

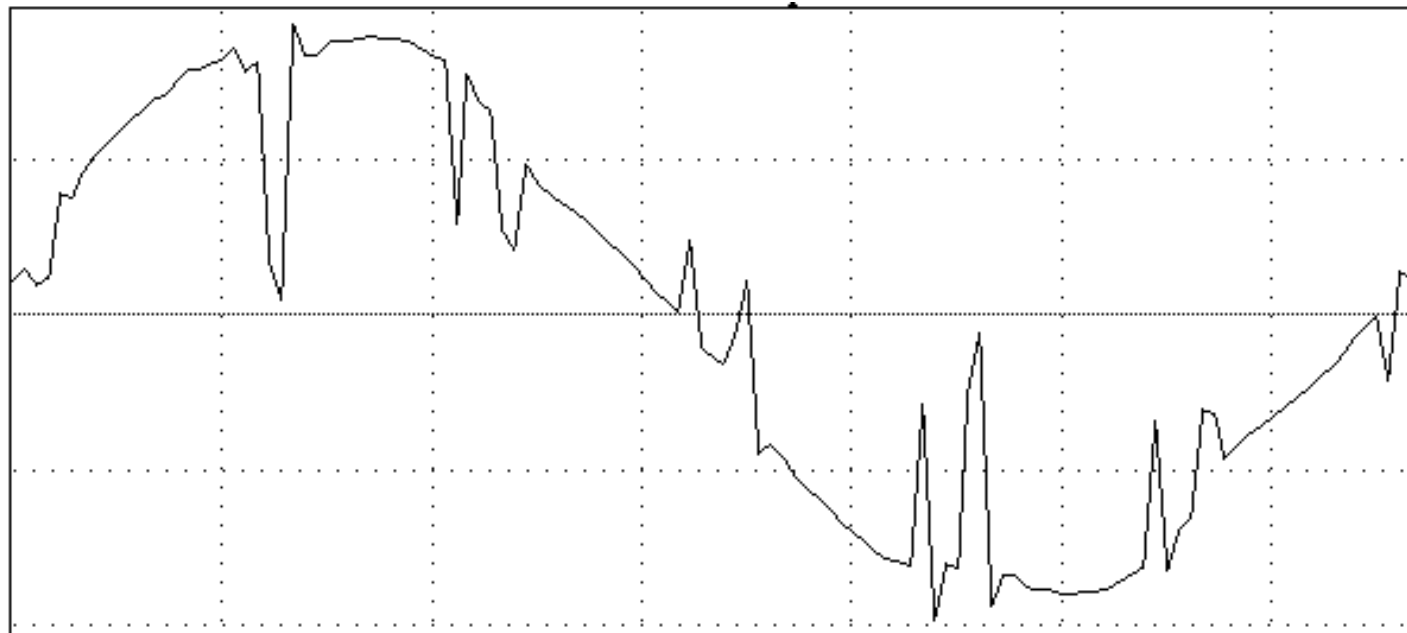


# **Power Quality Design Issues for AC Drives**

**Keith Benson  
IEEE- MCPQ  
2/1/2005**



**“Power Quality is not a problem  
for AC Drives unless it is a problem!”**



Horizontal 2500 microseconds/division      Vertical 500 Volts/division  
Urms: Prev=610.7, Min=605.5, Max=605.5      - Worst Imp=      0 Vpk, 0 deg



# PQ Issues

---

**Either**

- **PQ creates Drive Problems**

**Or**

- **Drive creates PQ problems for  
other connected equipment**



# What is an AC Drive

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## Electronic Power Module

With Fixed Voltage, Fixed Frequency **Input**

ie 460 VAC, 3Phase, 60 Hz

And Variable Voltage, Variable Frequency **Output**

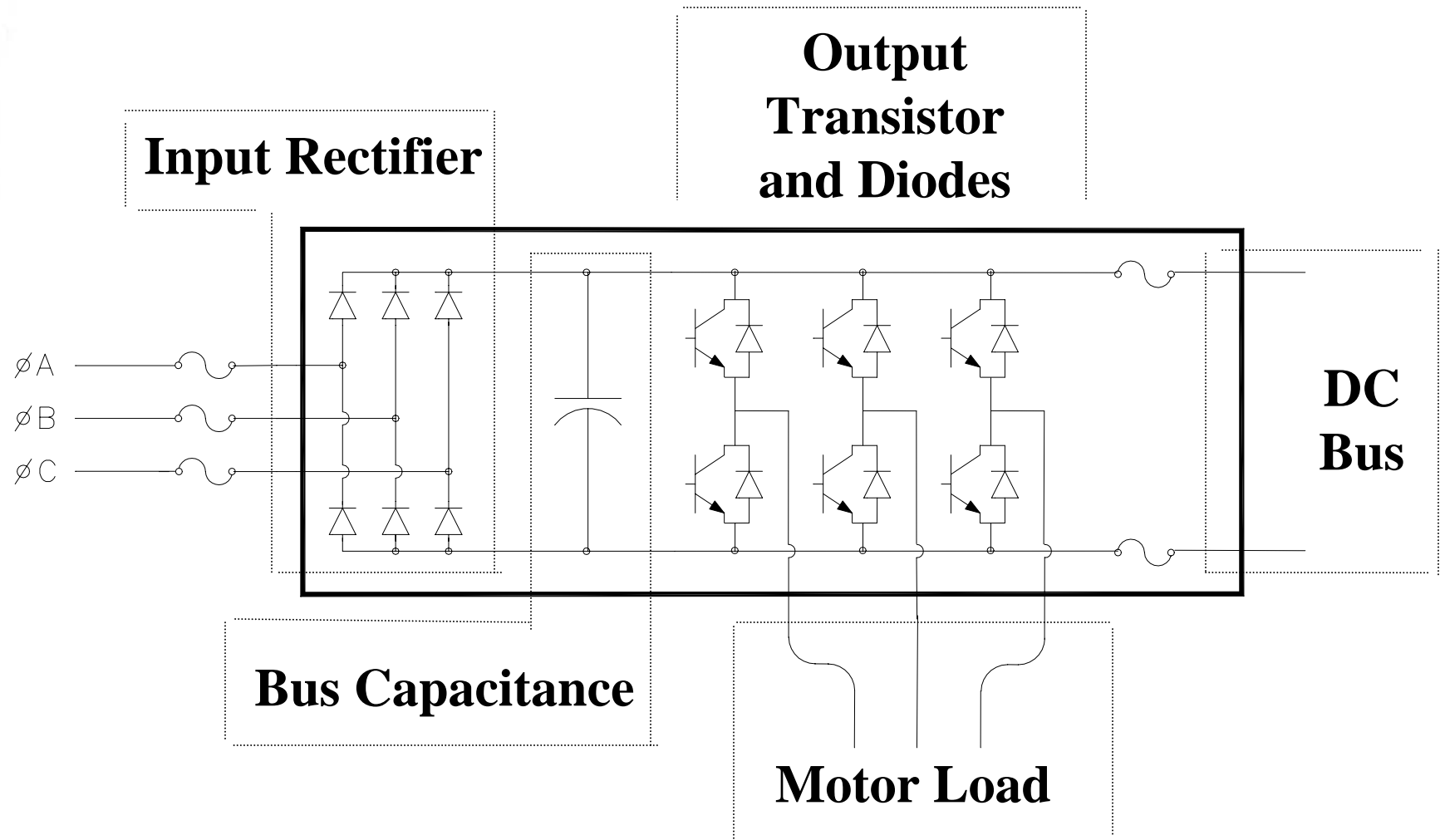
ie 230 VAC, 3Phase, 30 Hz

That is used to achieve **Control** of:

Speed, Torque, Flow, etc.



# Typical PWM Drive Topology





# AC Drive Input/Output

---

## Equal

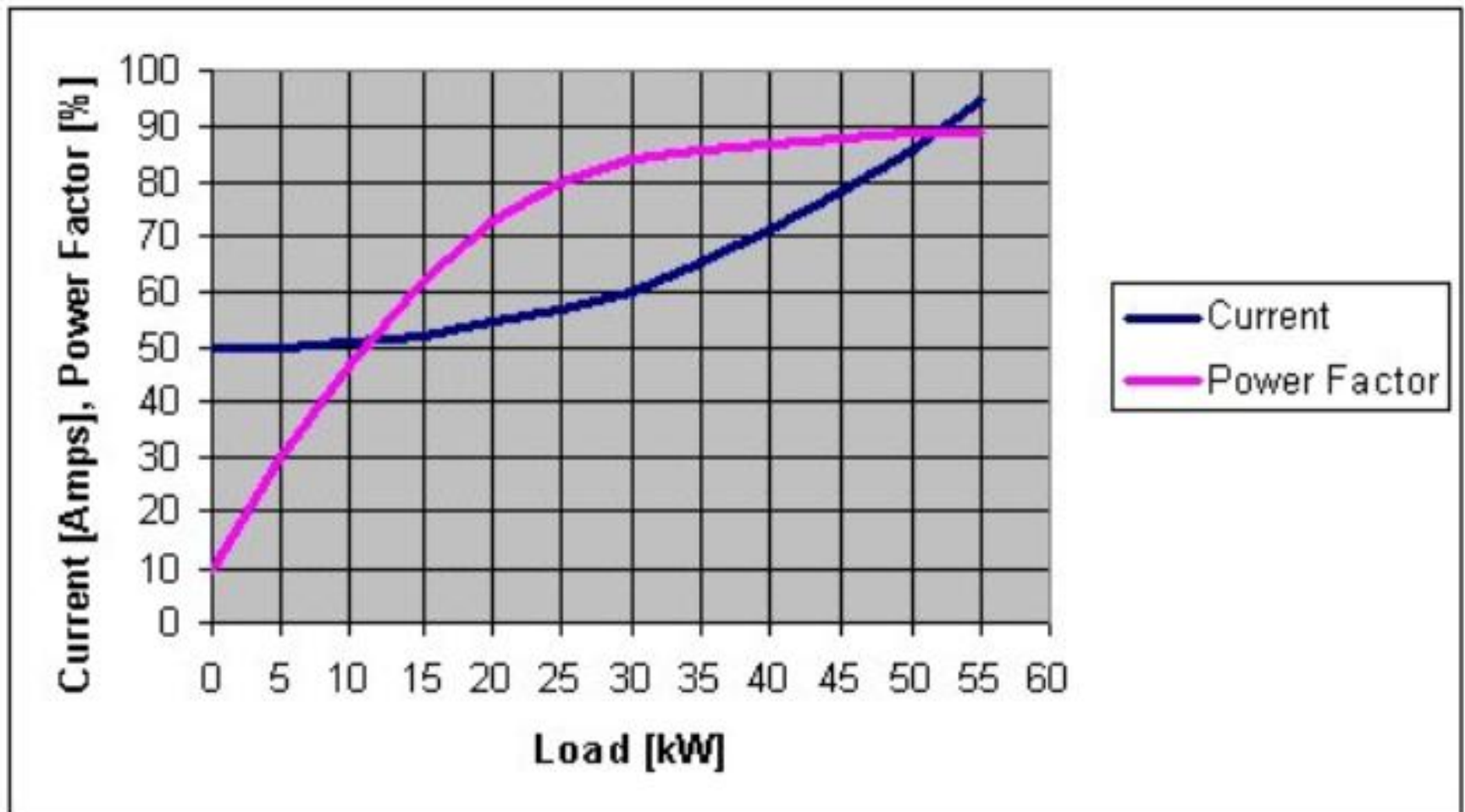
- Kw

## Not Equal

- KVA, Current, Power Factor, Harmonics, etc.

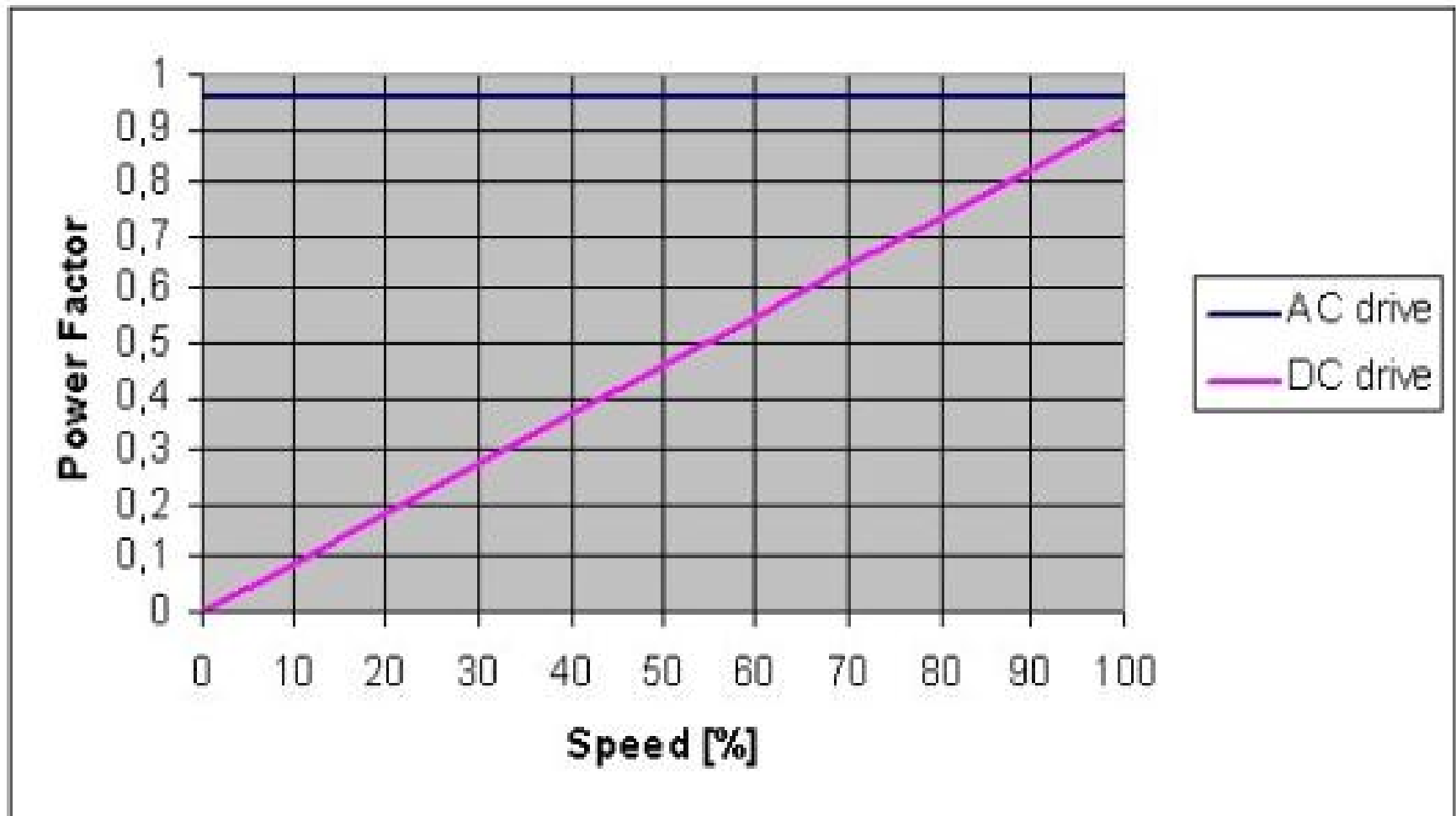


# AC Motor Power Factor





# AC / DC Drive Power Factor







# Drive PQ Problems

---

- **Loss of Drive Enable**
- **Component Failure**
- **Over Voltage**
- **Under Voltage**



