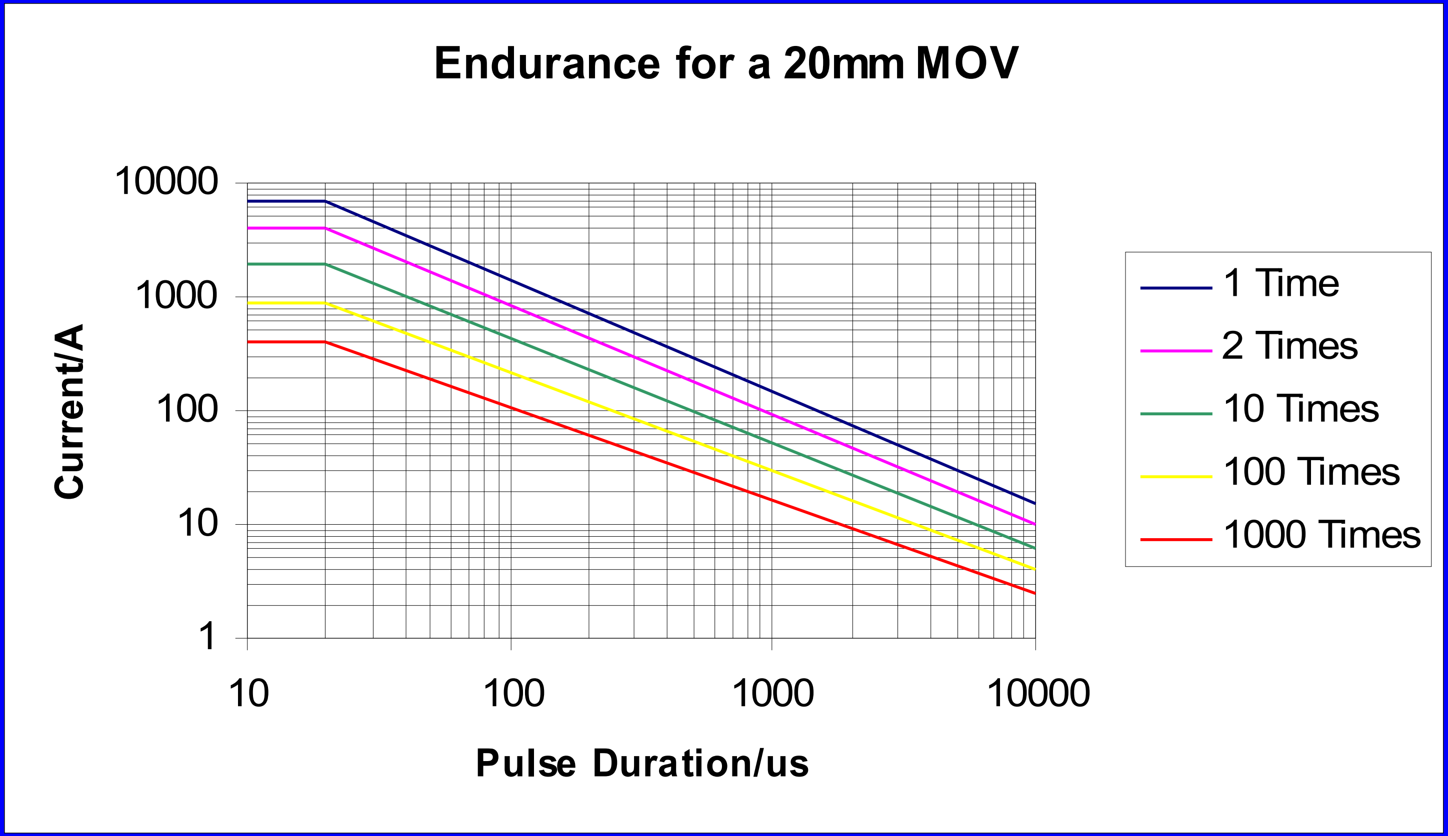
4000V Surge

20' long wiring

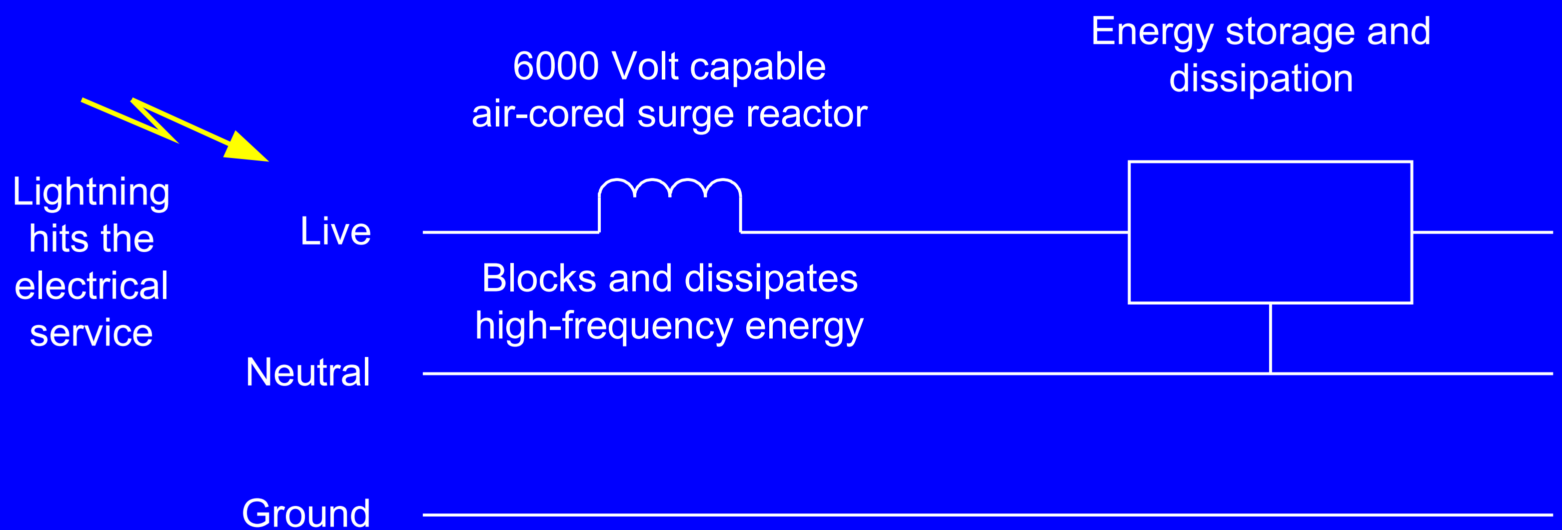
700V peak L-G



SHUNT MODE SURGE PROTECTION – Lifetime



SERIES MODE® SURGE PROTECTION

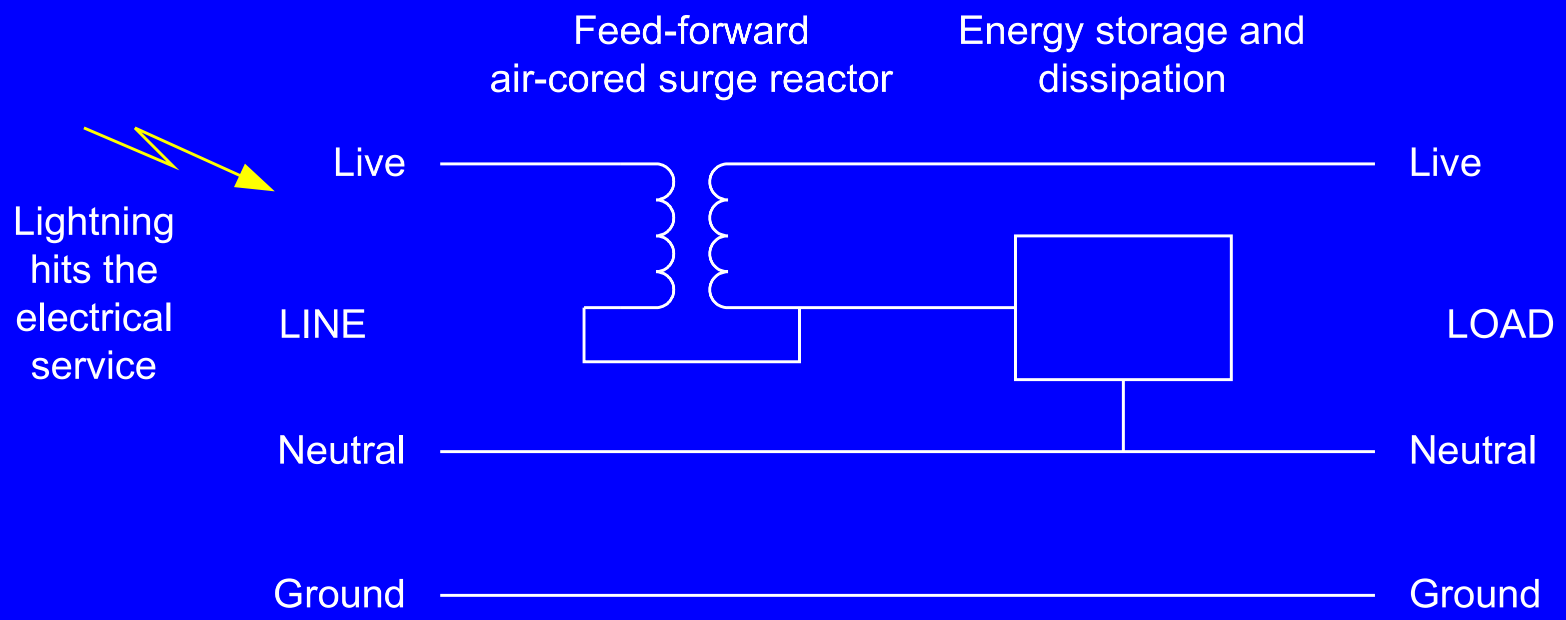


Series Mode Technology Blocks And Contains Surge Energy