# Loss of Drive Enable

---

## What

- **Initiates drive shutdown command**

## When

- **Loss of 24 VDC I/O supply**
- **Loss of Interlock Contactor**



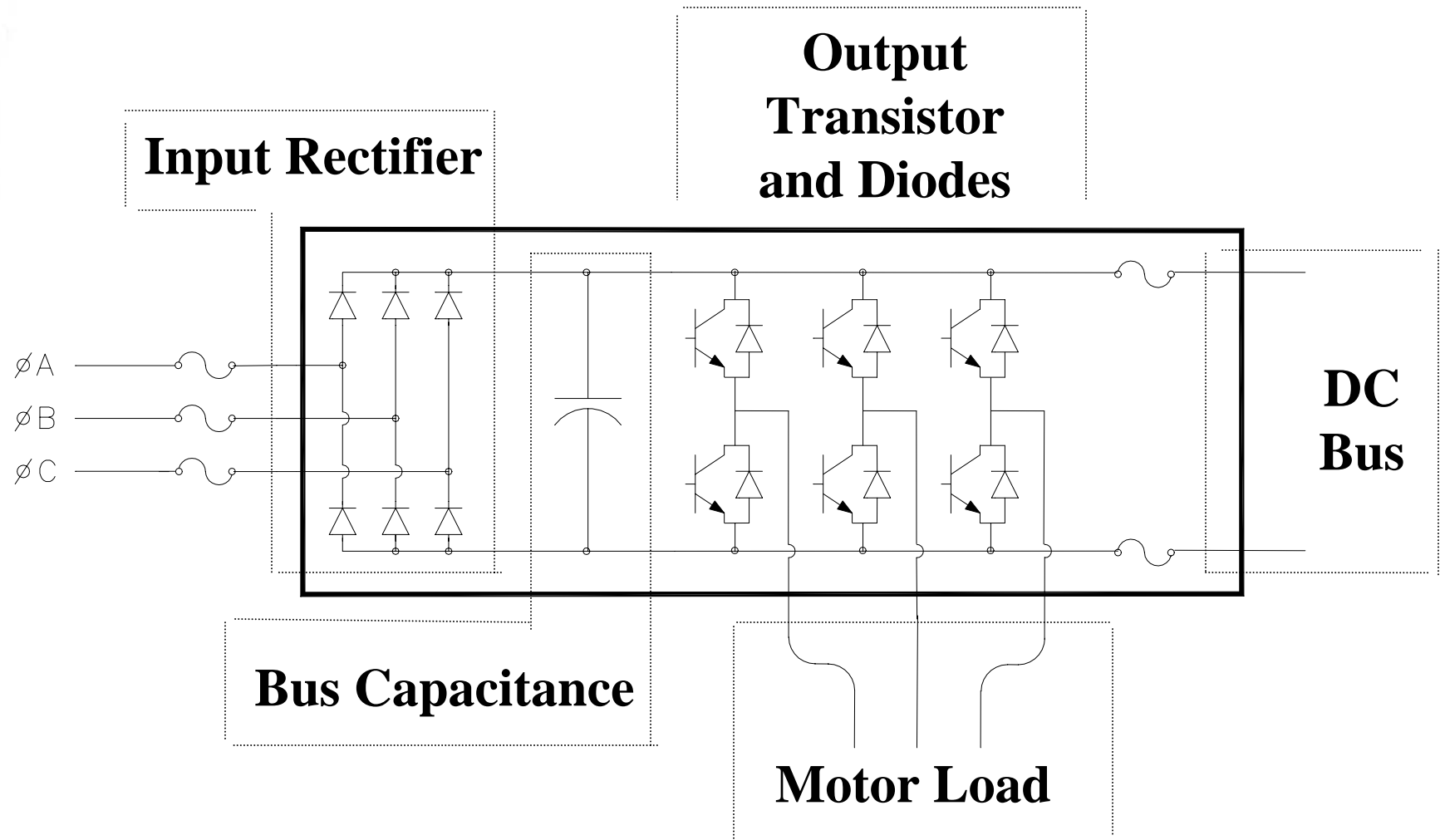
# Component PQ Failures

---

- **Fuse**
- **Capacitor**
- **Transistor**
- **Precharge**
- **MOV**



# Typical PWM Drive Topology





# Fuse PQ Failures

---

## Why

- **High RMS Currents**

## When

- **Single Phasing**
- **Line Unbalance**



# Capacitor PQ Failures

---

## Why

- **High Ripple Currents**

## When

- **Single Phasing**
- **Line Unbalance**



# Transistor PQ Failure Causes

---

## Why

- **VDC > 2x Nominal**
- **High Frequency Transients**

## When

- **Power factor Capacitor Switching**
- **SCR Ringing**



# Precharge Circuit PQ Failures

---

## What

- **Contacts welding**

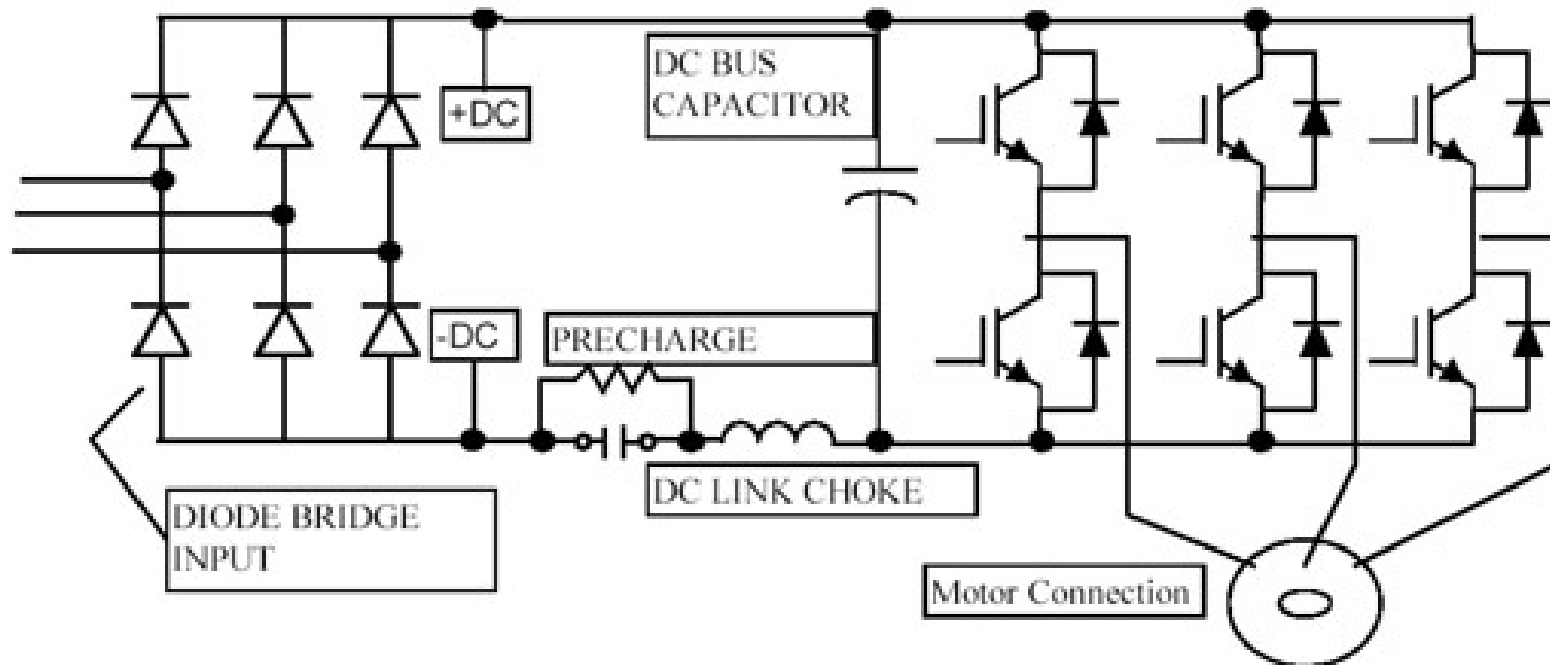
## When

- **On Power Dip Recovery**  
**High surge Currents**





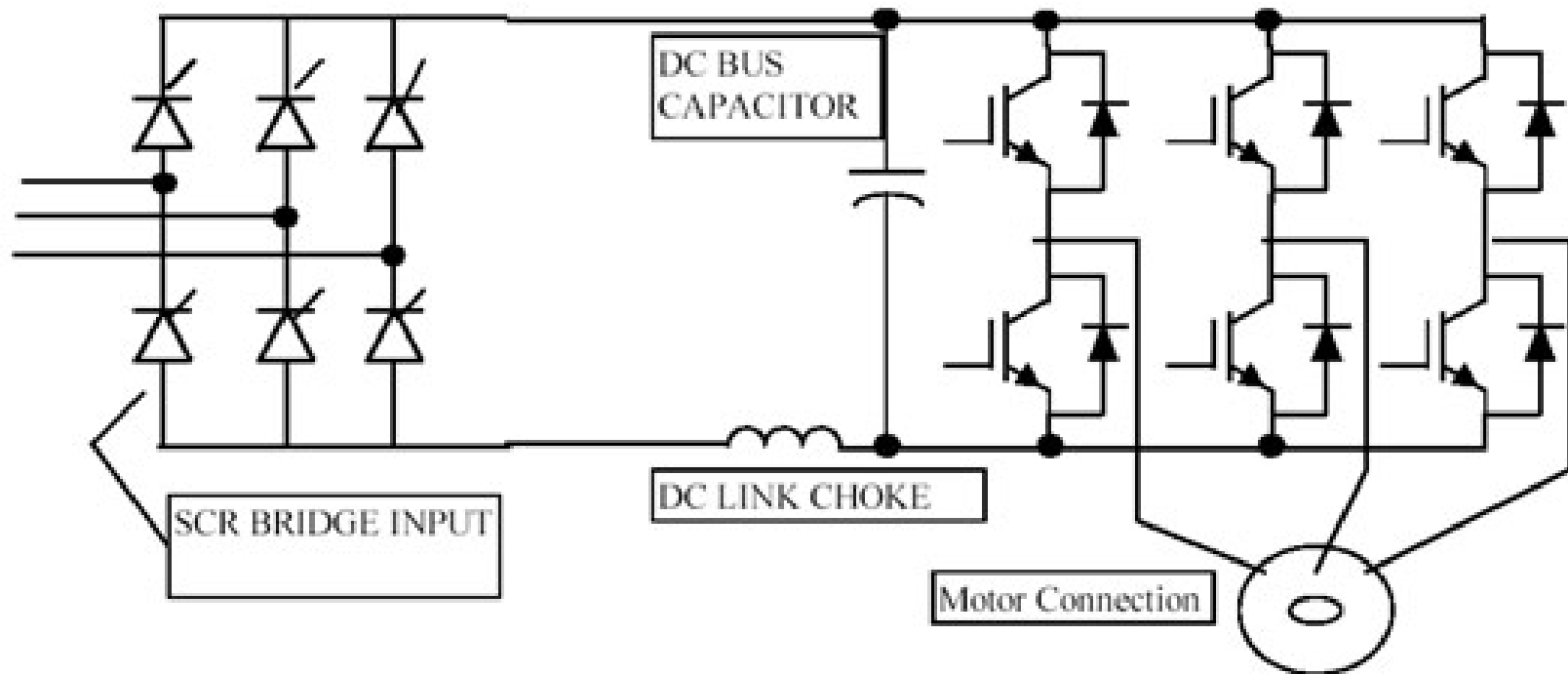
# Drive Precharge with Resistor



Smaller Drives < 25 Hp



# Drive Precharge with SCR's



Bigger Drives > 25 Hp



# MOV PQ Failures

---

## Why

- **High Peak Over Voltage**

## When

- **Line Surges and Swells**
- **Repetitive Transients**
- **Ring Waves**



# Over and Under Voltage Faults

## What

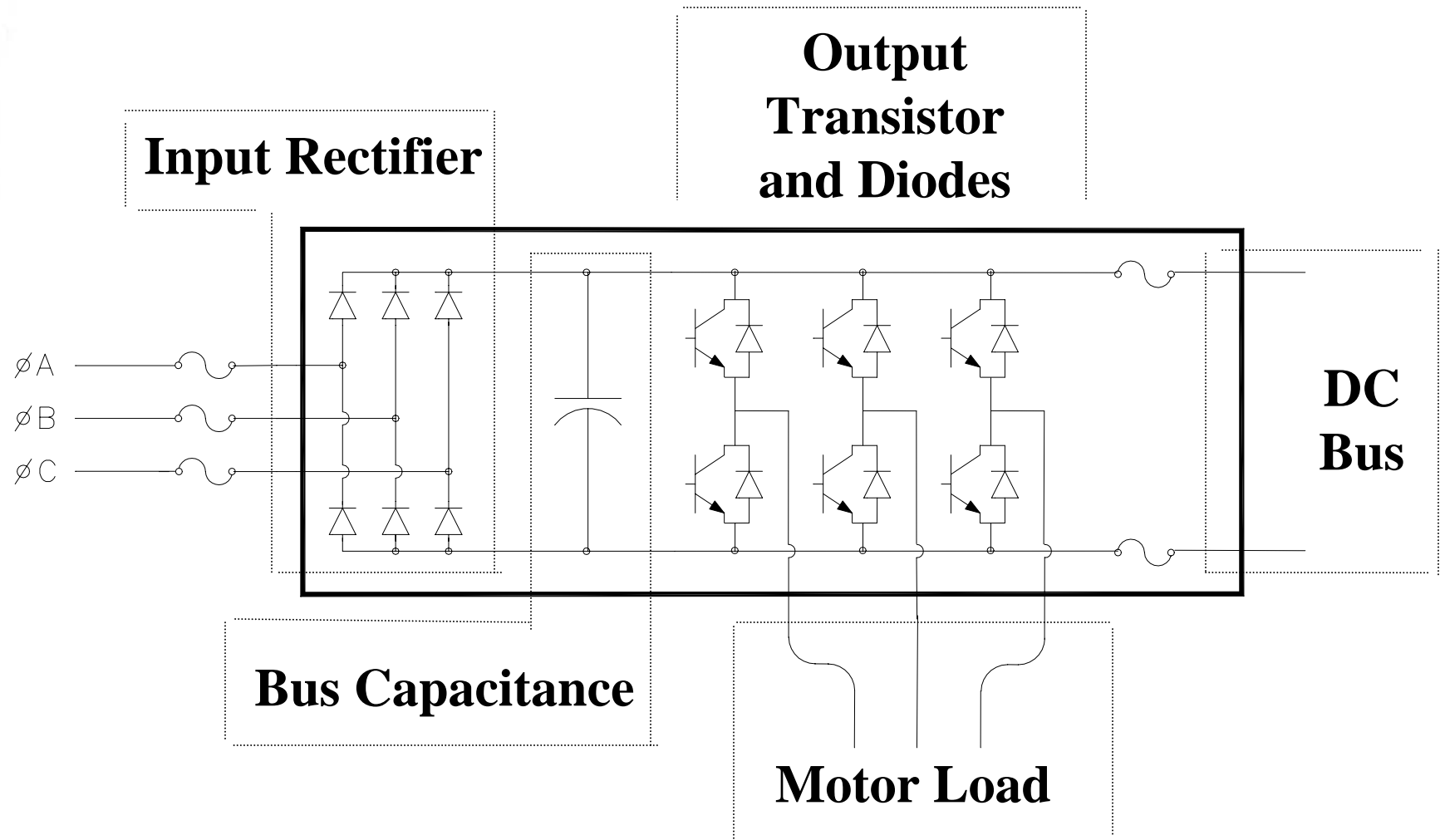
- PQ shutdowns are Voltage related,  
not Current Related

## How Sensed

- DC Bus



# Typical PWM Drive Topology





# Typical Parameters for 460/480 VAC Drives

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**DC Bus = 640 VDC (460 VAC), 670 VDC (480 VAC).**

**DC Bus + 10% = 740VDC (480 VAC).**

**Over Voltage**

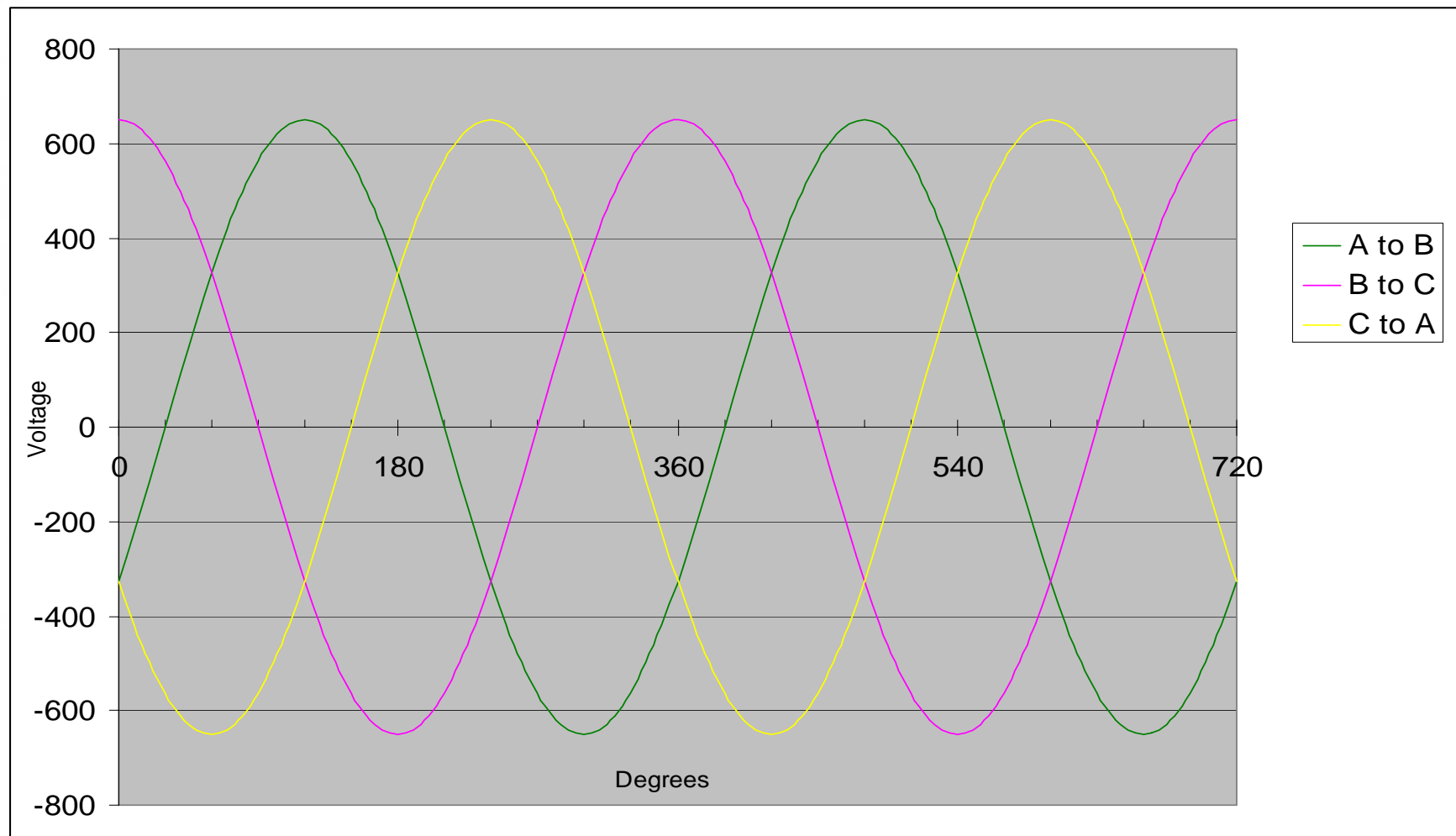
**Drive Over Voltage Trip at 800 VDC.**

**Under Voltage**

**DC Bus \* 85% = 544 VDC (460 VAC).**

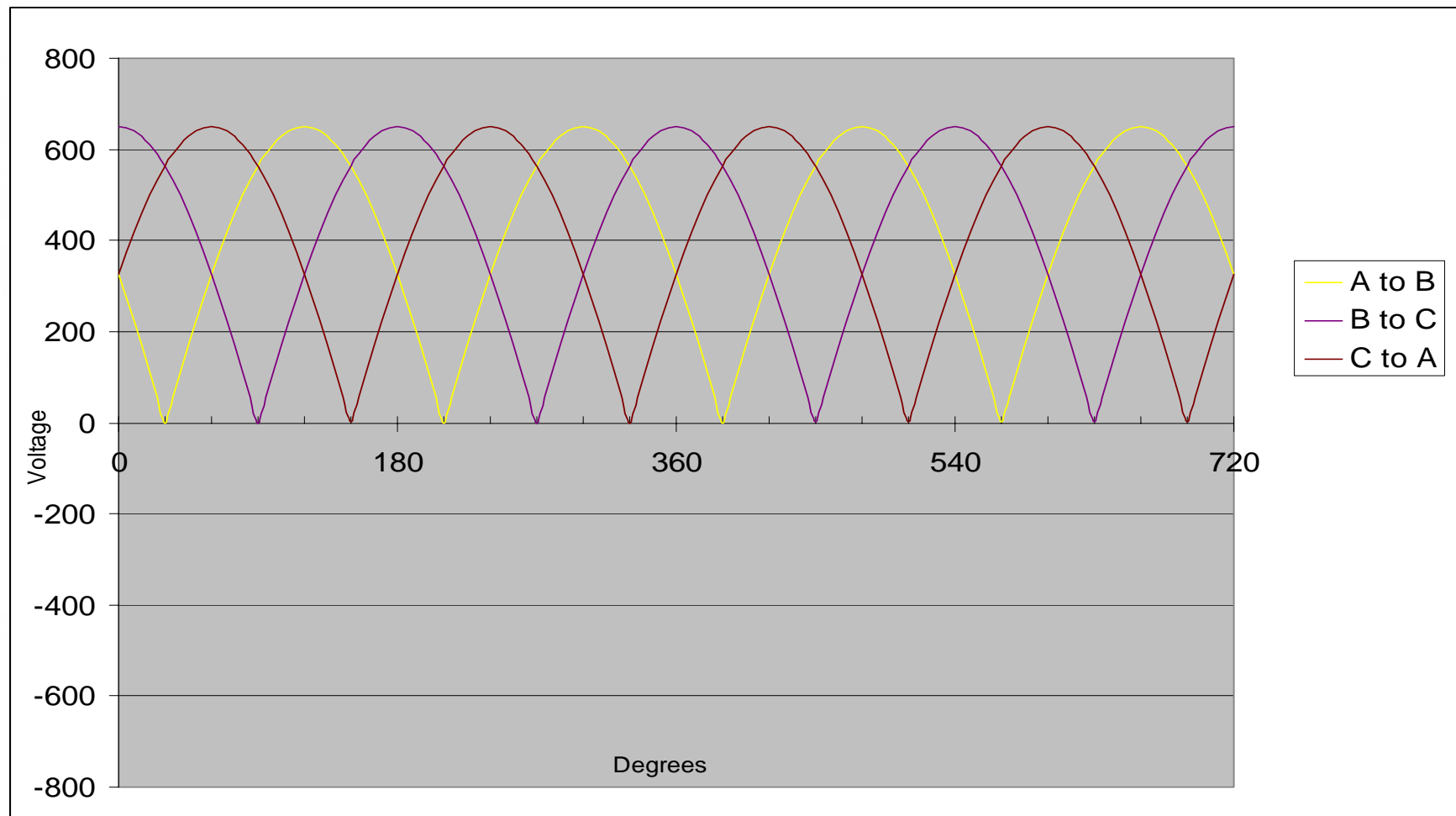


# 3 Phase Input





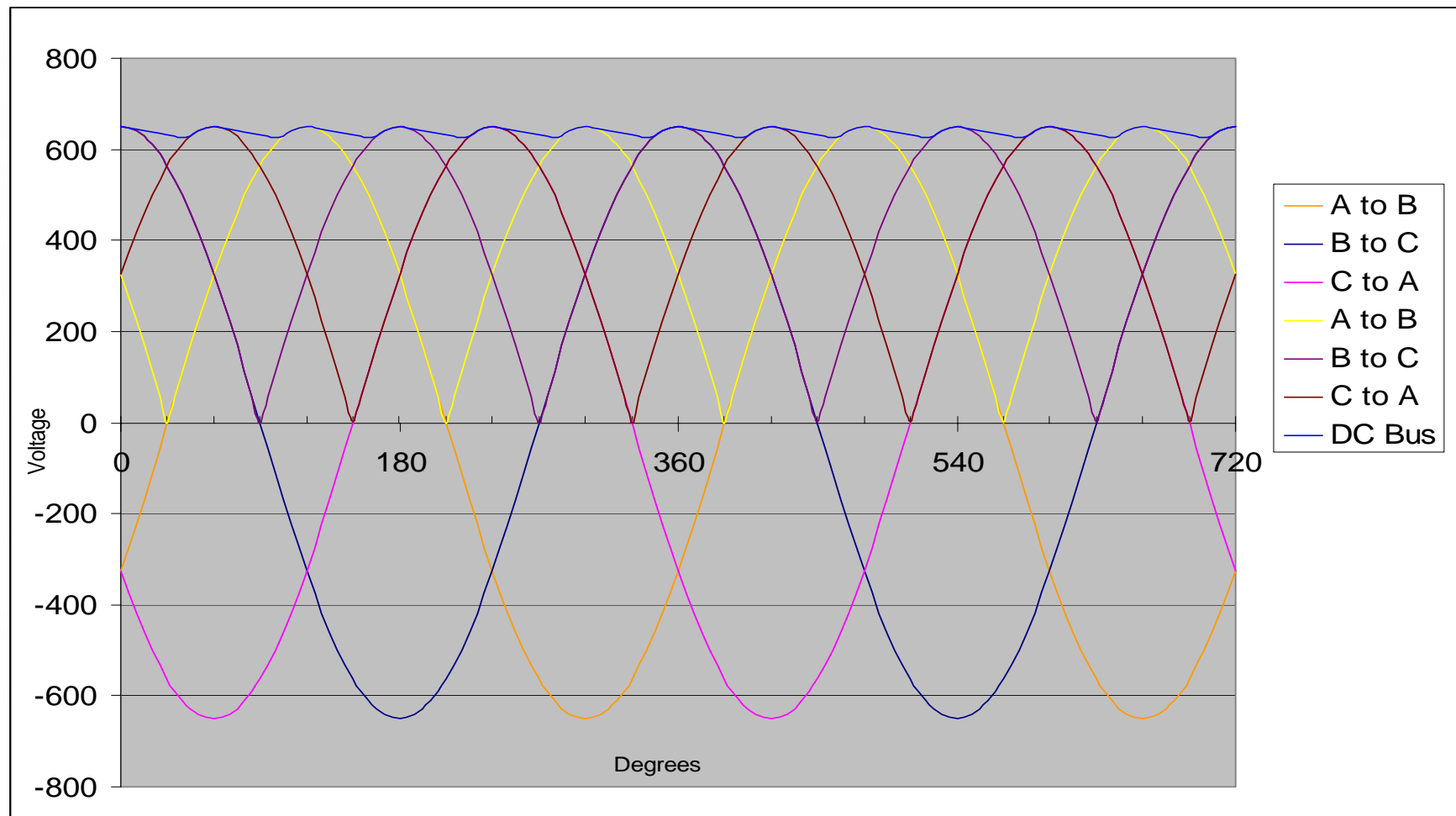
# 3 Phase Rectified





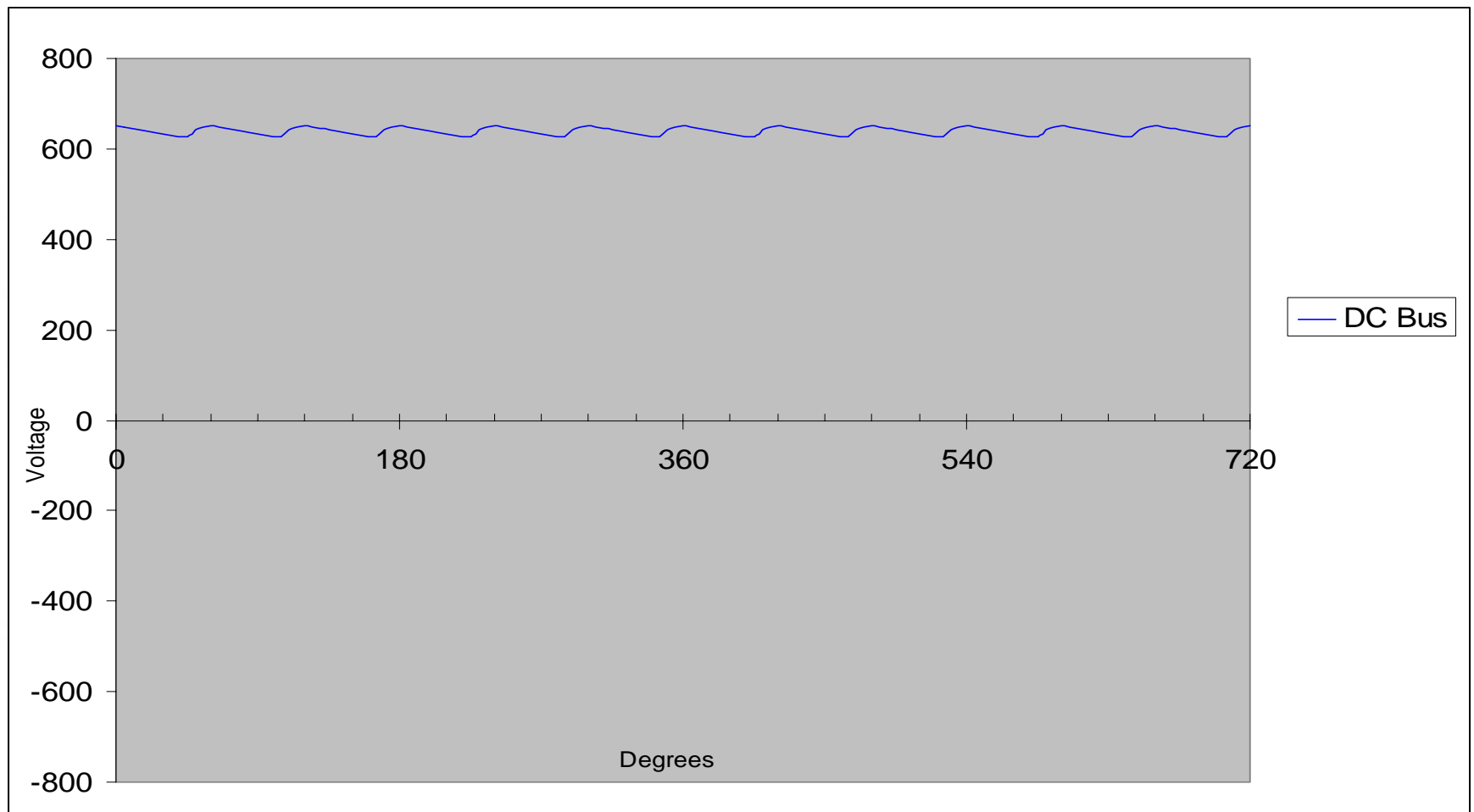


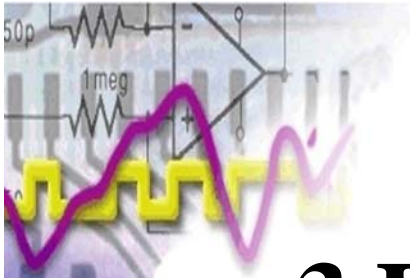
# 3 Phase AC, Rectified & DC



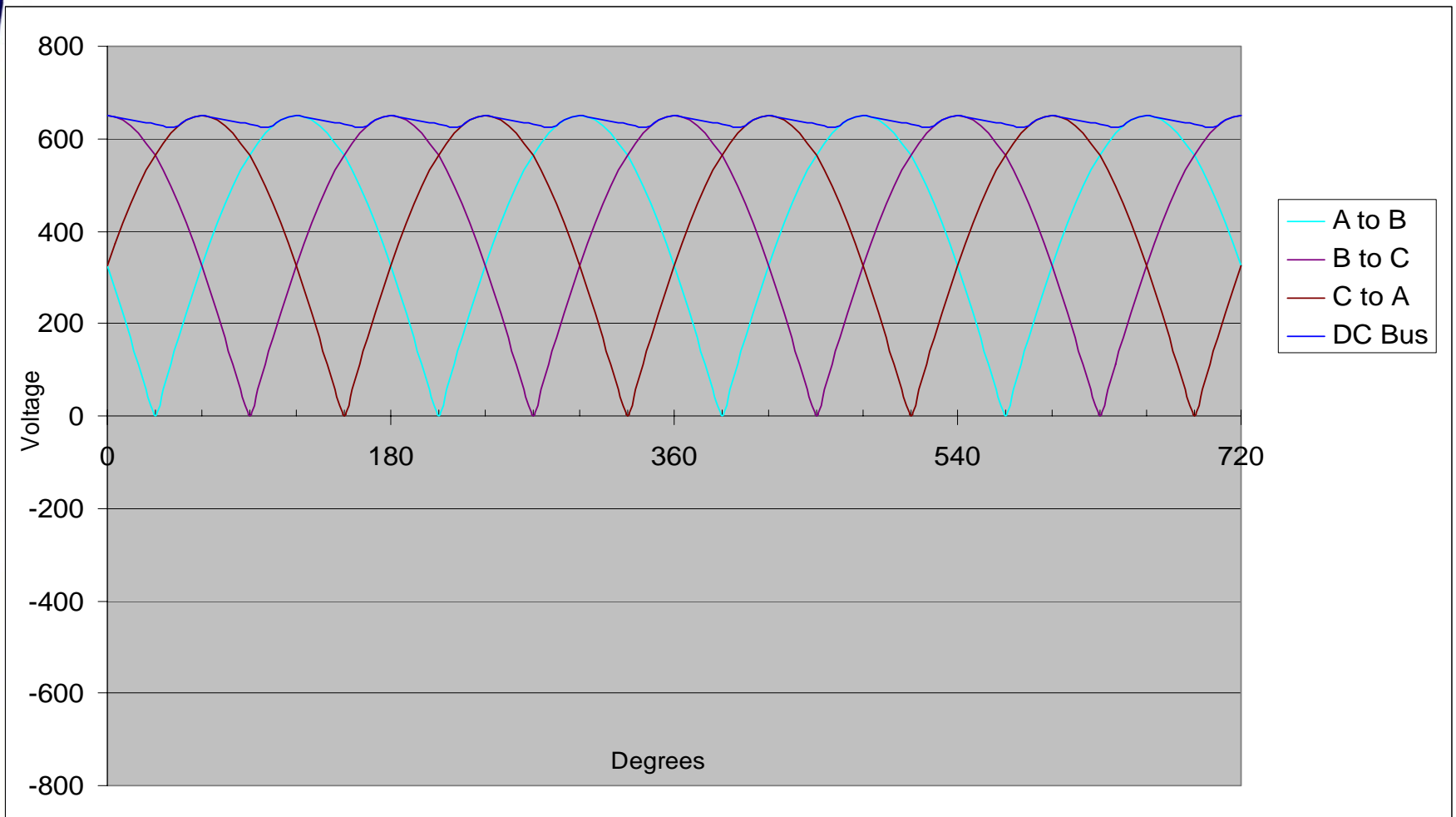


# 3 Phase Filtered



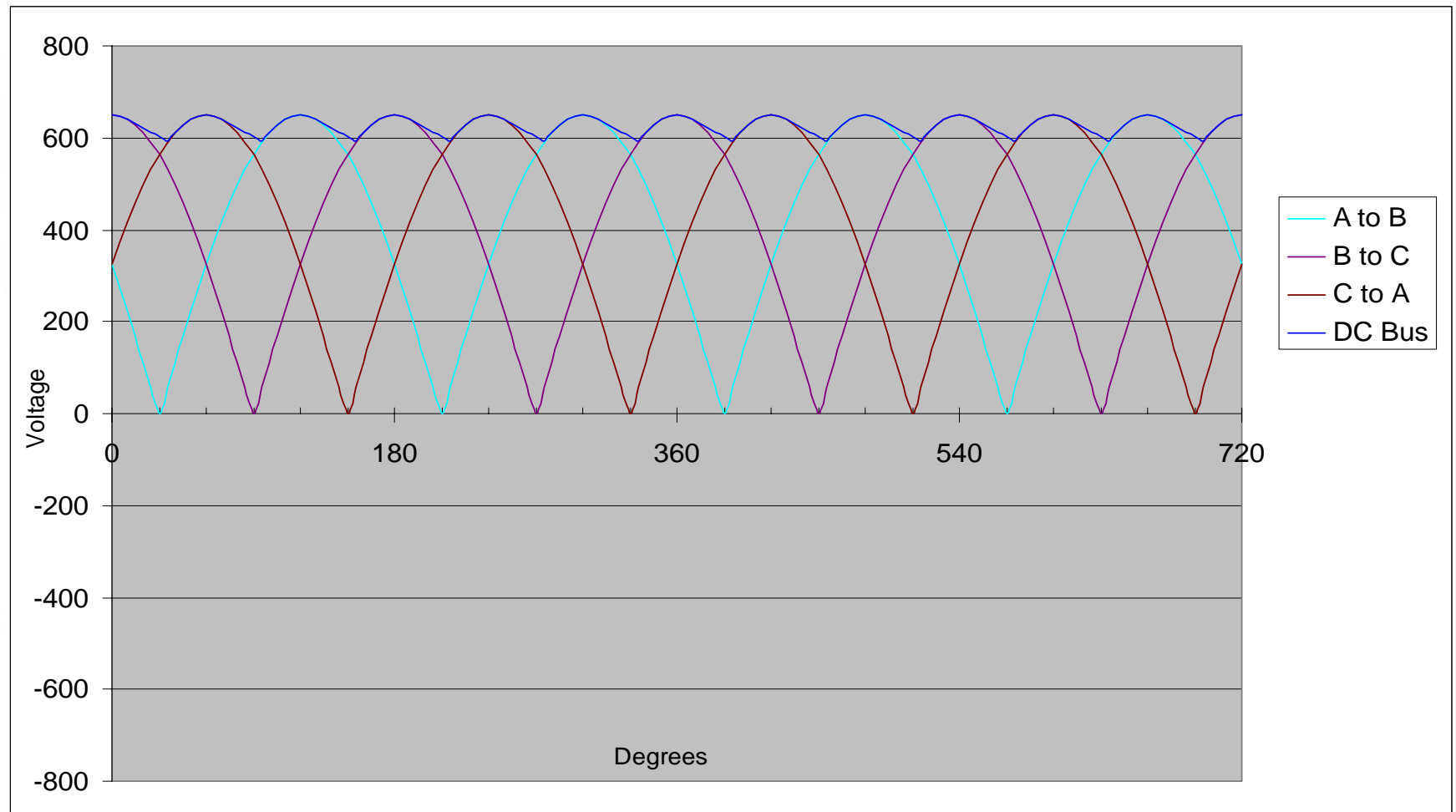


# 3 Phase, Light Load, Big Cap





# 3 Phase, Heavier Load, small Cap





# Increasing Bus Capacitance

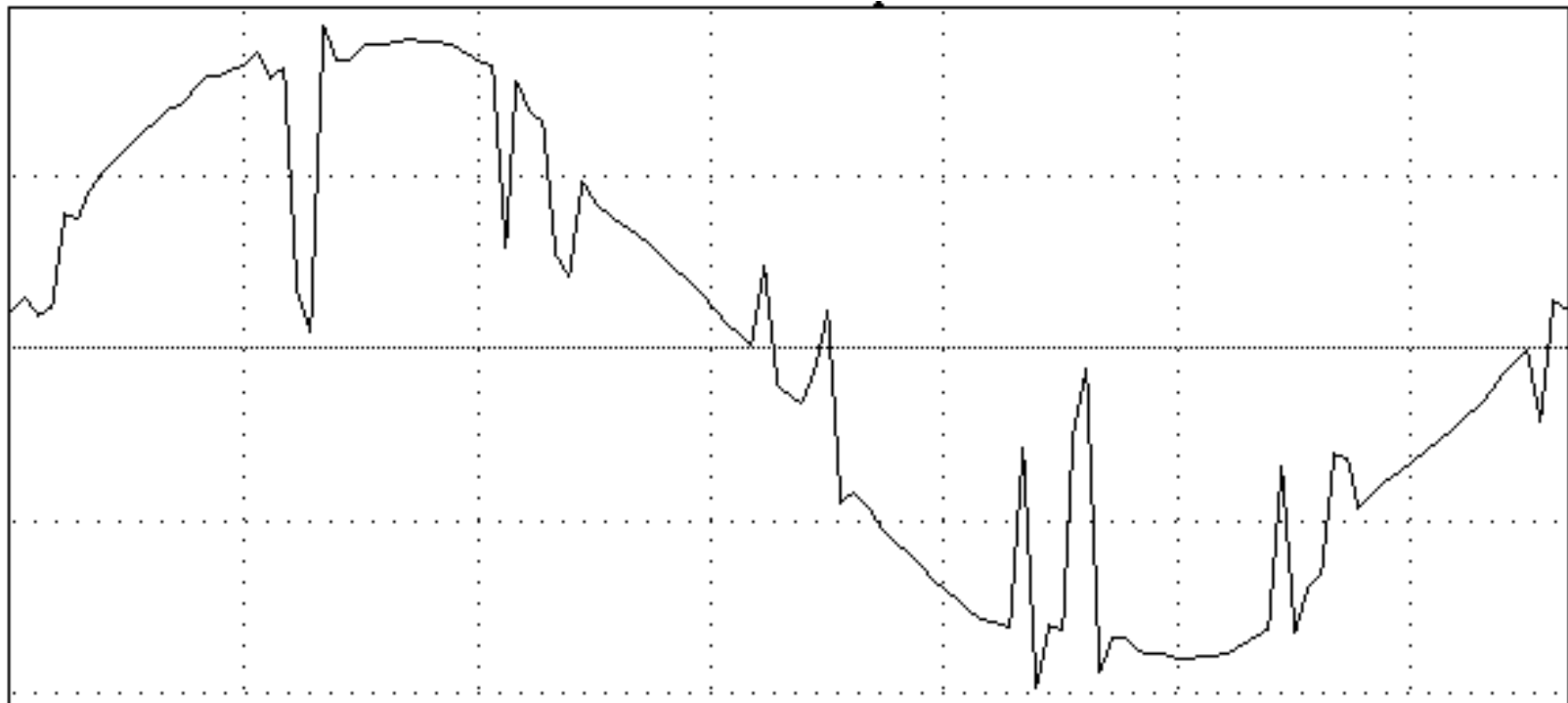