SERIES MODE® SURGE PROTECTION – Characteristics

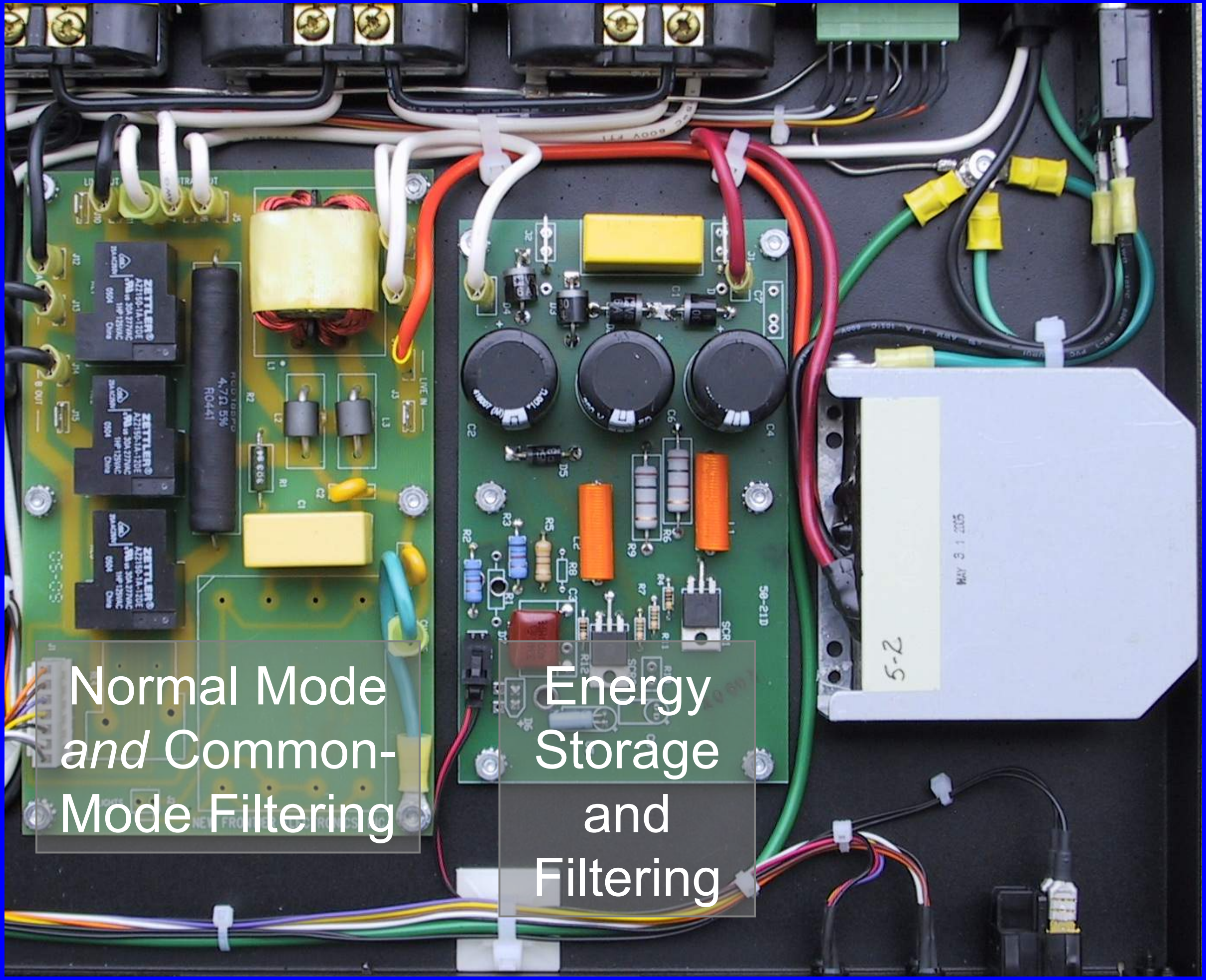
- Reliably handles worst-case surges
- Filters smaller transients and noise
- Lowest let-through voltage
- Does not contaminate Ground
- Does not produce common-mode surges
- Does not need an ideal ground path
- Safe for use on branch circuits and networks