---

- **Decreases the Ripple voltage**
- **Typically sized for 1 to 4 Cycles of Power Loss**

**Ride-Thru**



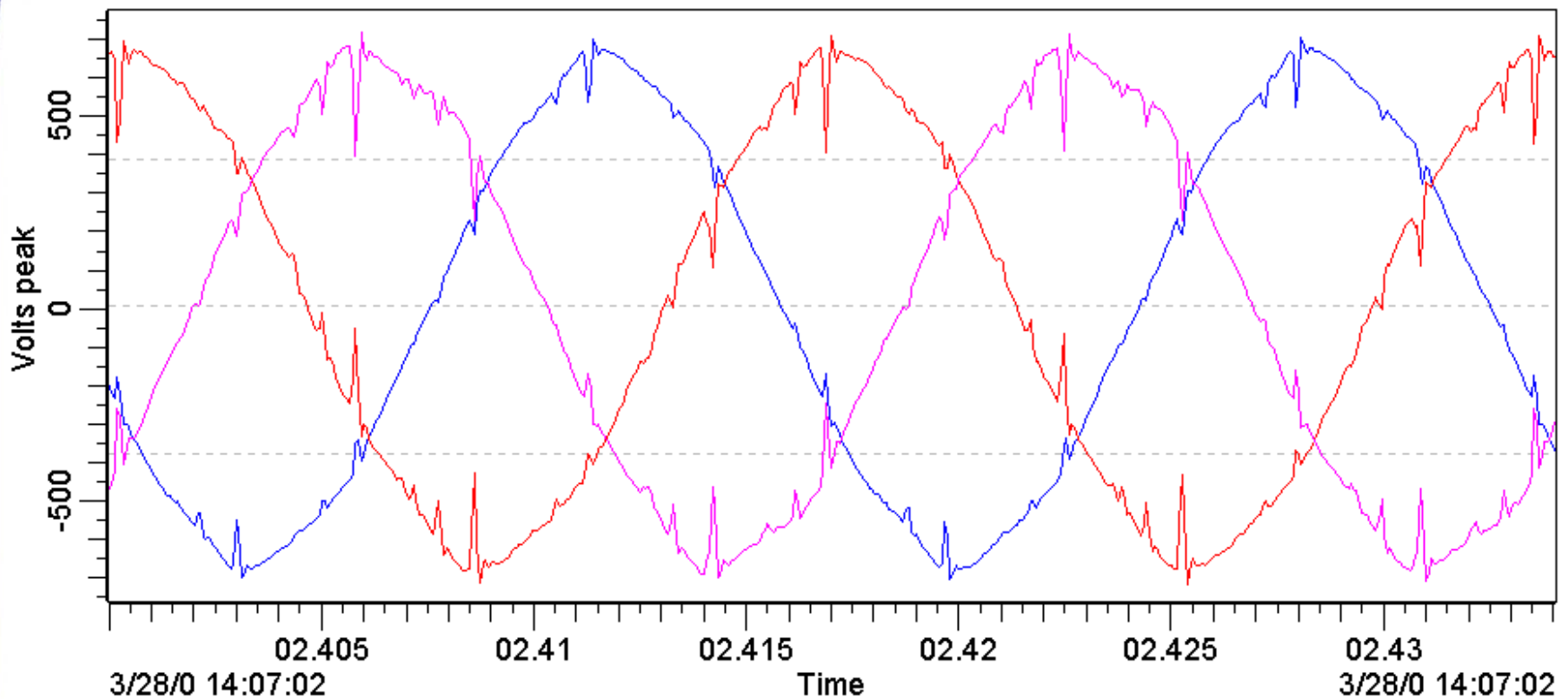
# Over and Under Voltage Faults?



Horizontal 2500 microseconds/division      Vertical 500 Volts/division  
Urms: Prev=610.7, Min=605.5, Max=605.5      -      Worst Imp=      0 Vpk,      0 deg



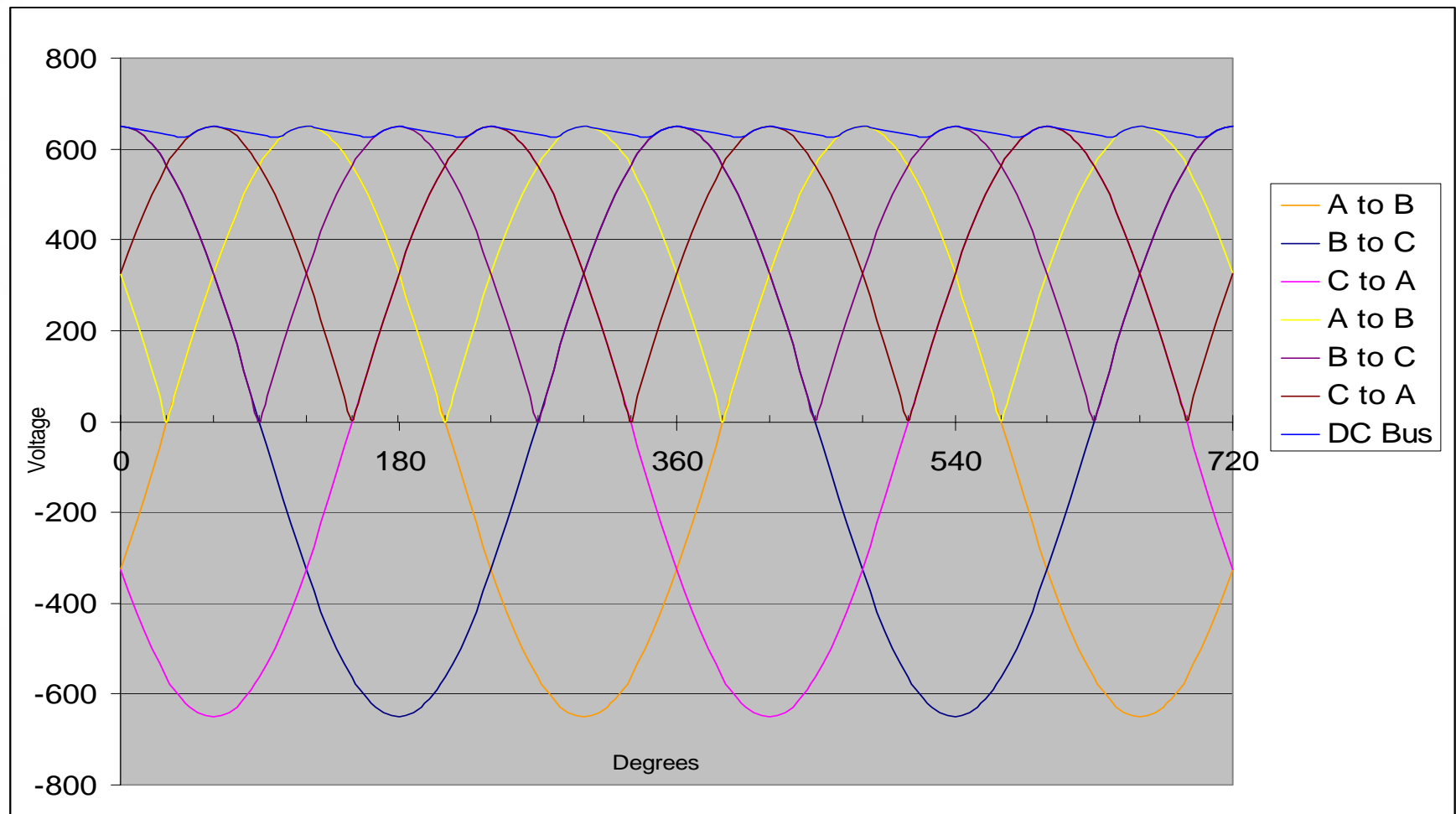
# Faults ?



Measurement	Minimum	Maximum
Time	March 28, 2000 14:07:02.399	March 28, 2000 14:07:02.434
Voltage Waveform L1L2 Inst.	-702.2Vpk	707.1Vpk
Voltage Waveform L2L3 Inst.	-715.8Vpk	711.9Vpk
Voltage Waveform L3L1 Inst.	-703.6Vpk	719.8Vpk



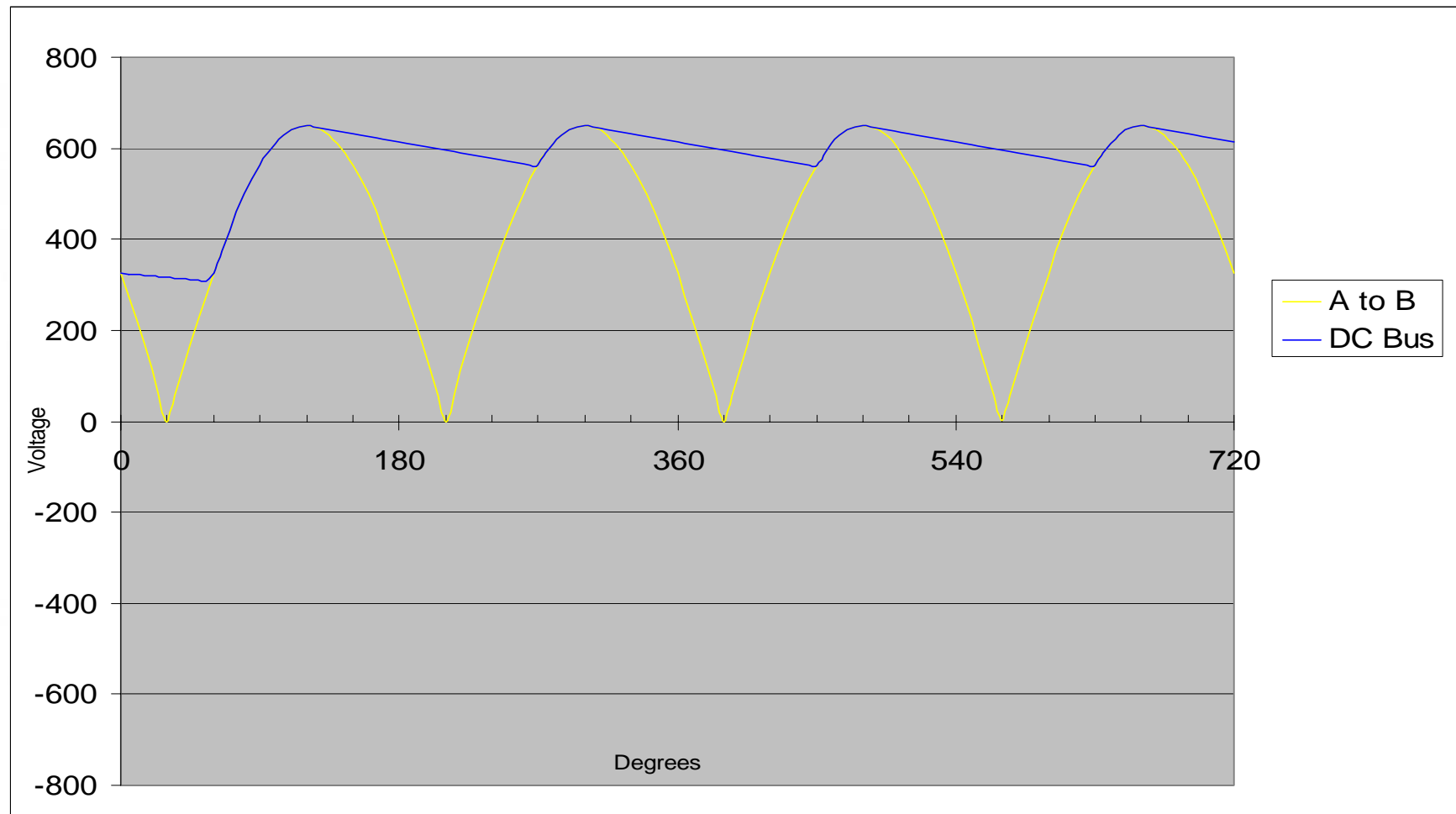
# 3 Phase AC, Rectified & DC







# Single Phase, Blown Fuse





# Over Voltage Faults from Load

## When

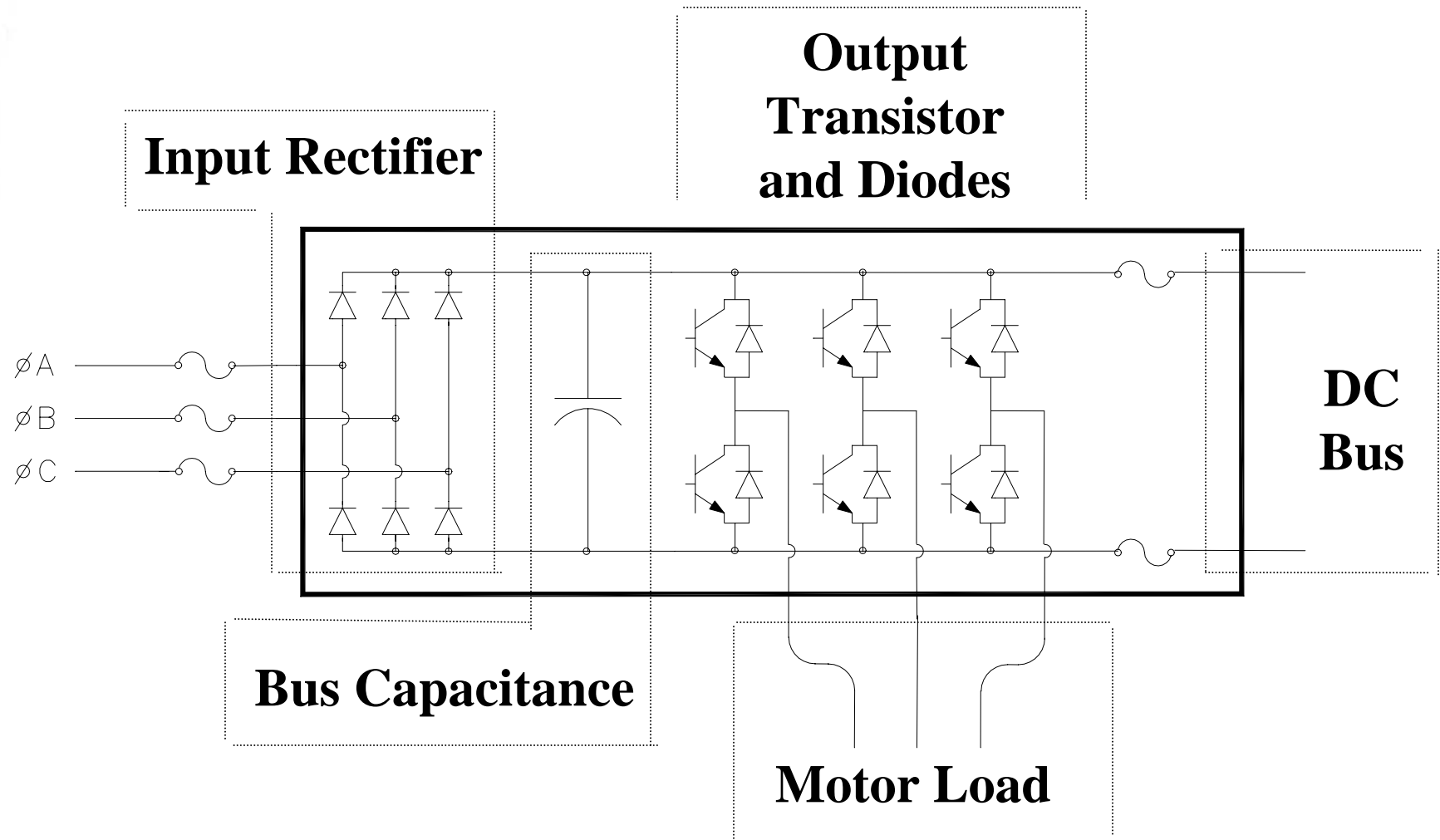
- **Motor Braking**

## How

- **Parallel Bridge across IGBT's**



# Typical PWM Drive Topology

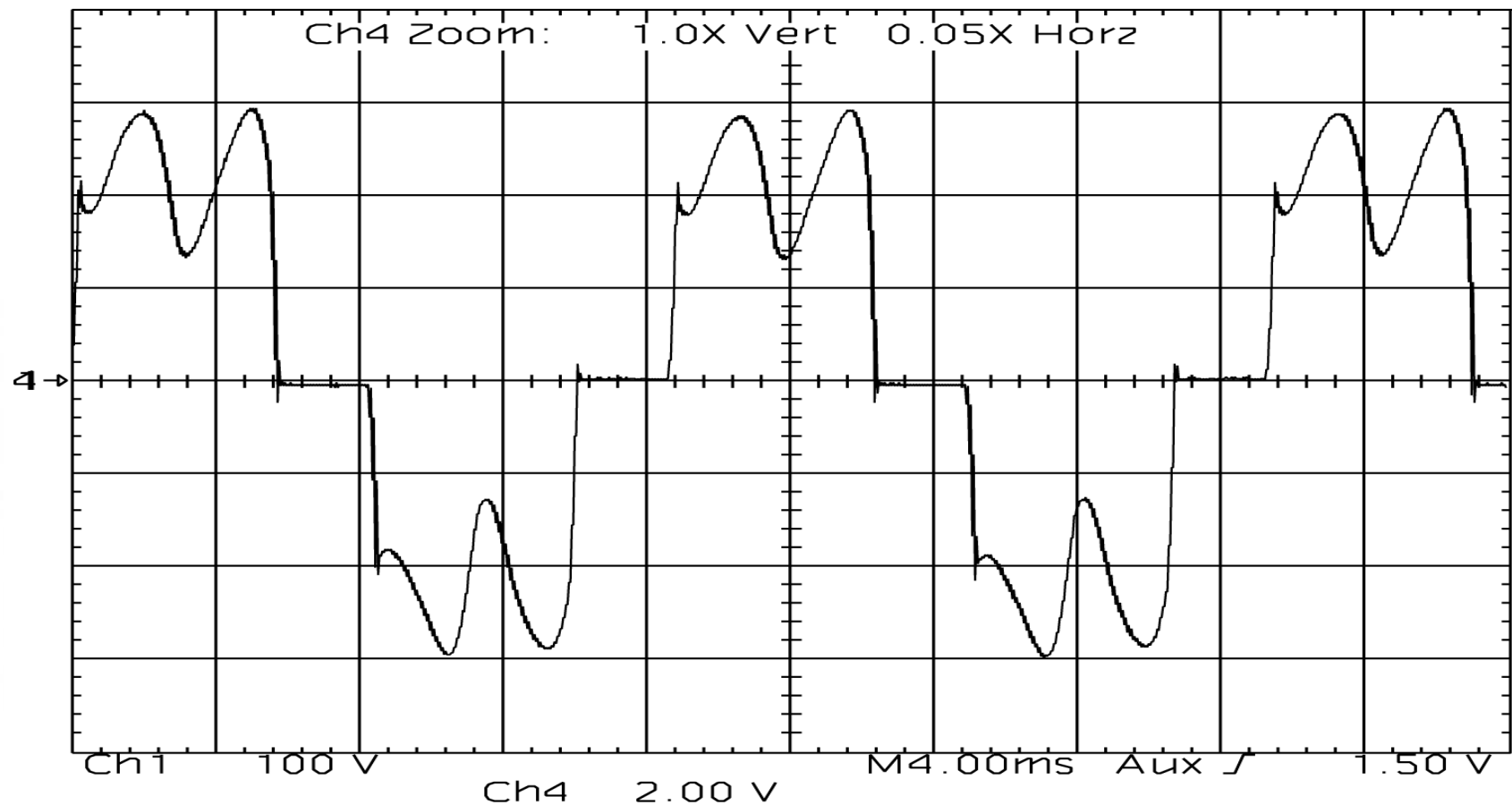




# AC Drive Input Current

Tek Stop: 250kS/s

592 Acqs





# Current Considerations

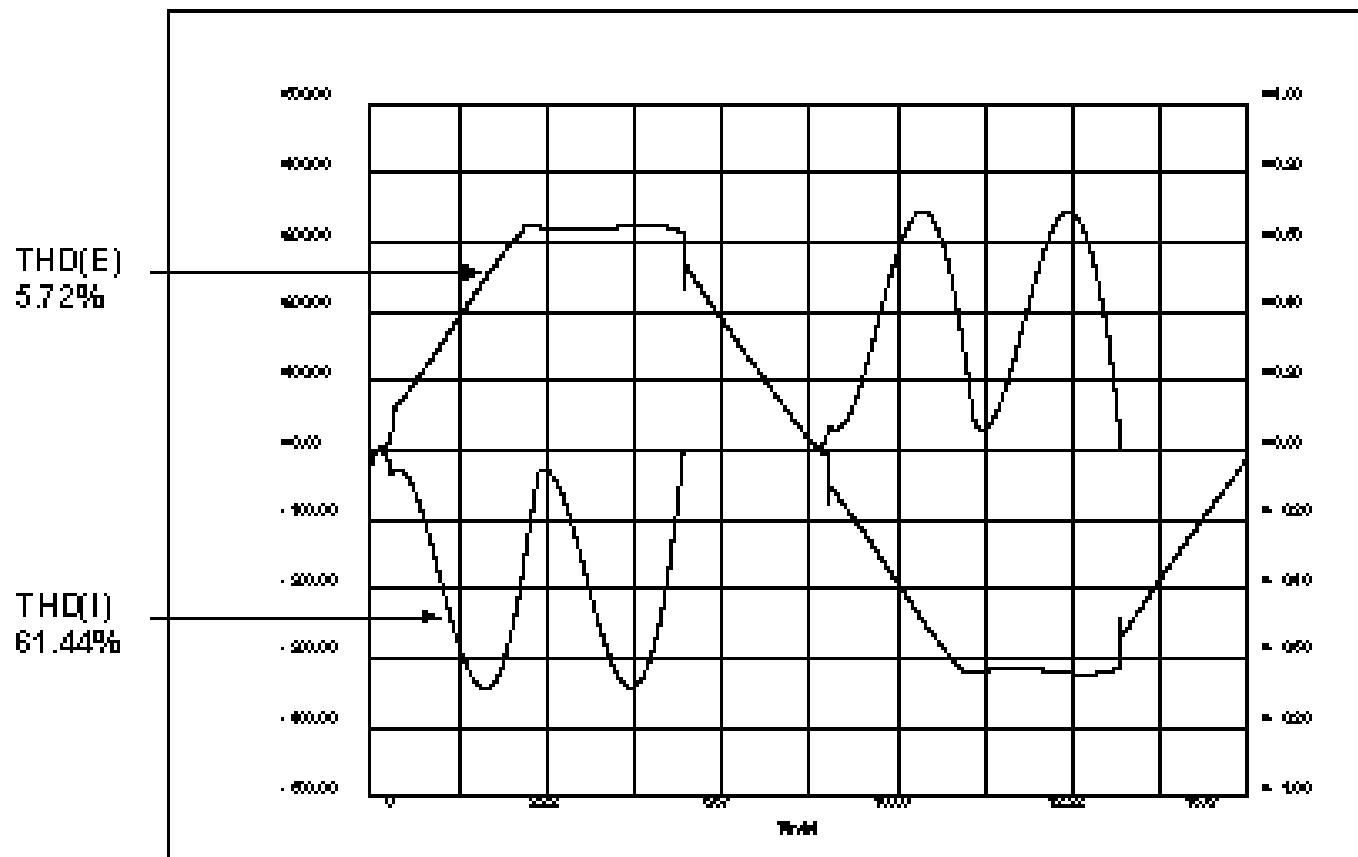
---

- **Magnitude**
- **Power Factor**
- **Distortion / Harmonics**



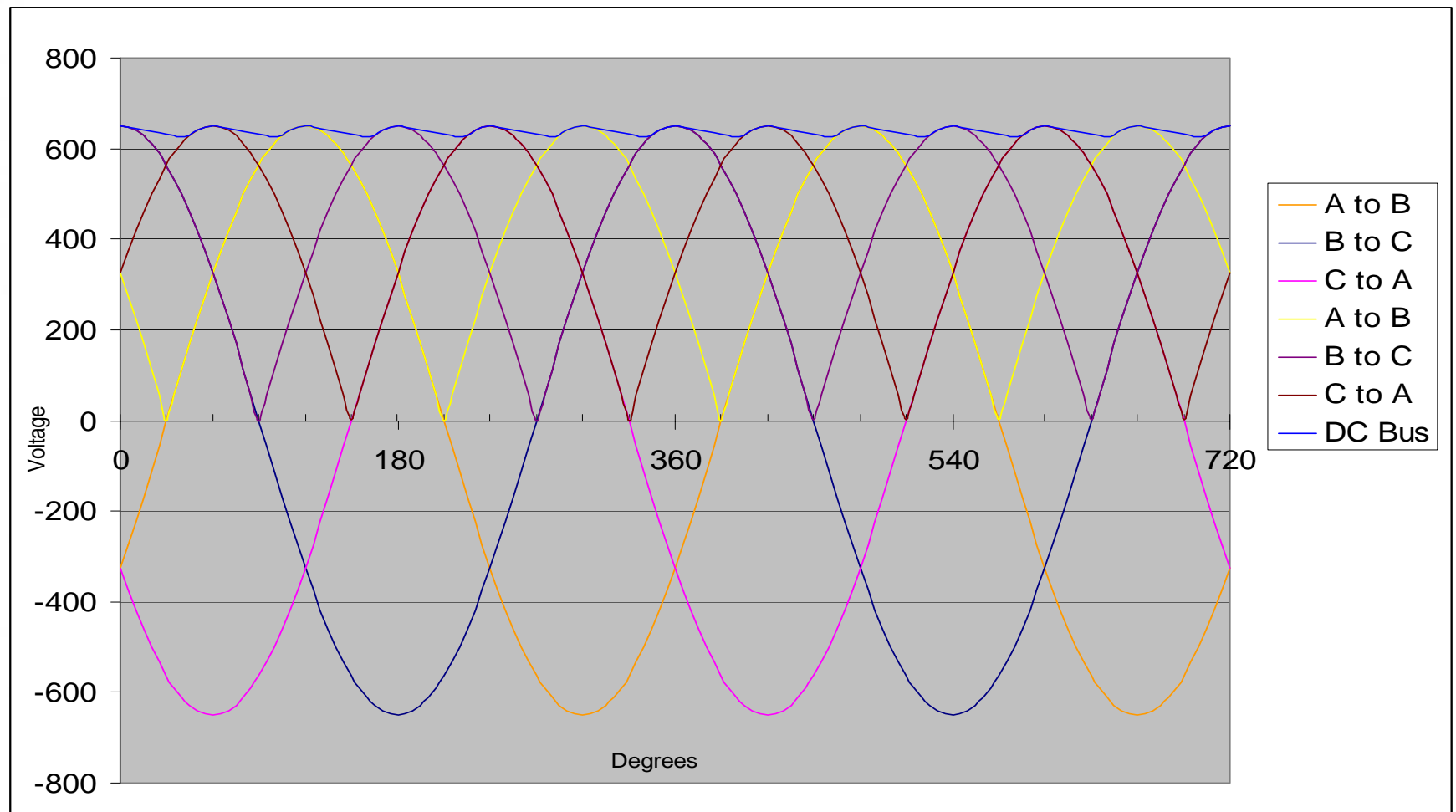
# 3 Phase Current Waveforms

VFD WITHOUT INPUT INDUCTORS





# 3 Phase AC, Rectified & DC





# Decrease Current Distortion

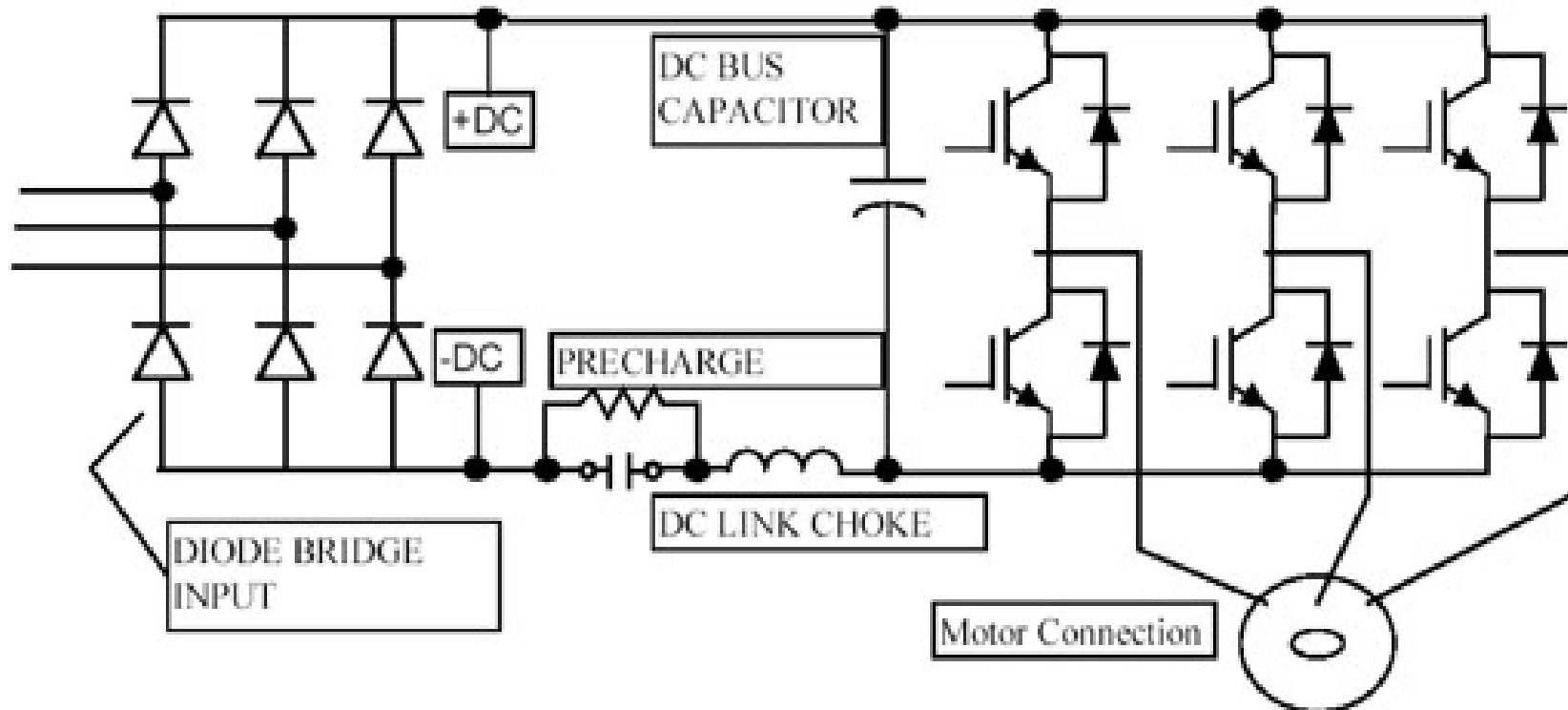
---

- **DC Link Chokes**
- **Input Line Chokes**





# Drive Schematic

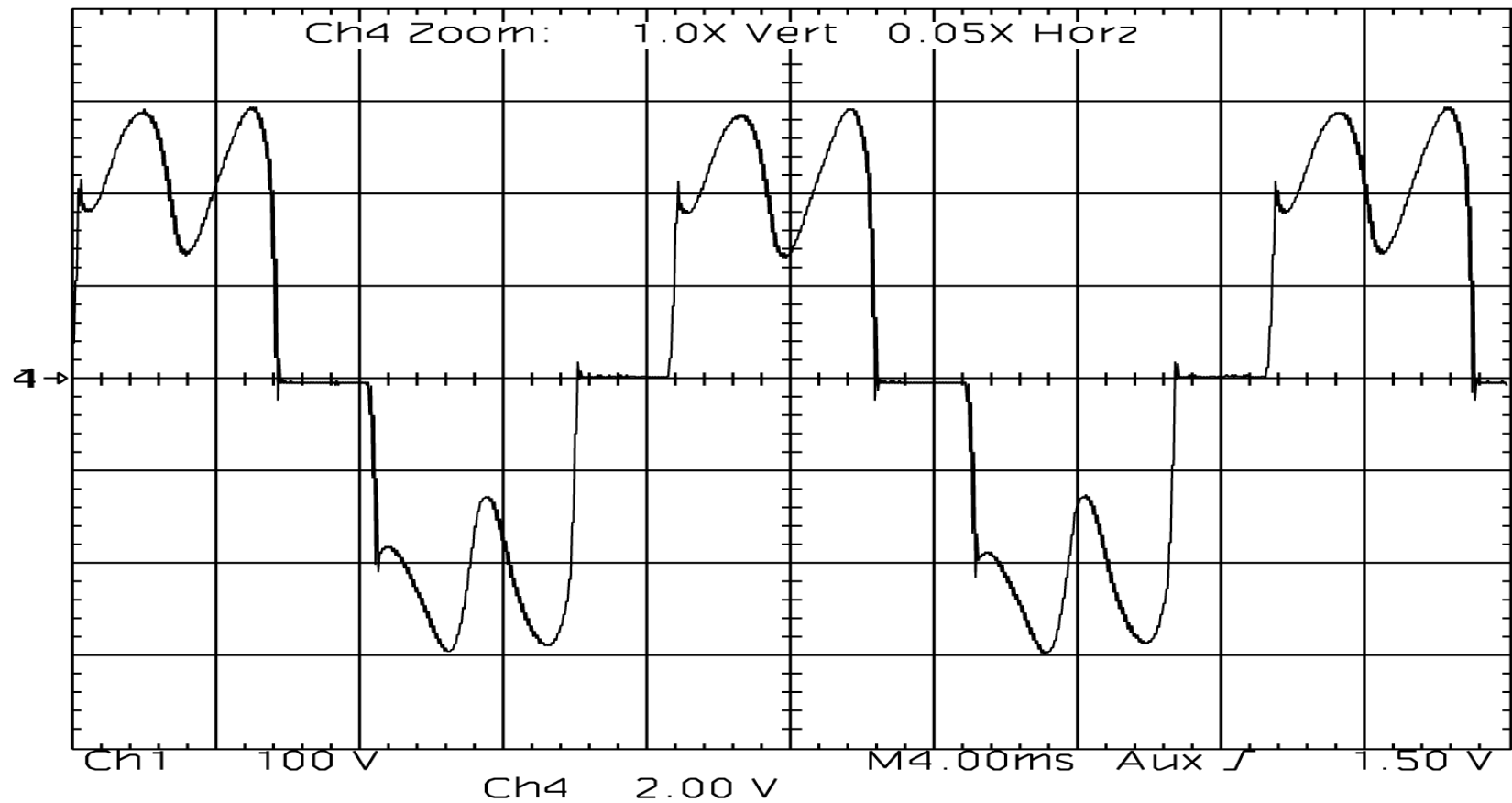


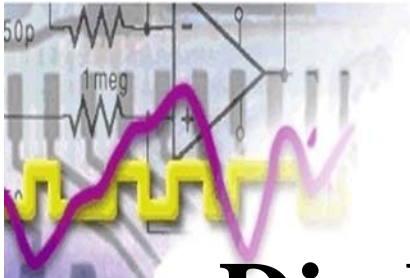


# AC Drive Input Current

Tek Stop: 250kS/s

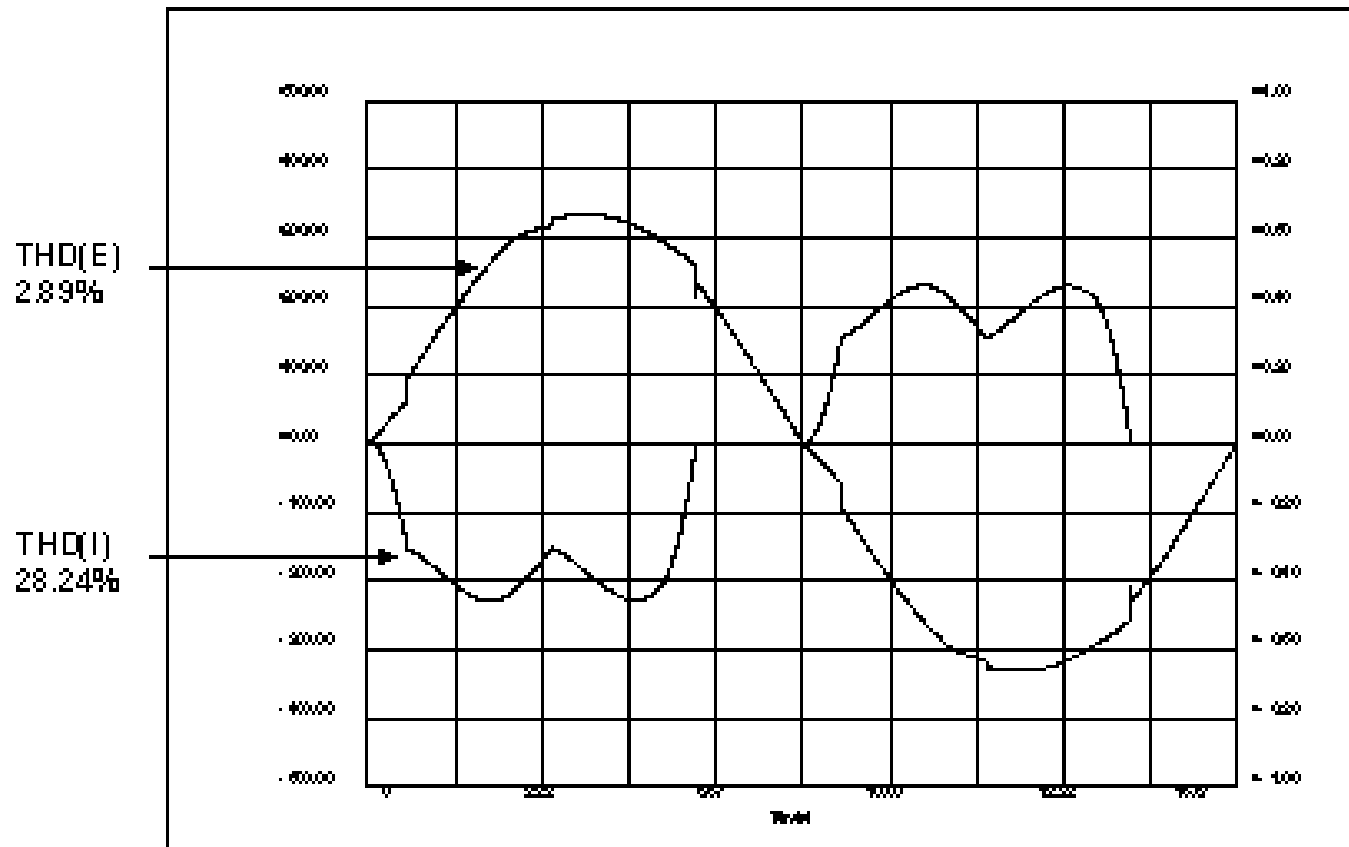