ADVANCED SERIES MODE



Advanced Series Mode Technology Completely Eliminates Surges

ADVANCED SERIES MODE

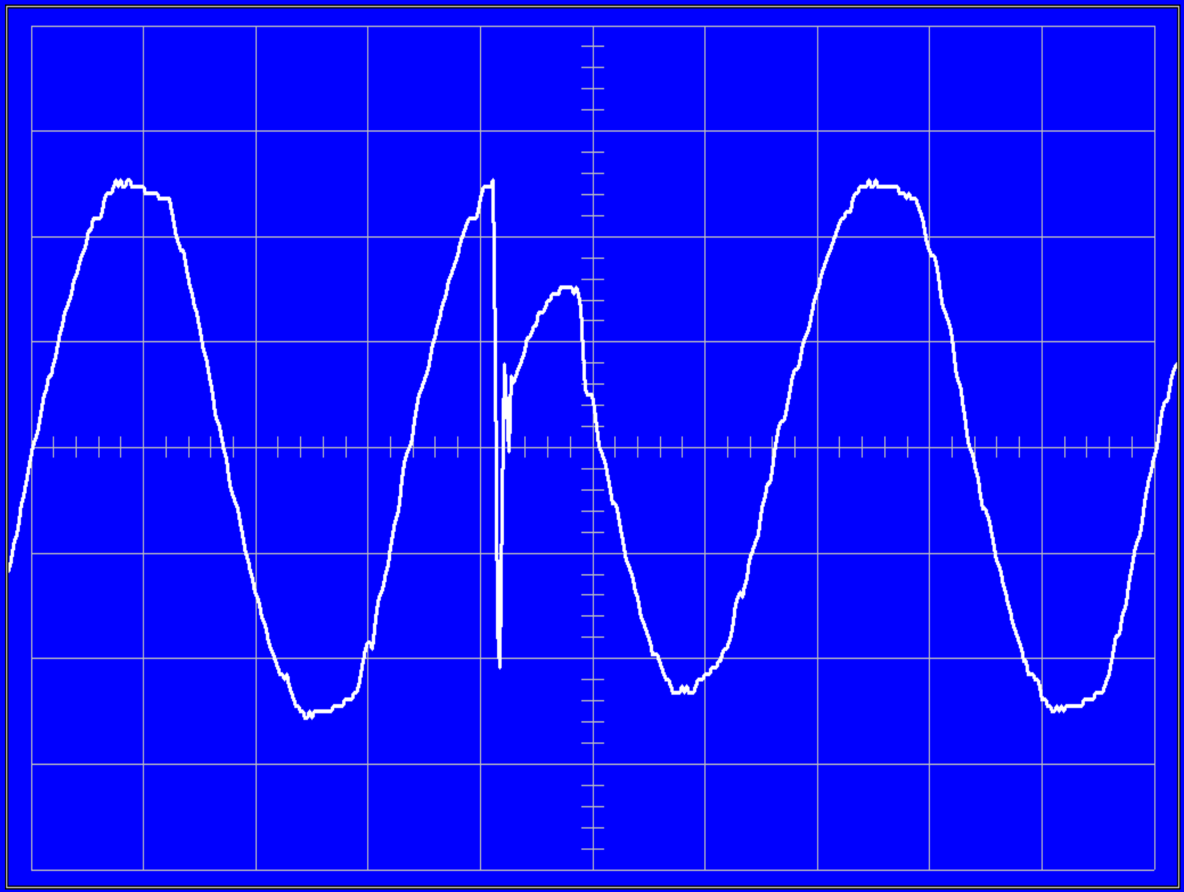


6000V Air-cored Surge Reactor

ADVANCED SERIES MODE

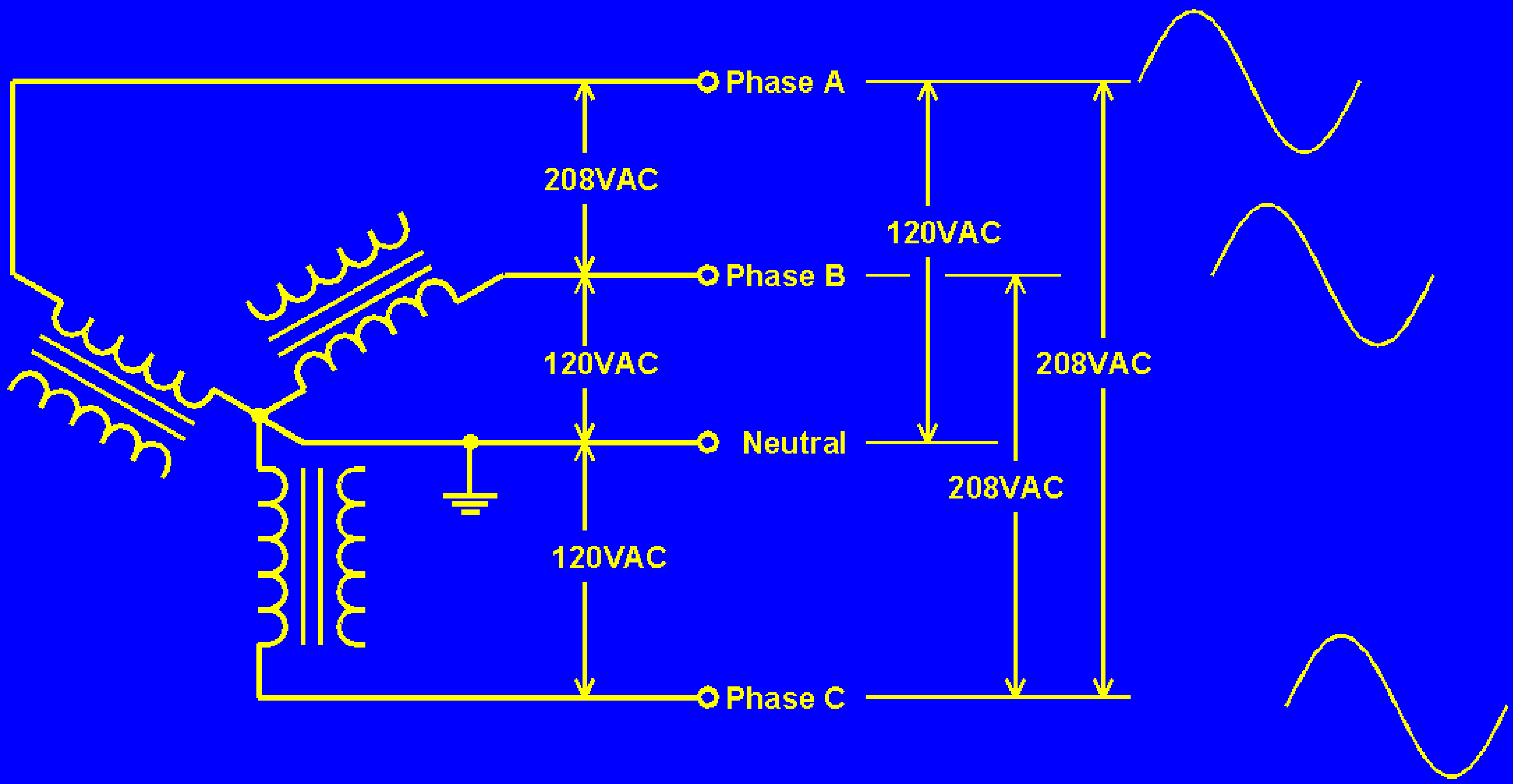
6000V Surge is applied

Disturbance is kept within the powerwave



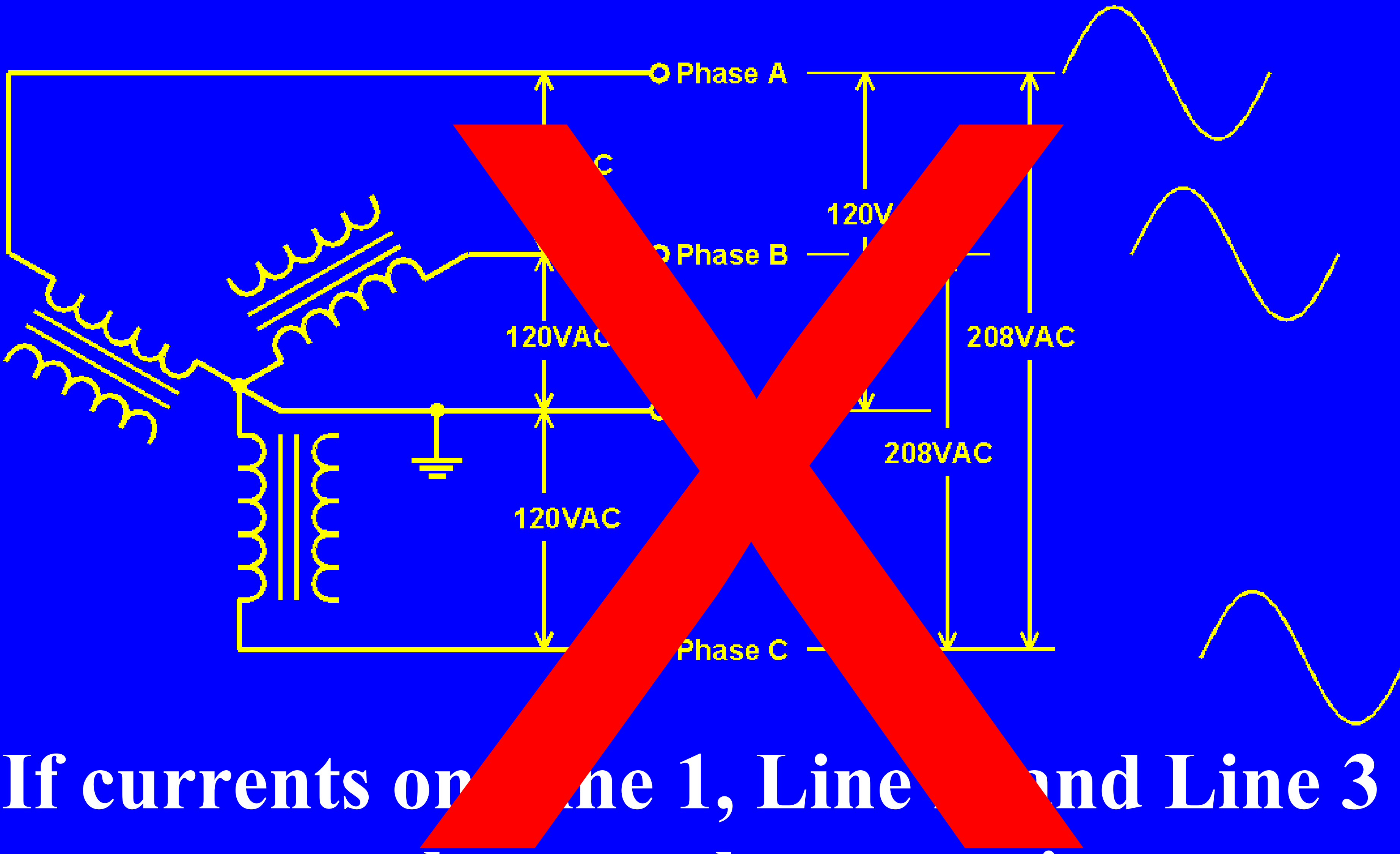
The Harmonic Problem

Remember This Circuit?



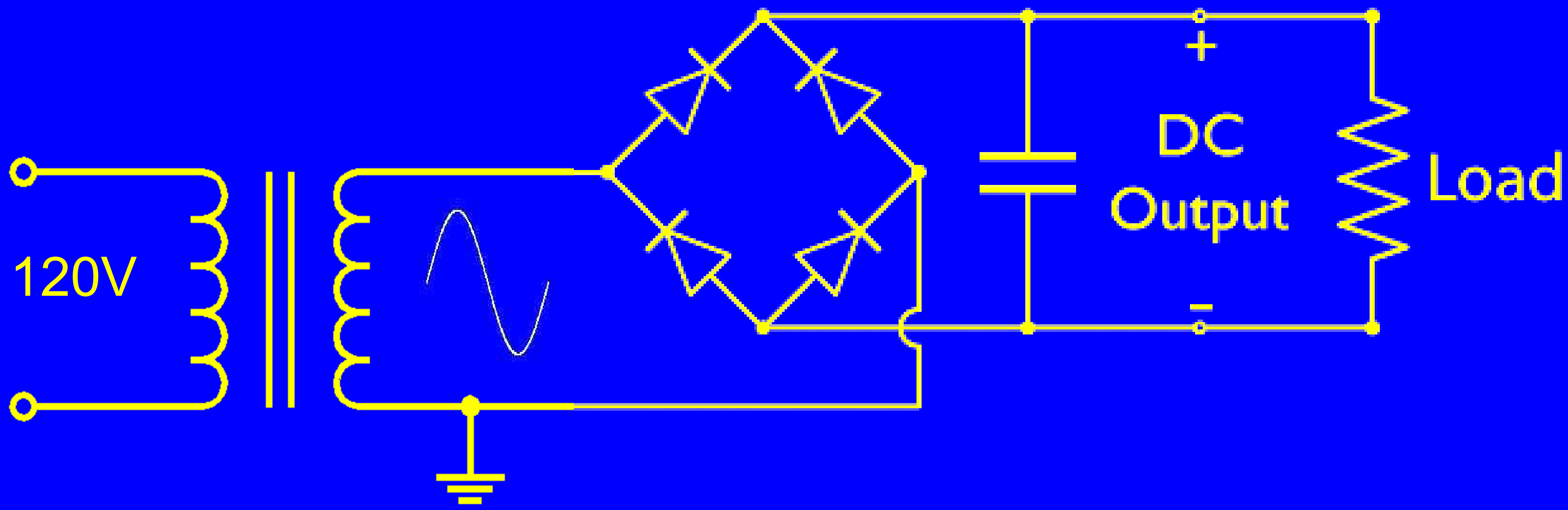
If currents on Line 1, Line 2, and Line 3 are equal, neutral current is zero

There's a Big Problem with it!



If currents on Line 1, Line 2 and Line 3 are equal, neutral current is zero

Waveform Distortion



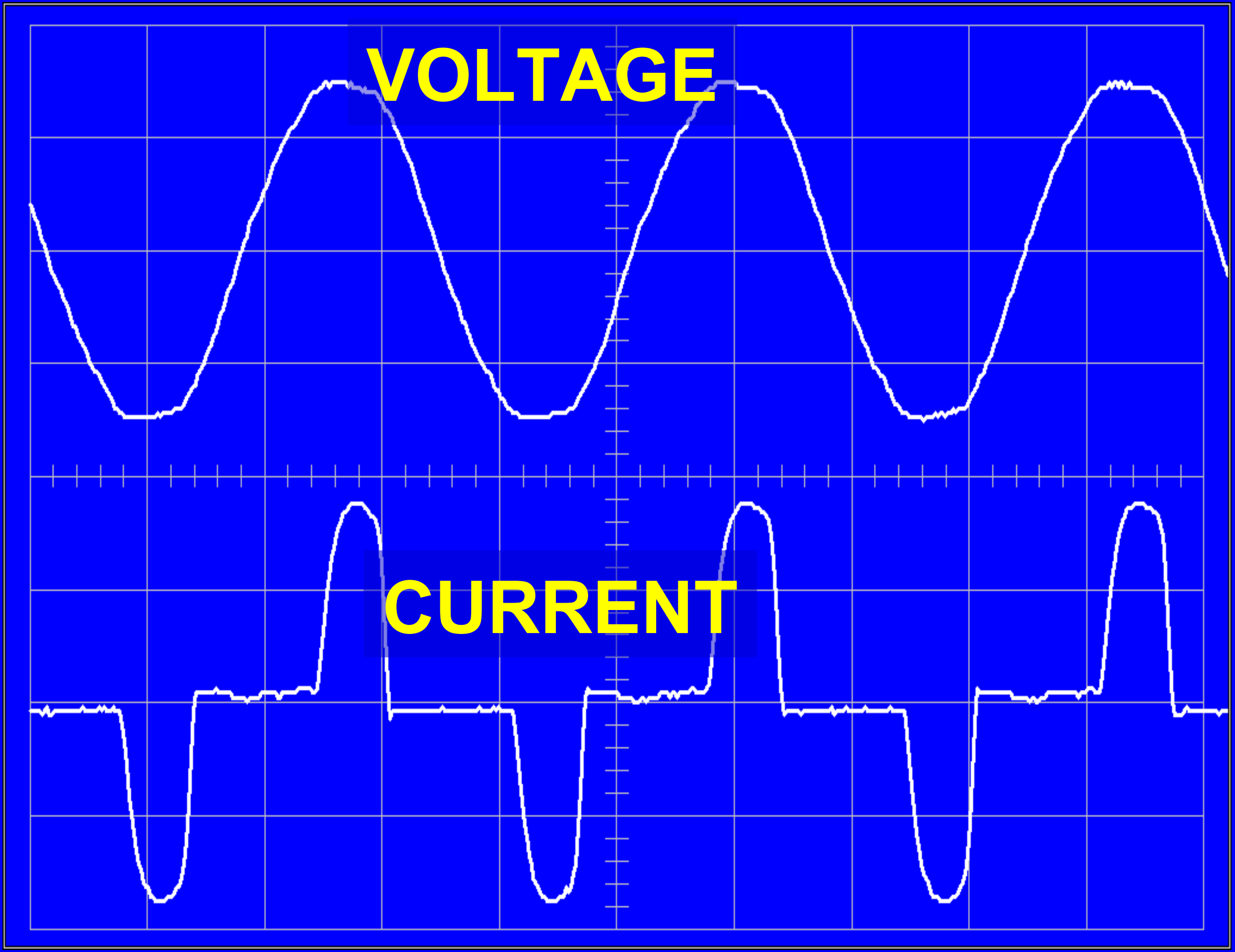
- Current flows only at peaks of AC cycle