592 Acqs





# Diode Reactor Input Waveforms

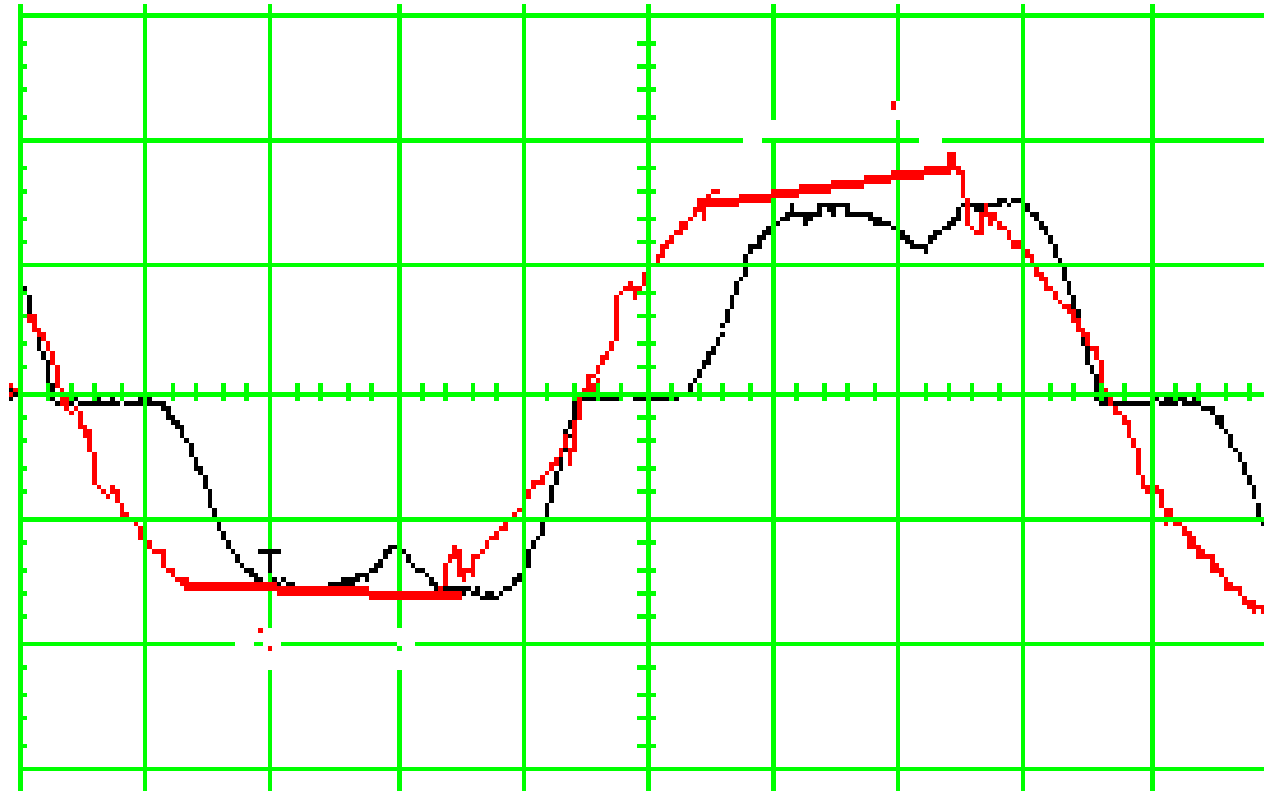
VFD WITH 3%Z LINE INDUCTOR+3%Z DC LINK INDUCTOR





# High Z – Flat Topping

---





# Increasing Bus Capacitance

---

$$I = C * (dV/dt)$$

- **Increased Current Amplitude**
- **Increased Flat topping from IR drop**
- **Decrease in Conduction Time**



# Harmonic Solutions

---

## What

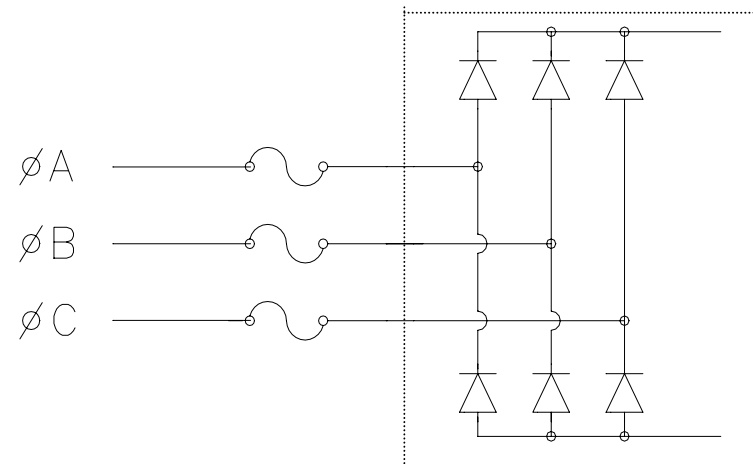
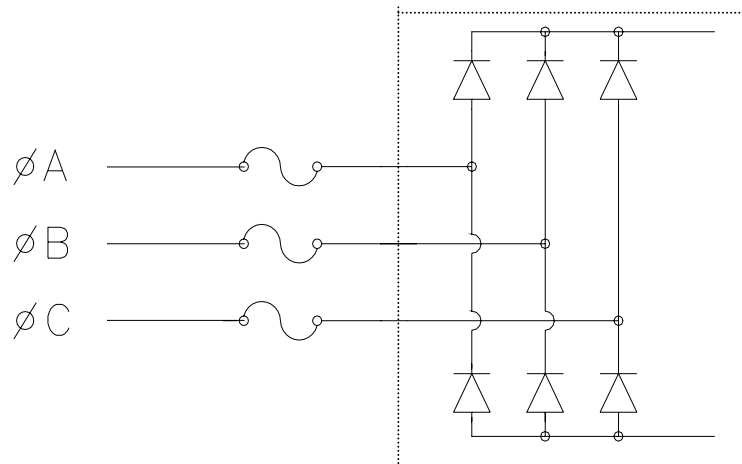
- **Multi Pulse Inputs**  
ie 12 pulse, 18 pulse

## Requires

- **Additional Diode Bridge**
- **Phase shifted Transformer**



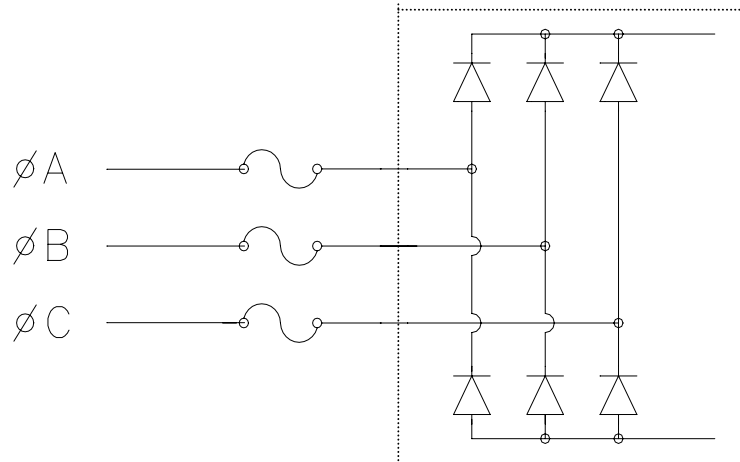
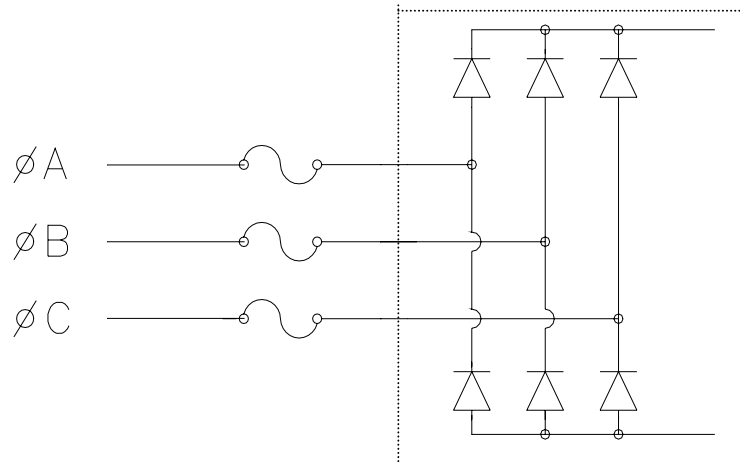
# Multi Pulse Parallel



- **1:1 Transformer w/phase shift**
- **Easier to Implement**
- **Balancing, Cancellation Problems**
- **Lower Losses**



# Multi Pulse Series



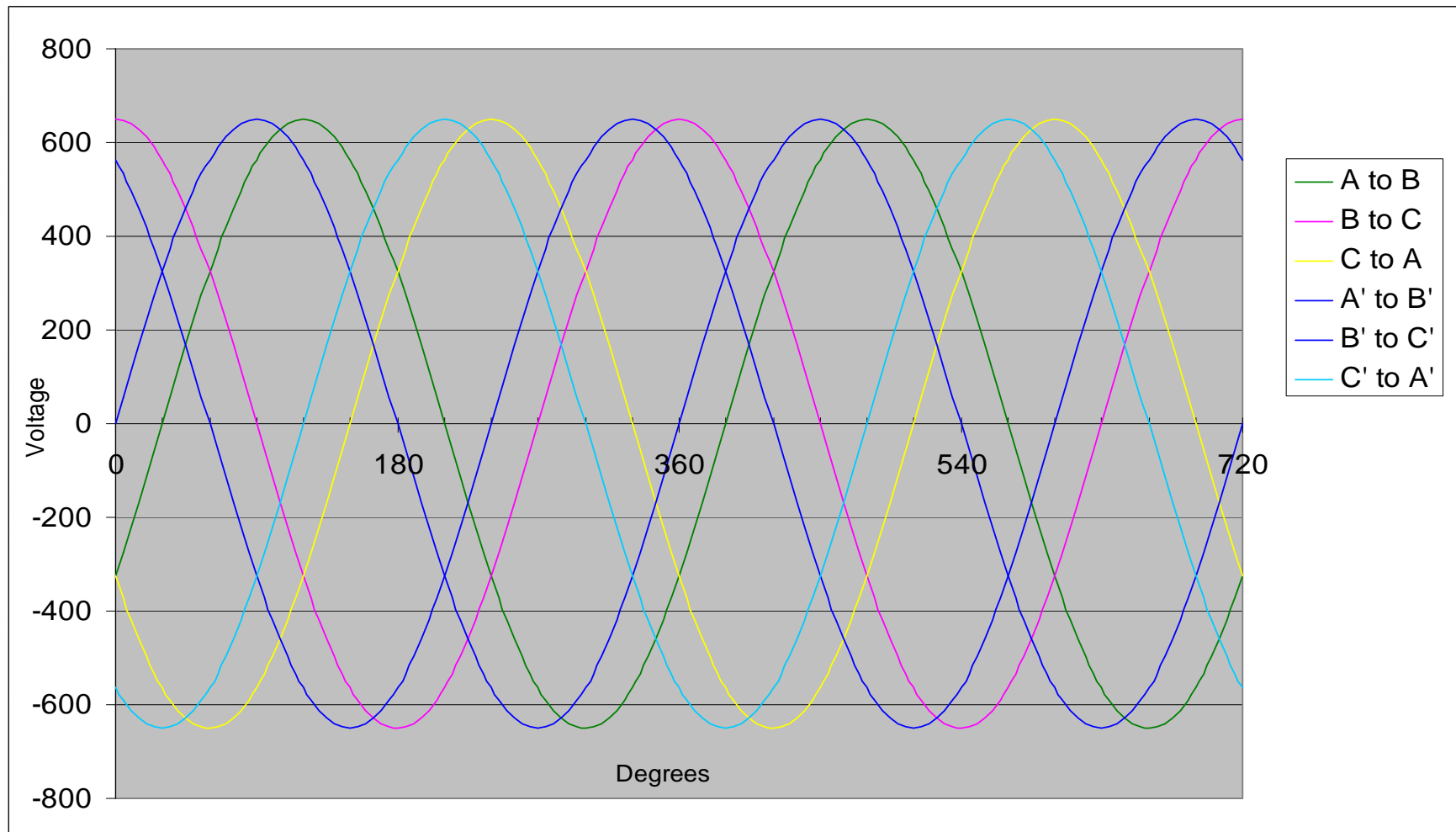
- **Equal Currents**
- **Forced Cancellation**
- **Higher Losses**
- **2:1 Transformer**