WAVEFORM DISTORTION – CAUSES

QSC
RMX850
AC Current
Draw

Running at:
1KHz In
100W Out

4.4A RMS
9.1A Peak



The Harmonic Problem

- Nearly all electronic loads have power supplies with capacitor-input filters

  so:

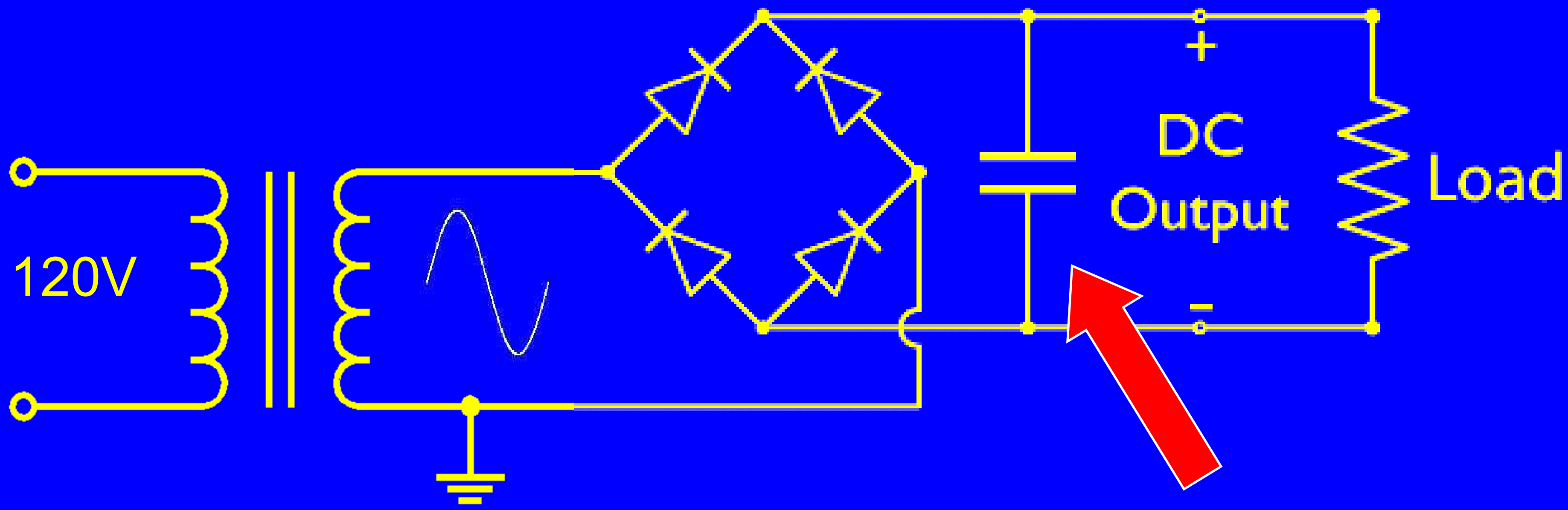
- Load current is drawn in short pulses at peaks of the input sine wave

  thus:

- Phase and neutral currents are highly distorted

The Harmonic Problem

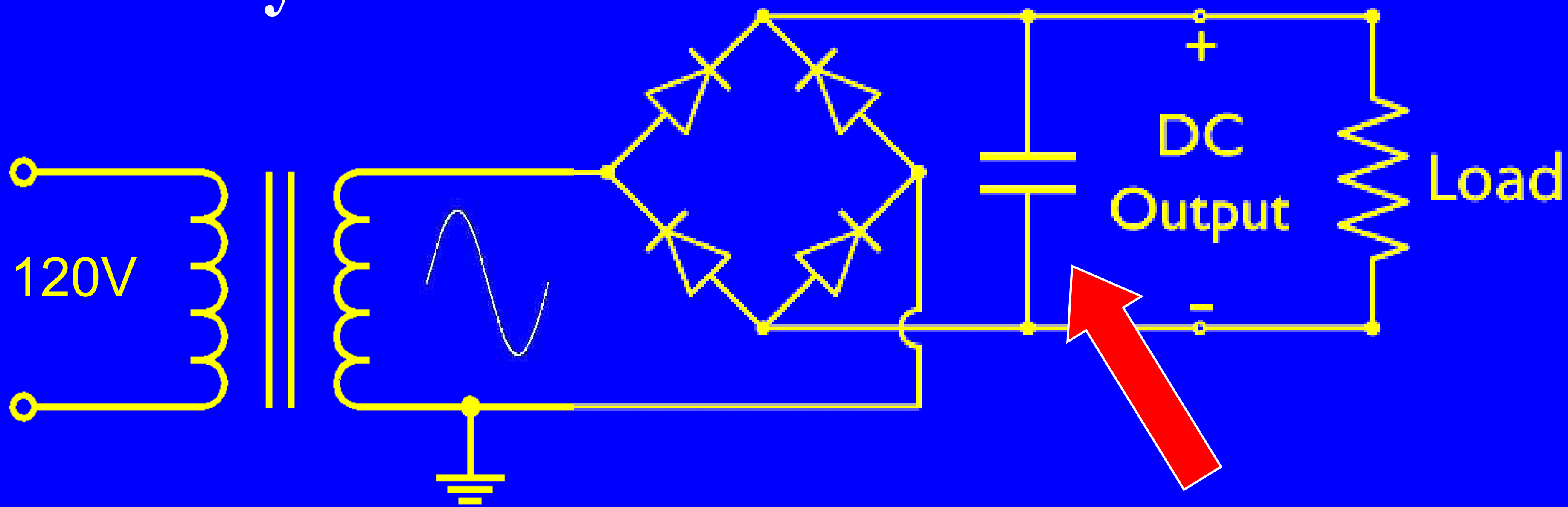
- **Remember this power supply?**



Something like it is in <u>every</u> piece of electronic gear – audio, video, computers, printers, copiers (even switching power supplies)

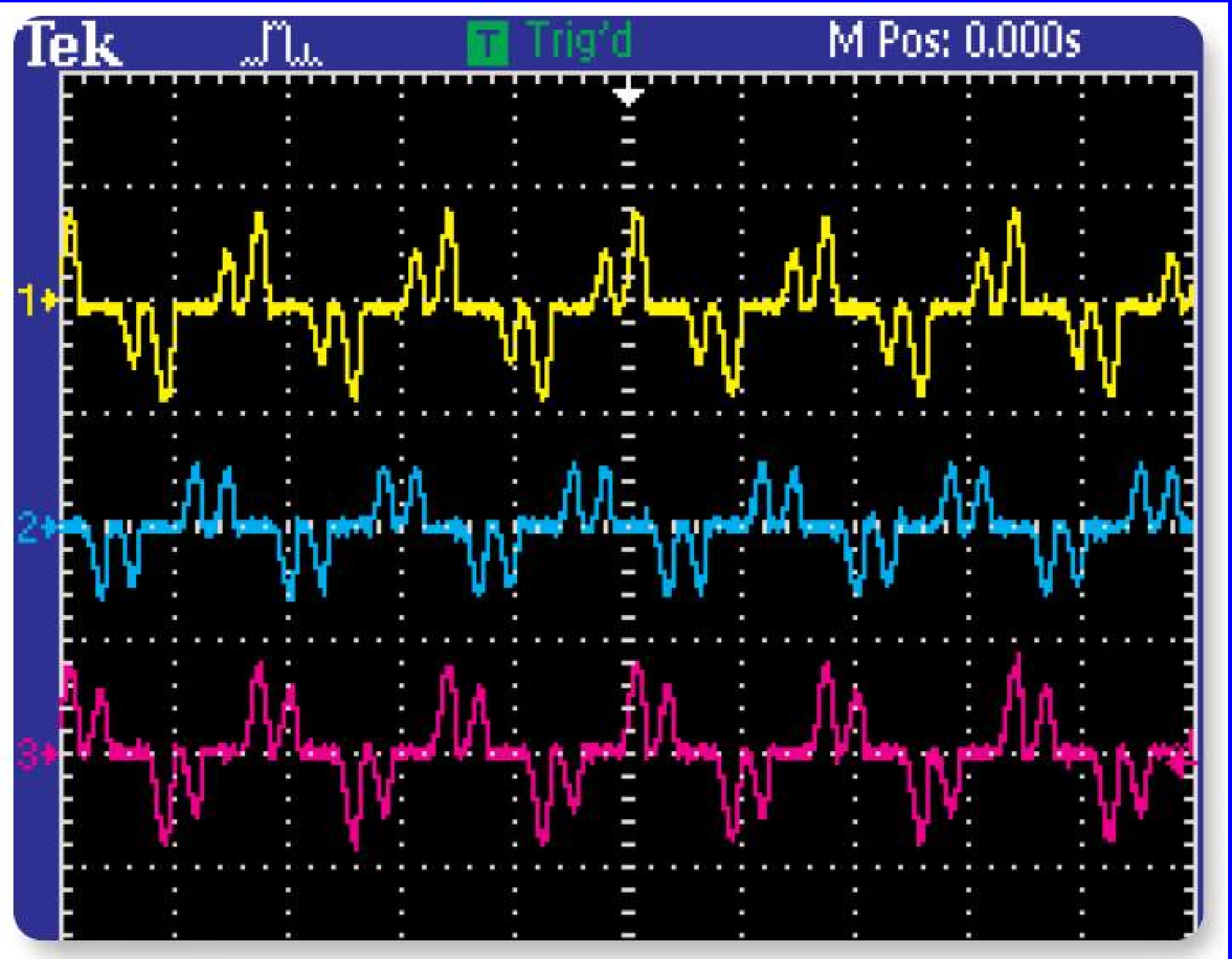
It Also Causes the Harmonic Problem

- The capacitor recharges at the peak of each cycle



- AC current is not even close to a sine wave
- Lots of harmonics of 60 Hz

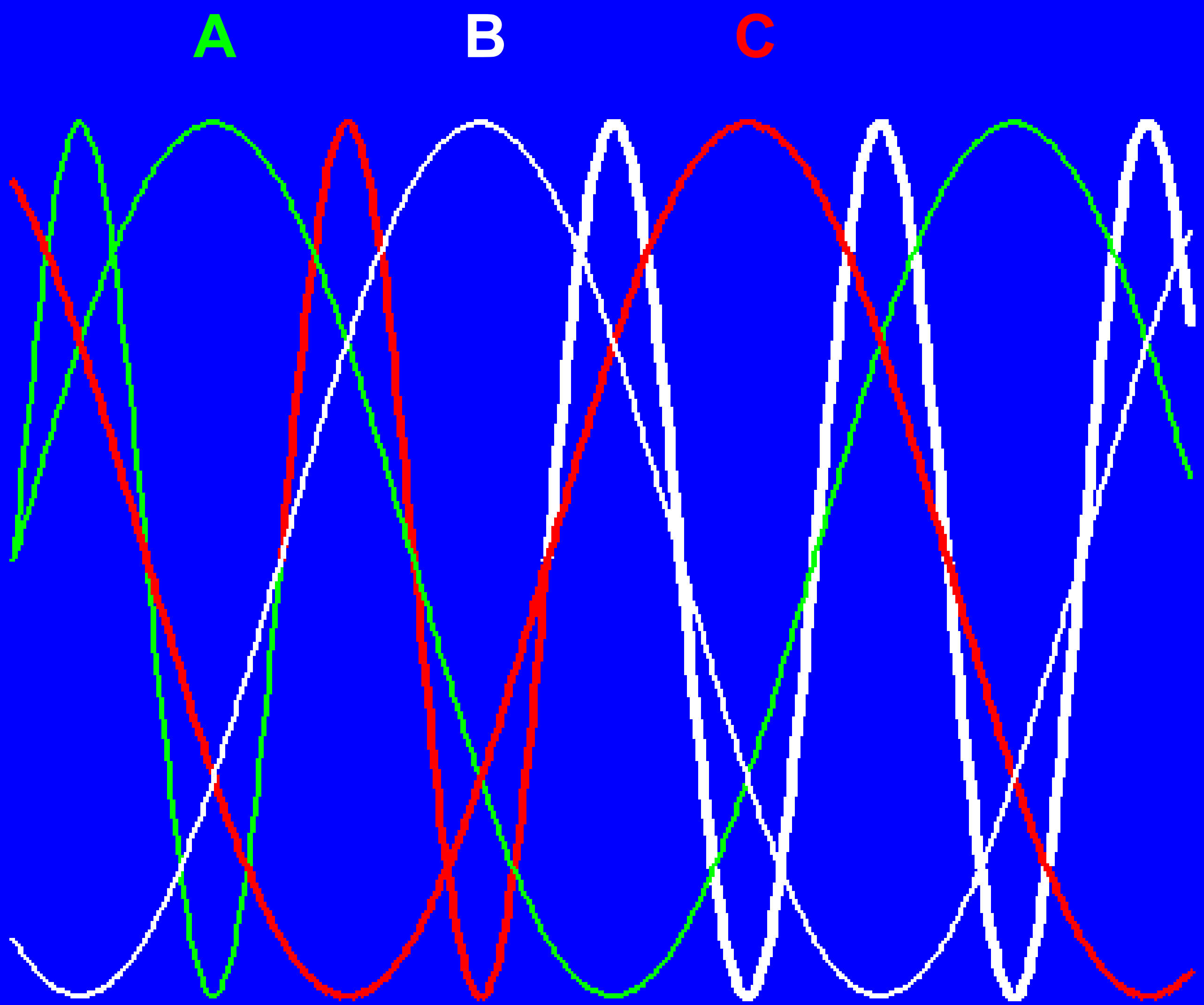
The Harmonic Problem



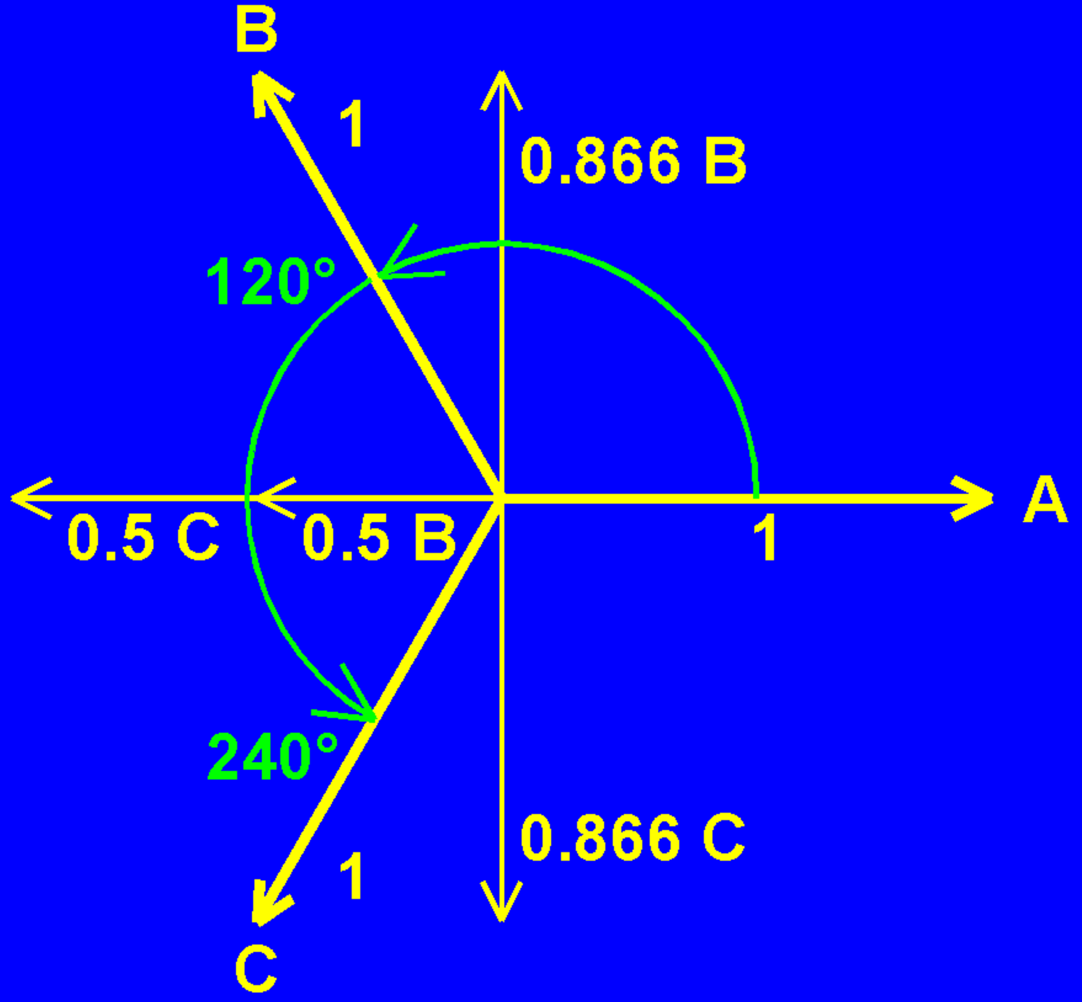
One Problem Occurs On the Neutral

- Fundamental cancels
- Most harmonics cancel
- Triplen harmonics ADD!