**w/phase shift**





# 12 Pulse AC





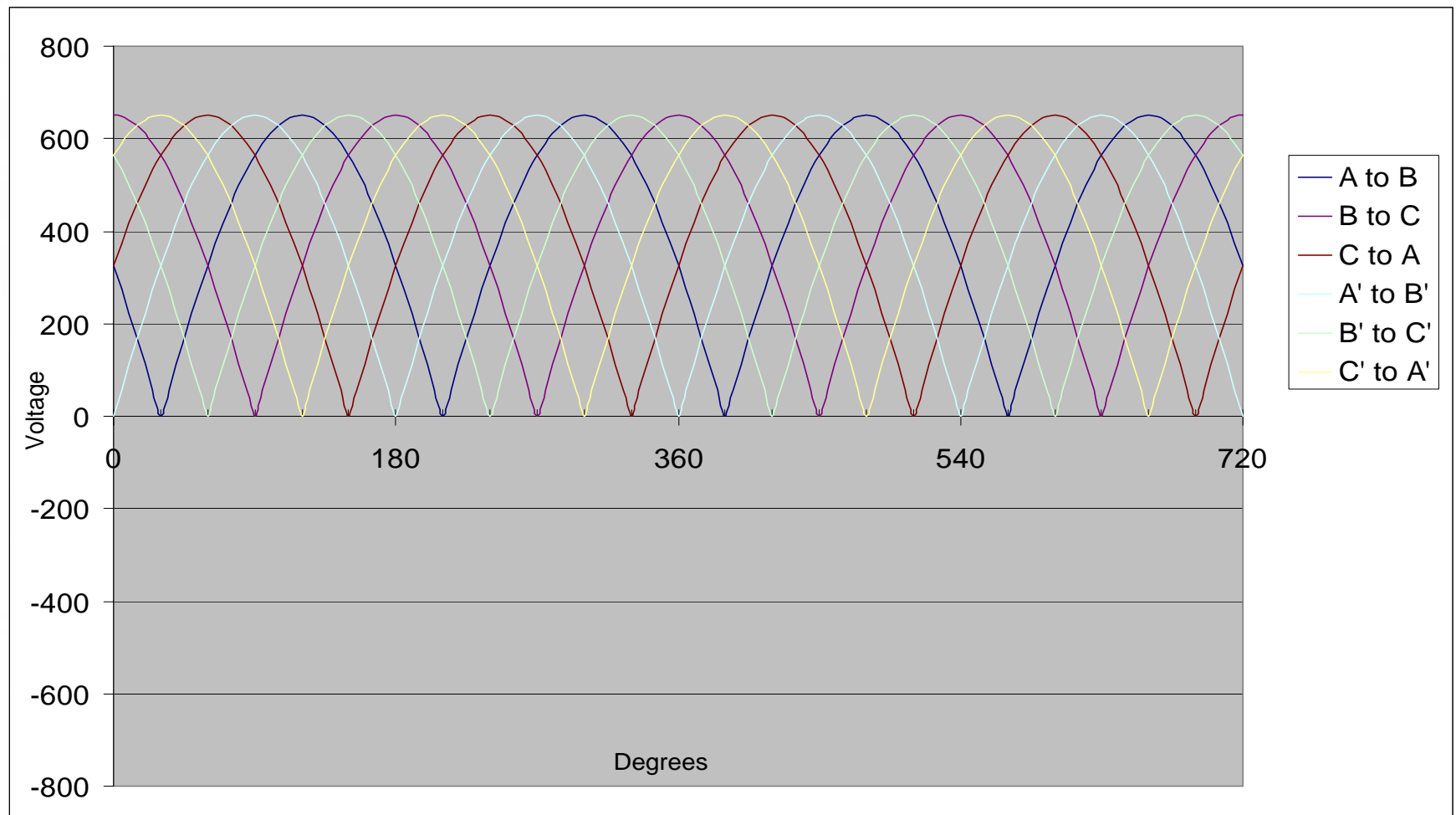
# Multi Pulse Timing

---

- **1 phase                      2 Pulse    120 Hz                      8.3 msec**
- **3 phase                      6 Pulse    360 Hz                      2.7 msec**
- **3 phase + 30 °    12 Pulse    720 Hz                      1.4 msec**
- **3 phase +/- 20°    18 Pulse    1080 Hz                      0.9 msec**

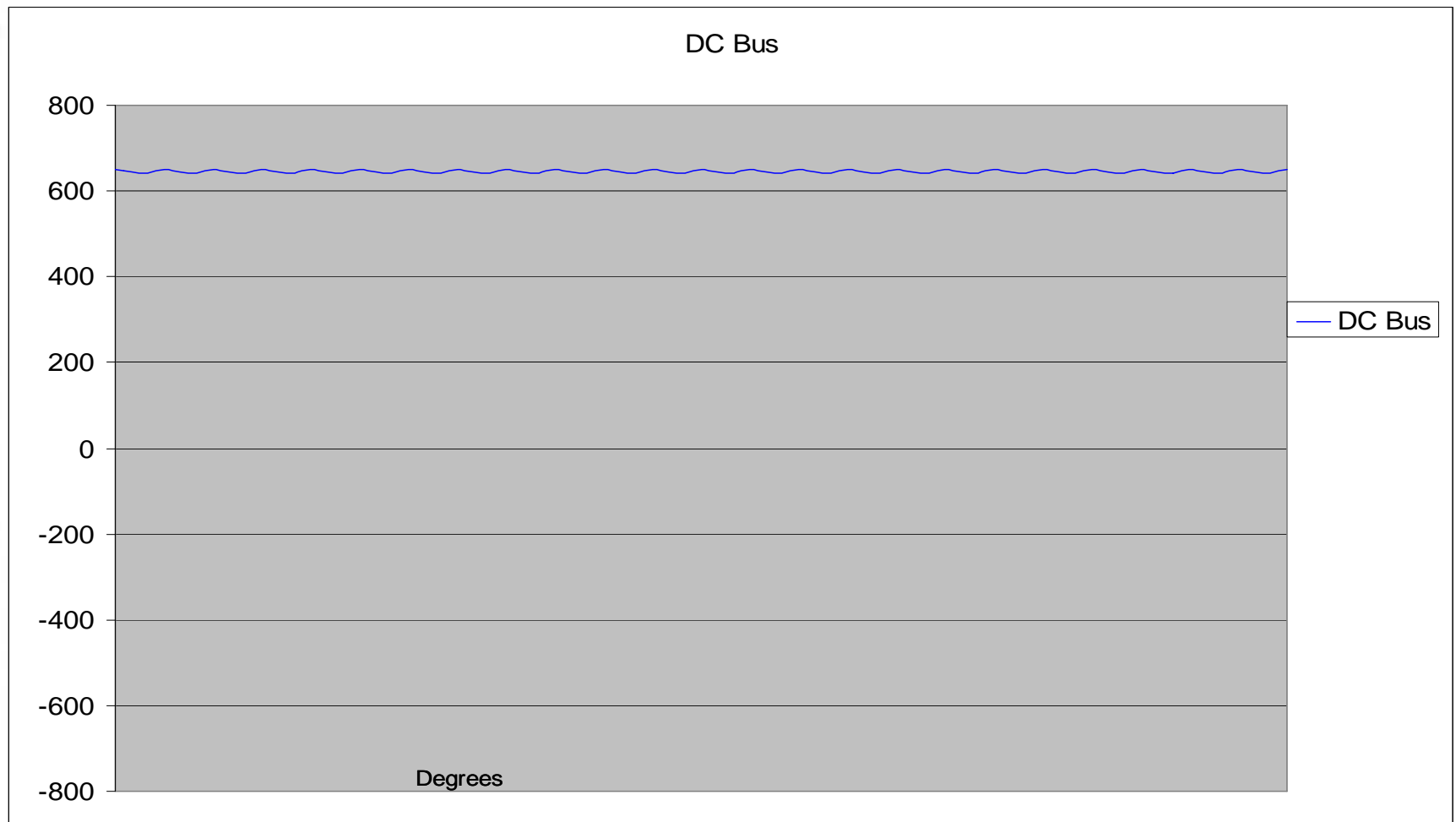


# 12 Pulse Rectified



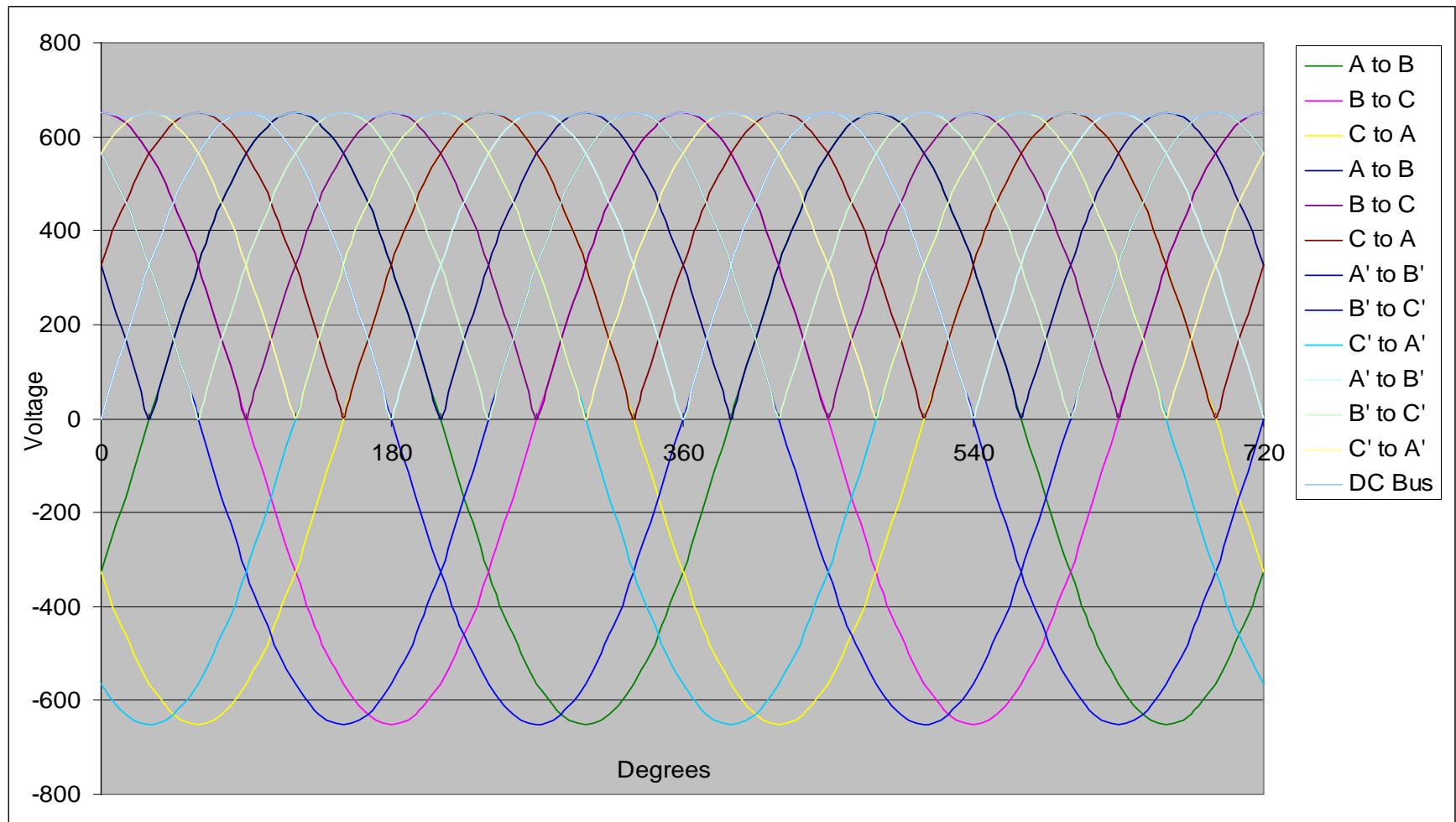


# 12 Pulse DC





# 12 Pulse AC, Rectified, DC





# Increasing Pulses

---

- **Decrease in Current Amplitude**
- **Increased Cap refresh rate**
- **Harmonic Cancellation**



# Harmonic Solutions

---

## What

- **Active IGBT Input Bridge**

## Advantage

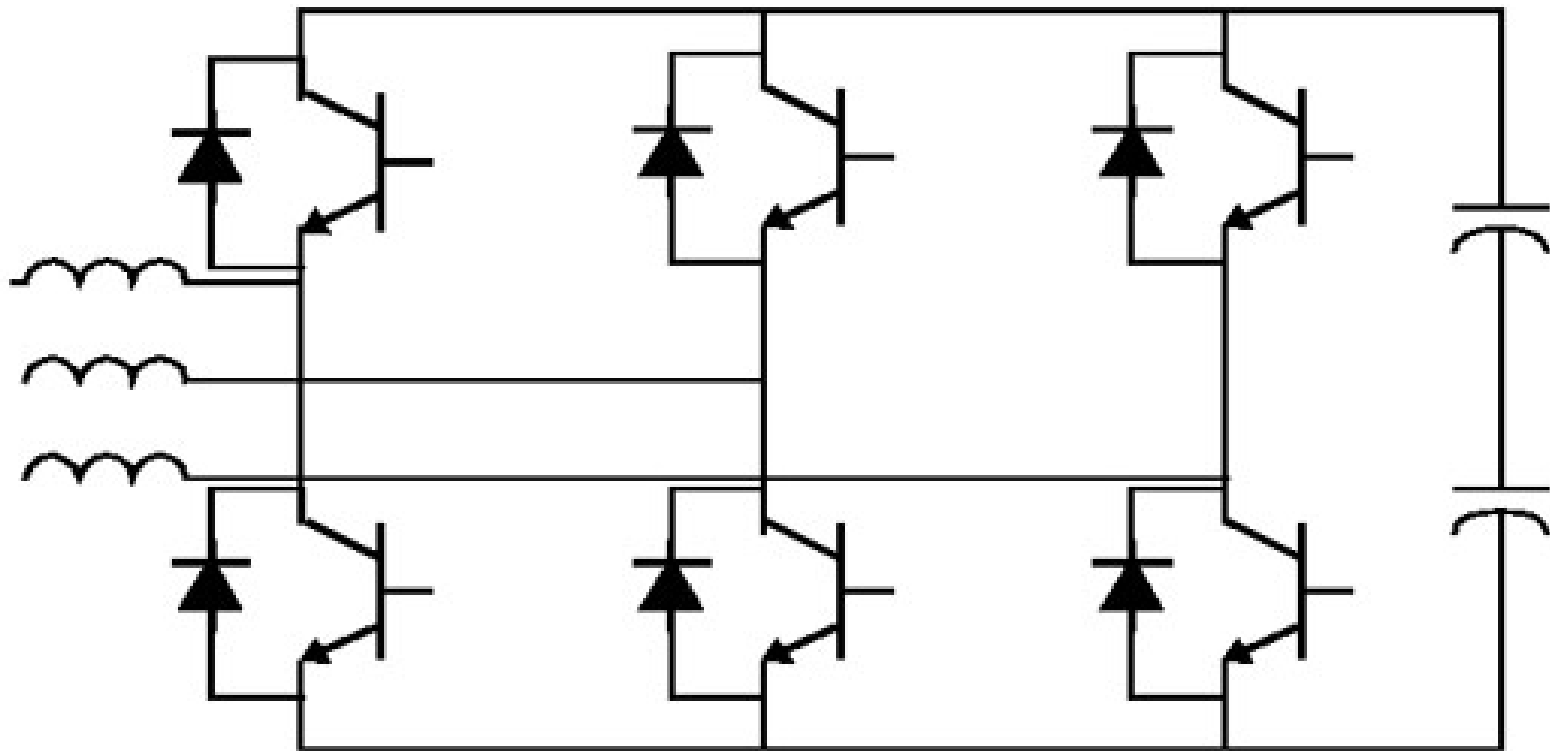
- **+/- 20% DC bus Regulation Typical**

## •Disadvantage

- **Electronic Cost and Heat Losses**
- **Requires Inductance 8 – 12%**



# Drive Schematic - Active



**PWM gating to achieve Sinusoidal Current**





# PWM Waveform

---

- **Requires Additional Impedance**
- **Requires Carrier Frequency Filter**



# Sag Solutions

---

## When

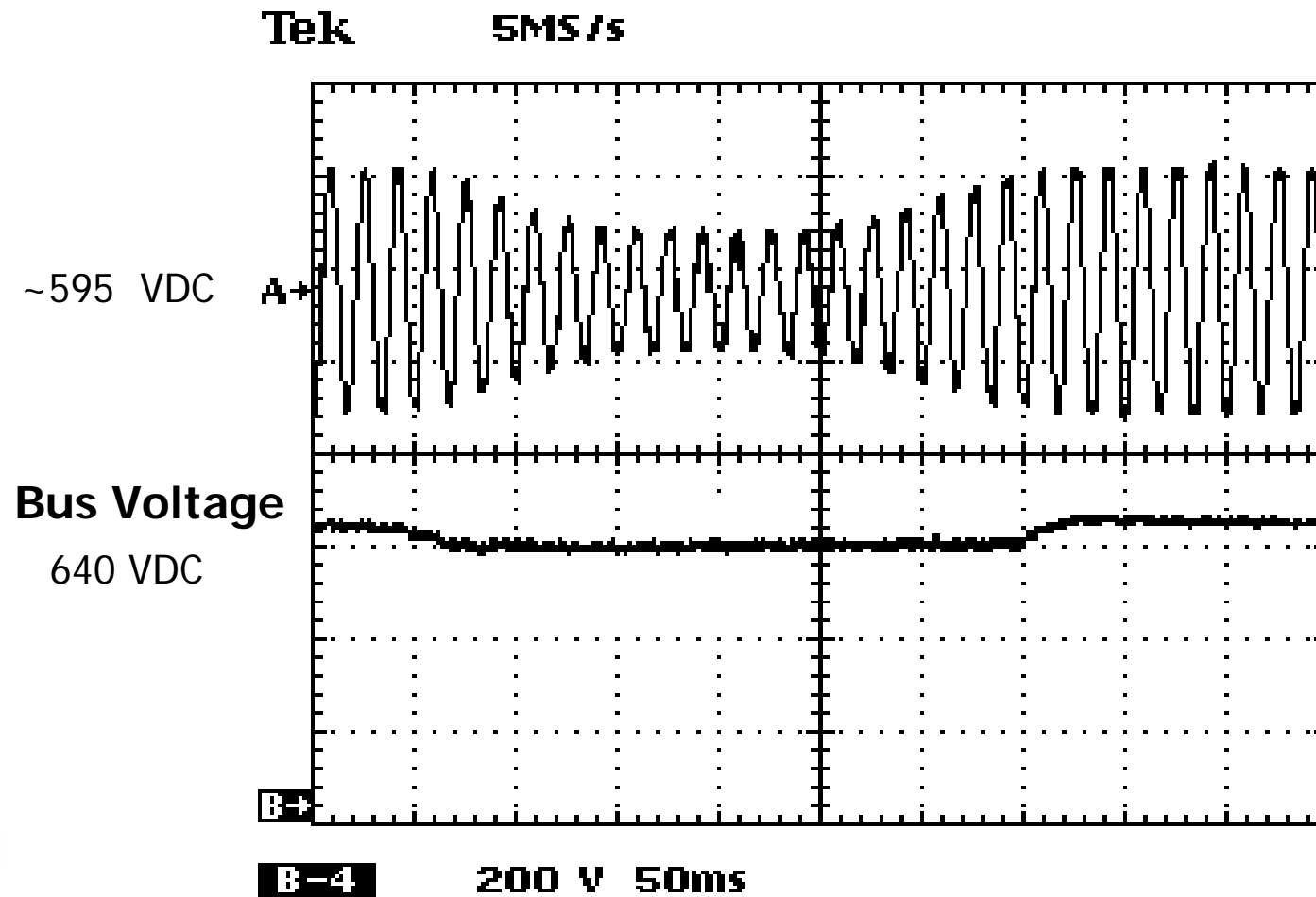
- **Low voltage for more than a cycle**

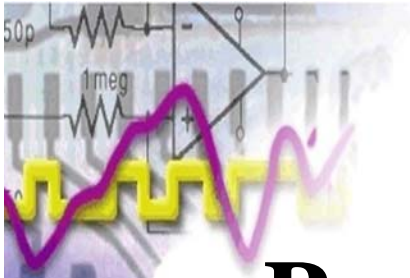
## Solutions

- **Increased Capacitance**
- **Boost Regulators**
- **Active IGBT Front End**



# Sag Event Example





# Power Ride Through Options

---

## Unregulated Speed/Toque

### Shut Down with Auto Restart

- Loss of Process Control
- May fail on successive Retries

### Kinetic Buffering

- Requires specific Drive Firmware
- Speed is decreased on Power Dip sense
- Motor becomes a Generator to the Drive
- Inertia of Motor System is used to Hold up Drive Bus
- Does not work well with frictional loads



# Power Ride Through Options

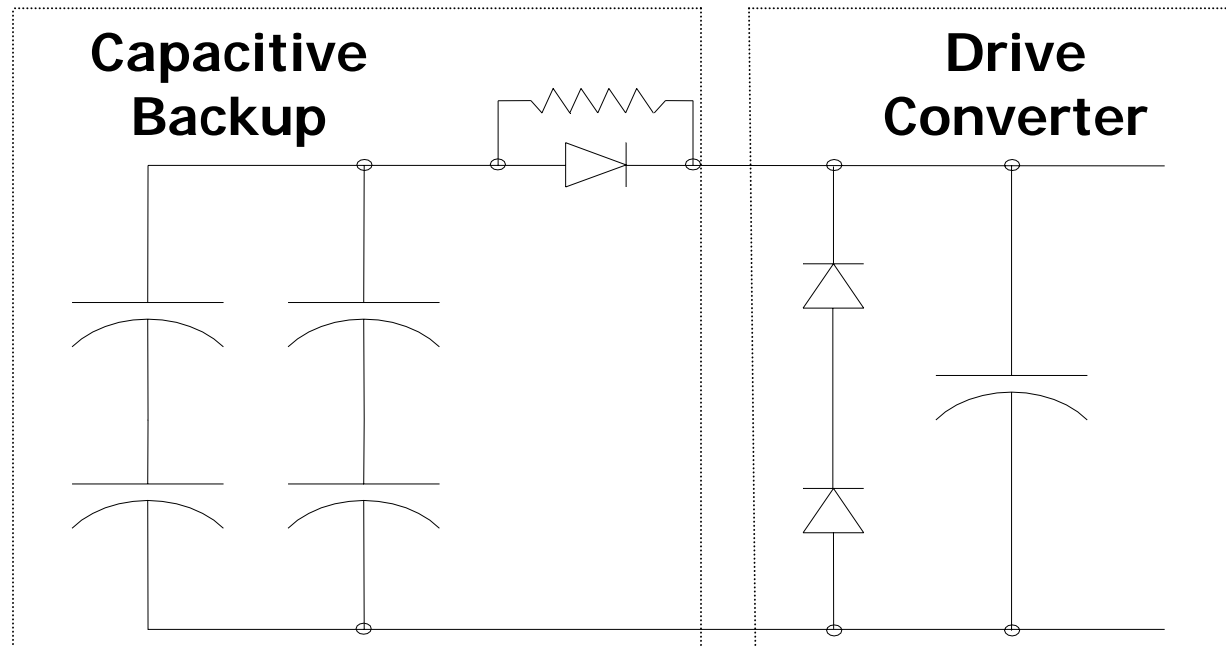
---

## Regulated Speed/Toque

- Capacitance Backup
- Chopper Boost Regulator
- Chopper Boost Regulator with Capacitors
- Active Front End



# Capacitive/Battery Ride Through





# Capacitive Energy Storage

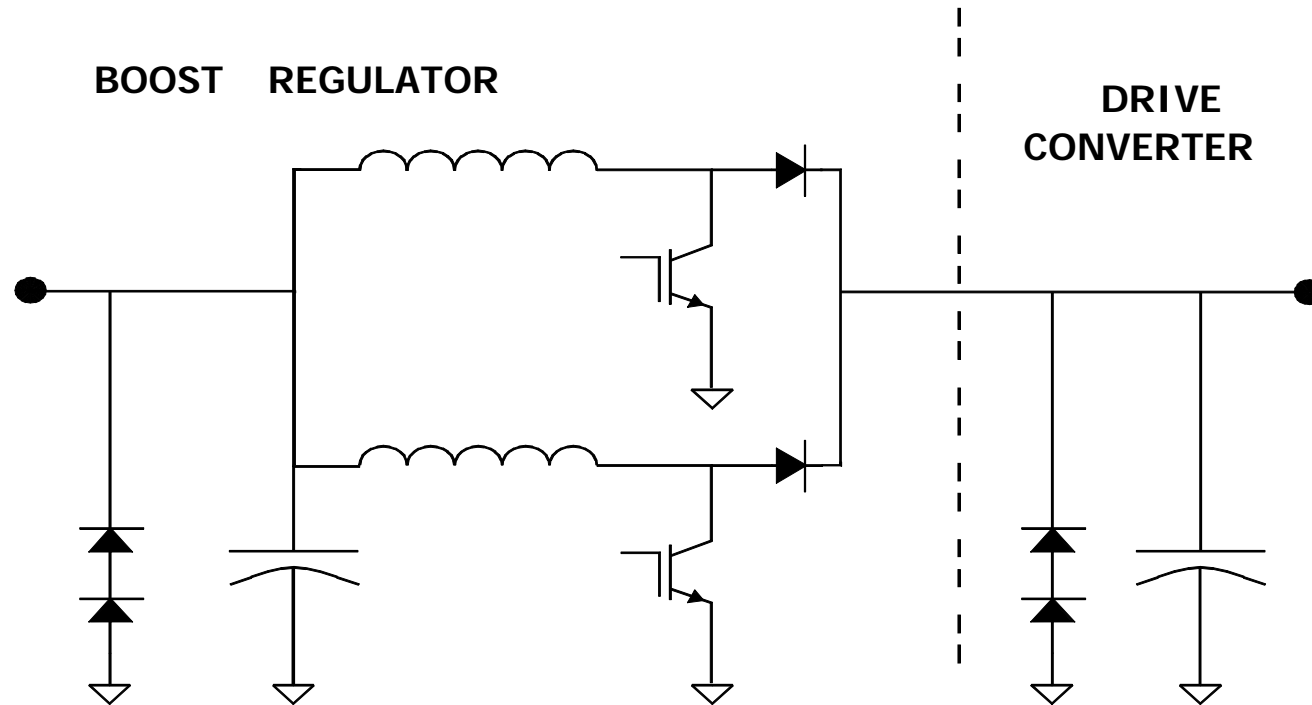
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$$J = \frac{1}{2} CV^2$$

$$J = \frac{1}{2} C(V_1 - V_2)^2$$



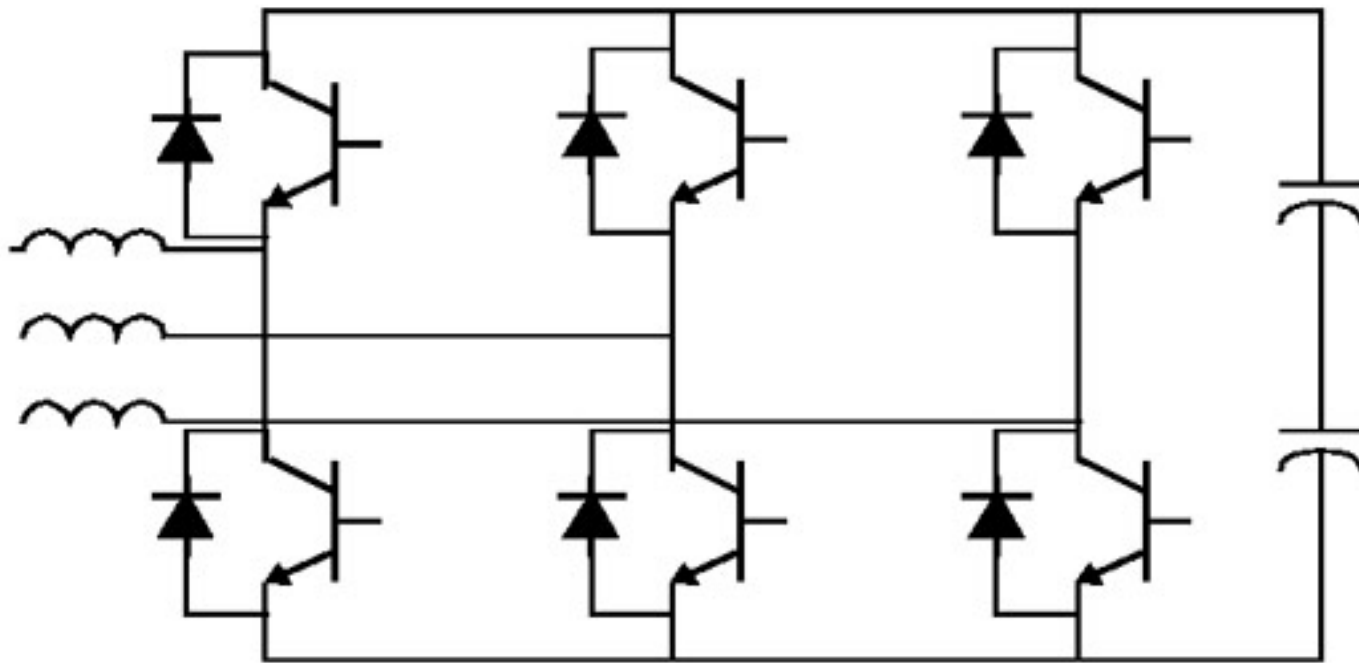
# Boost Chopper







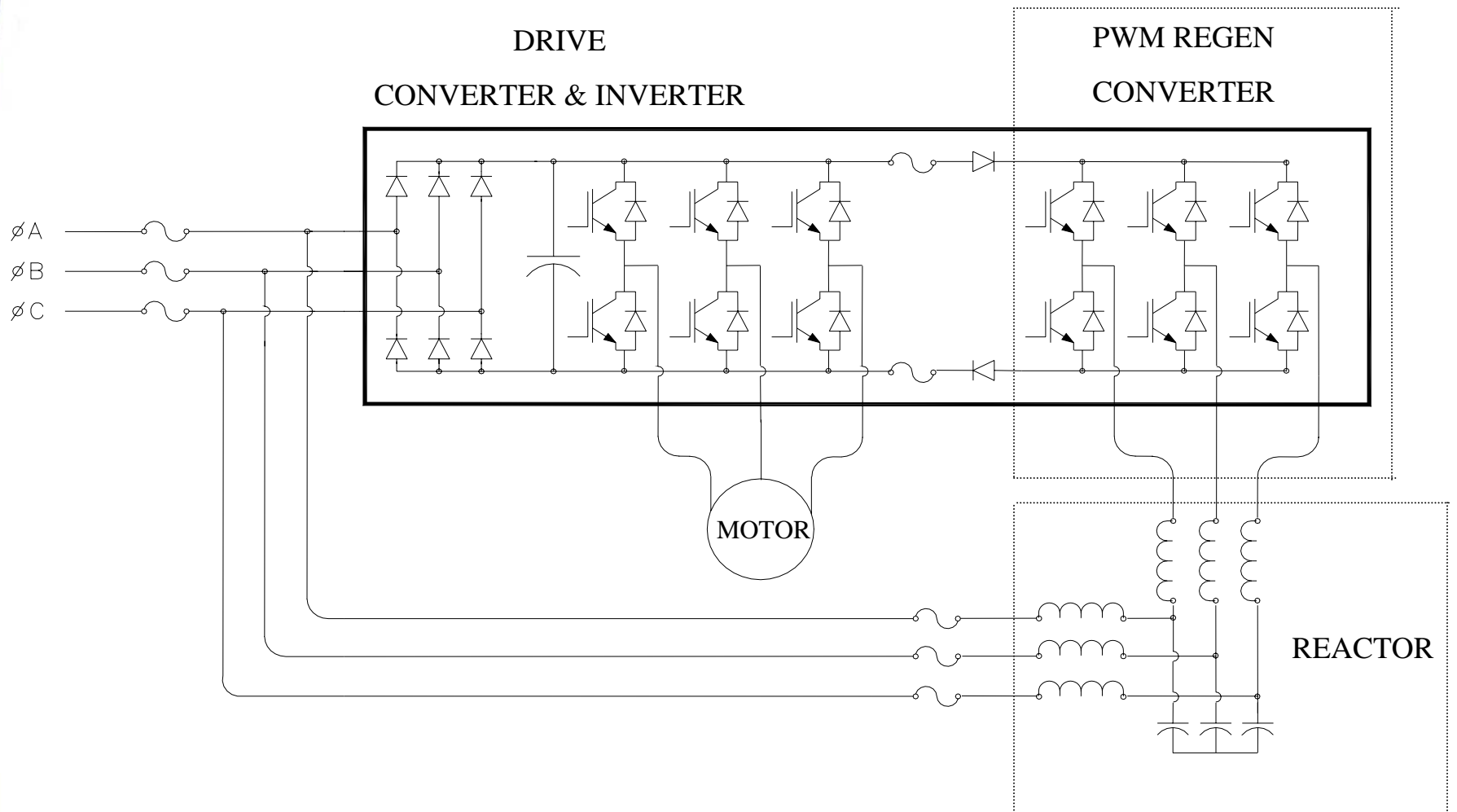
# Drive Schematic - Active



**PWM gating to achieve Sinusoidal Current**



# PWM Regen

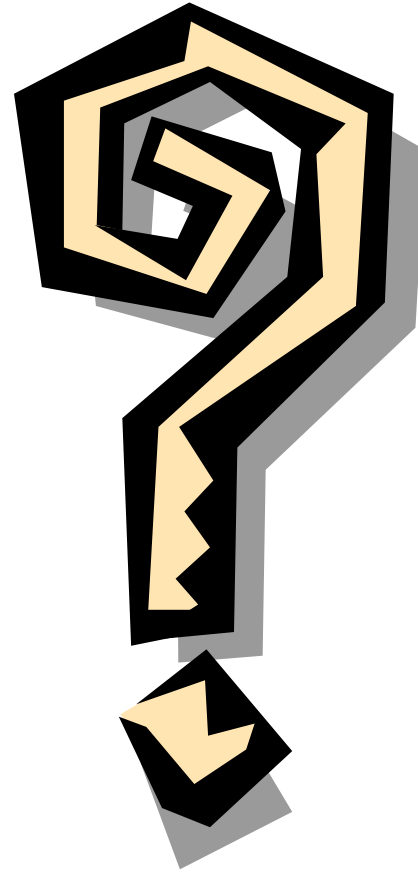




# Resources

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- [www.drivesmag.com](http://www.drivesmag.com)
- [www.epri-peac.com](http://www.epri-peac.com)
- [www.bonitron.com](http://www.bonitron.com)



# QUESTIONS