  - Third, sixth, ninth, etc
- And they also add on the Ground!

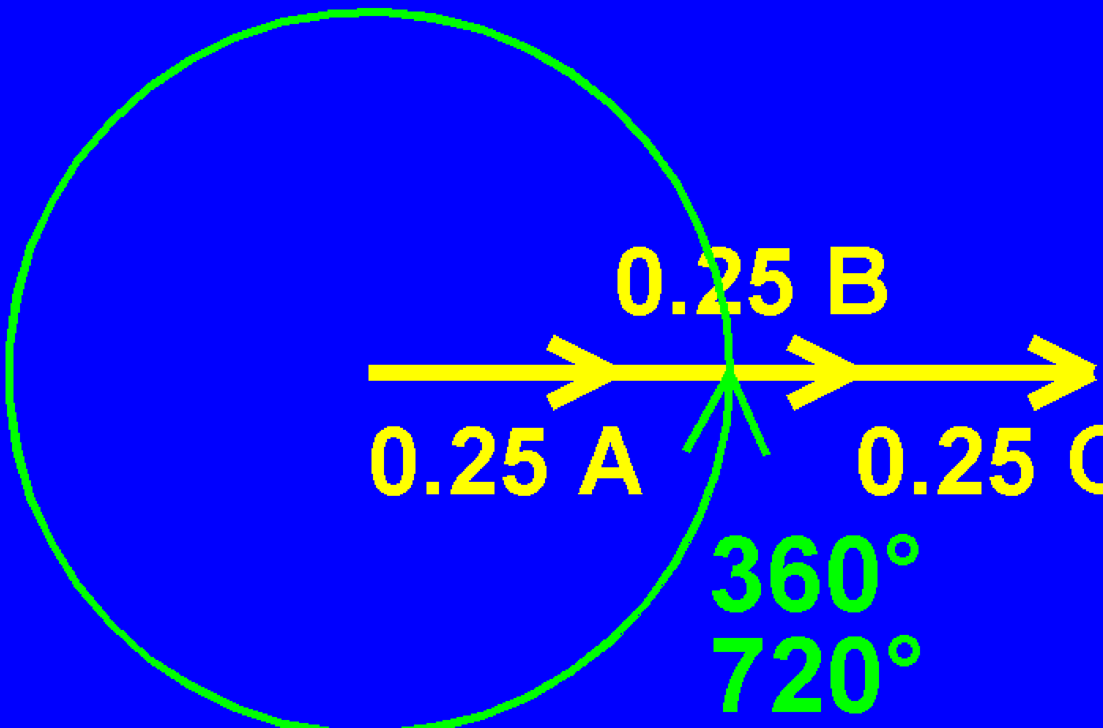
Fundamentals and Third Harmonics



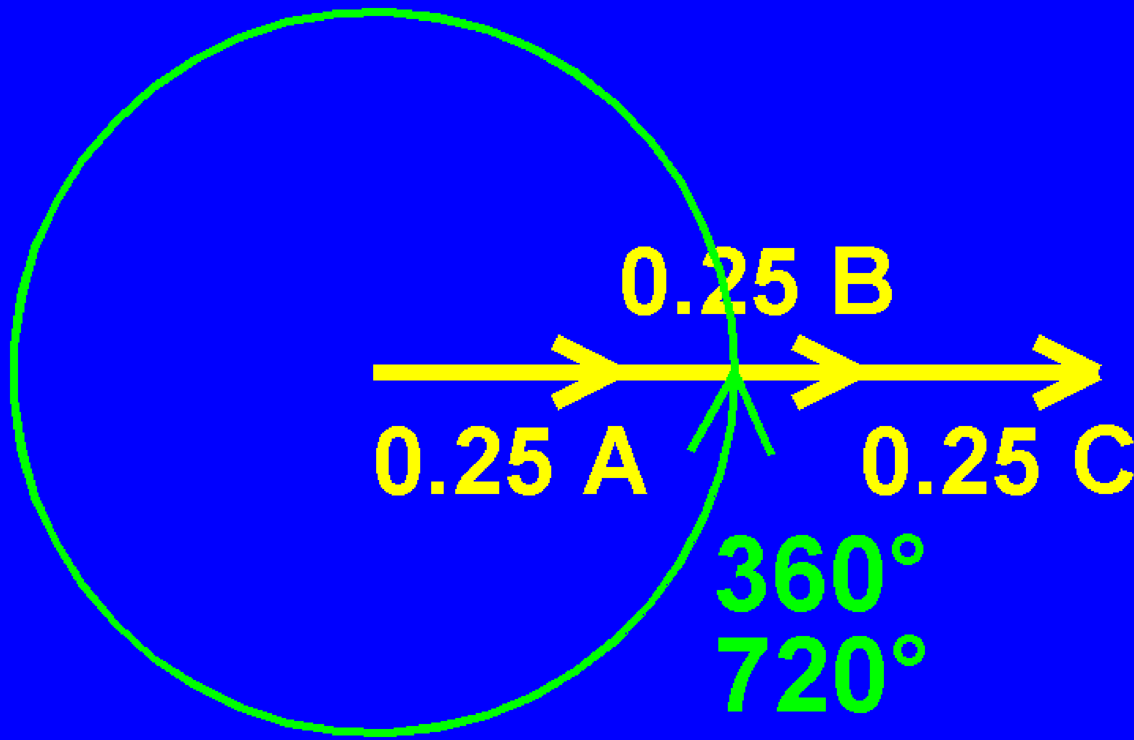
Three Phase Power Waveforms



3rd Harmonic on Neutral (Phasors rotate 3 times as fast as fundamental, so they all line up)



25% 3rd Harmonic on the Phases becomes 75% 3rd Harmonic on Neutral



What Happens in the Neutral?

- **Triplen harmonics ADD!**
  - **Third, sixth, ninth, etc**
- **Neutral current can be 1.7X the phase currents, even in a perfectly balanced system!**
- **Potentially dangerous overheating**
  - **Phase conductors (and contacts)**
  - **Transformers**
- **Use bigger copper in neutrals**
- **Use *K-rated* transformers**

Problems With Pulse Currents

- Because current flows in short pulses, the IR drop at the peak of the current waveform can be much greater than for a sine wave
  - Greater I^2R losses
  - Voltage waveform is distorted
  - Lower voltage delivered to equipment
  - Increased heating in phase and neutral conductors
  - Increased heating in transformers

K-Factor

- Describes heating effects of harmonics in iron cores of motors, transformers, etc
- $K = \Sigma h^2 (I_h)^2$ where I_h is fraction of total current in each harmonic
- $K = (I_1)^2 + 4(I_2)^2 + 9(I_3)^2$

$+16(I_4)^2 + 25(I_5)^2 + 36(I_6)^2$

$+49(I_7)^2 + 64(I_8)^2 + 81(I_9)^2$

$+100(I_{10})^2 + 121(I_{11})^2 + 144(I_{12})^2 \cdots$

K-Factor

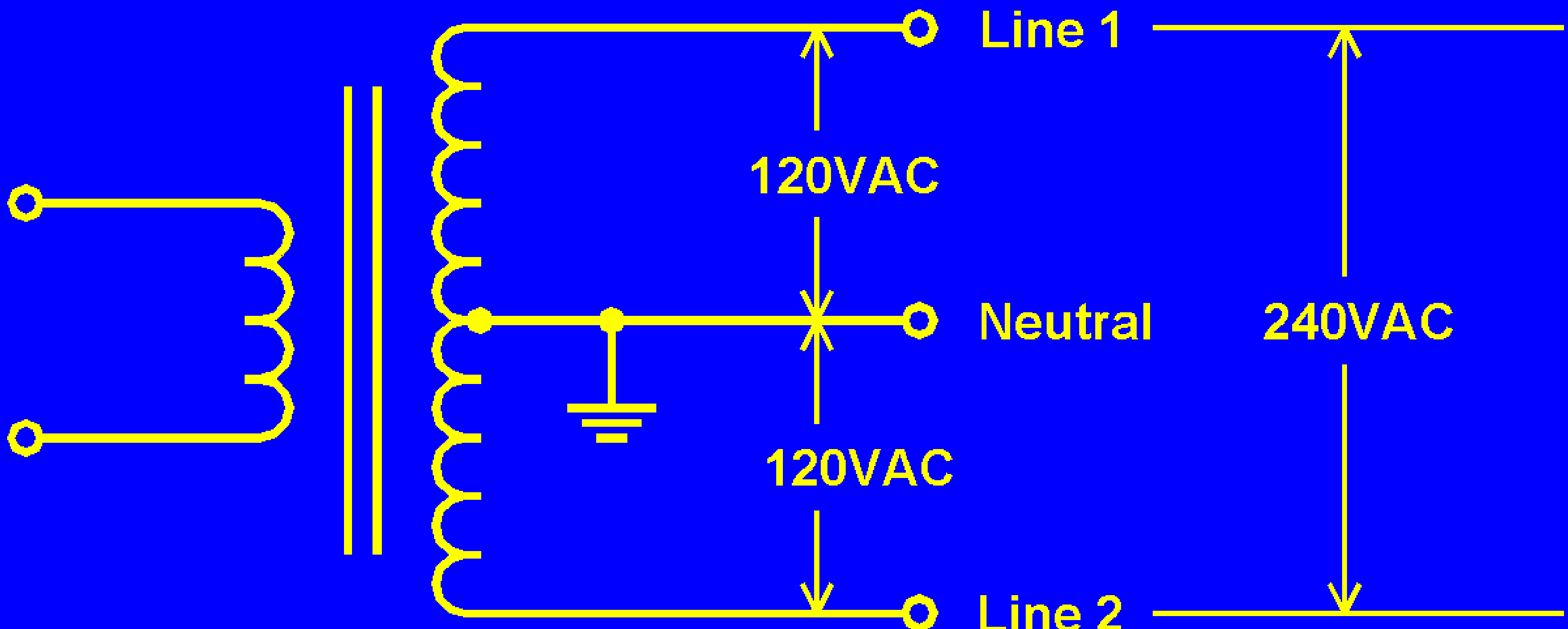
- Typical Values
  - 12 – 20 for electronic components
  - 3-6 for entire systems
  - Some cancellation occurs when many components are summed
- K-rated transformers and other components are designed to handle the harmonics
- Oversize the neutral by 2:1
  - Use double-size conductors (3 wire gauges)
  - switches and other hardware should be rated for twice the current

Why Three-Phase Power?

- **Power is generated by rotating machines that produce 3-phase power**
- **Pure sine waves cancel in the neutral if the phases are balanced**
- **Big motors run far more efficiently on 3-phase power**
- **None of this helps audio and video systems!**

Which power configuration is best for for Audio and Video Systems?

Single Phase Power (North America)
(Sometimes called “Split” Single Phase)

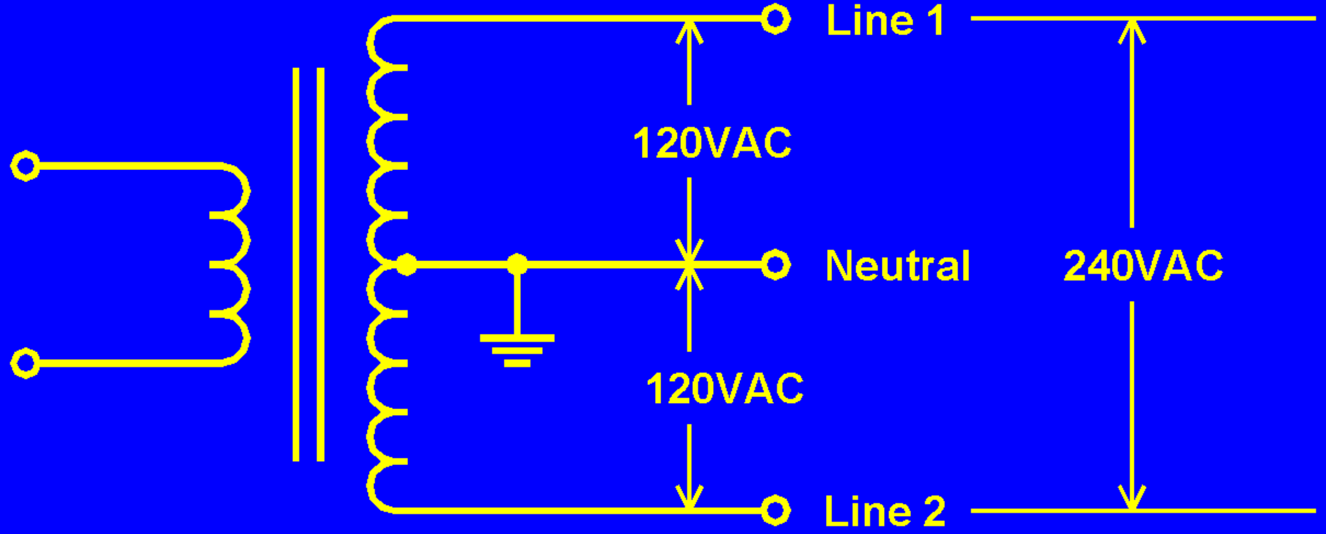


Split Single-Phase Power

- No harmonic problems in the neutral
  - Better cancellation of neutral current
  - Less noise coupled to audio and video systems
- Audio and video systems don't use a lot of power, so a split single phase system can easily supply <u>enough</u> power
- Audio and video systems don't use big motors, so 3-phase is not "better"

Split Single-Phase Power

- Double the voltage is available by using both sides of the center-tapped feed
  - Good for high power video projectors



Power and Grounding For Audio and Video Systems Part 1

Jim Brown

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