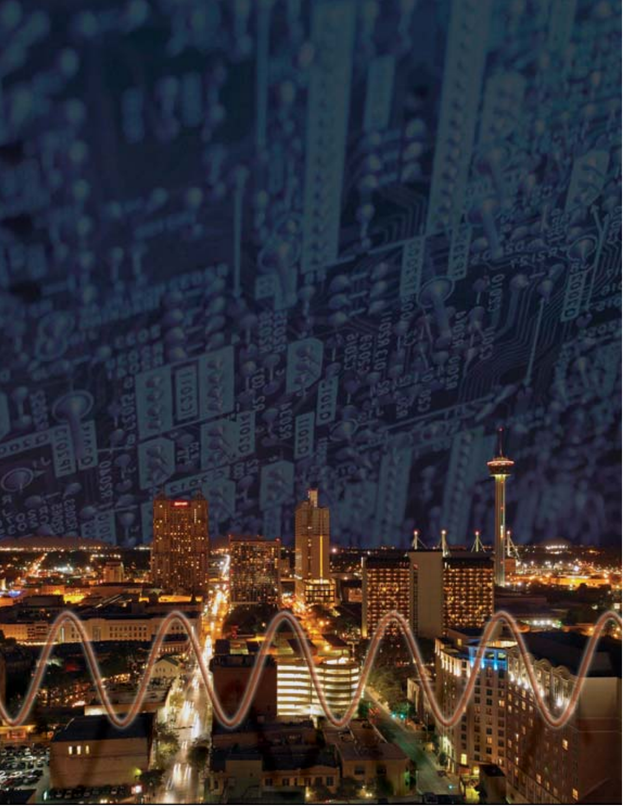

Voltage Sag Mitigation Methods

10/28/09 1:15 pm – 2:00 pm

Mark Stephens, PE
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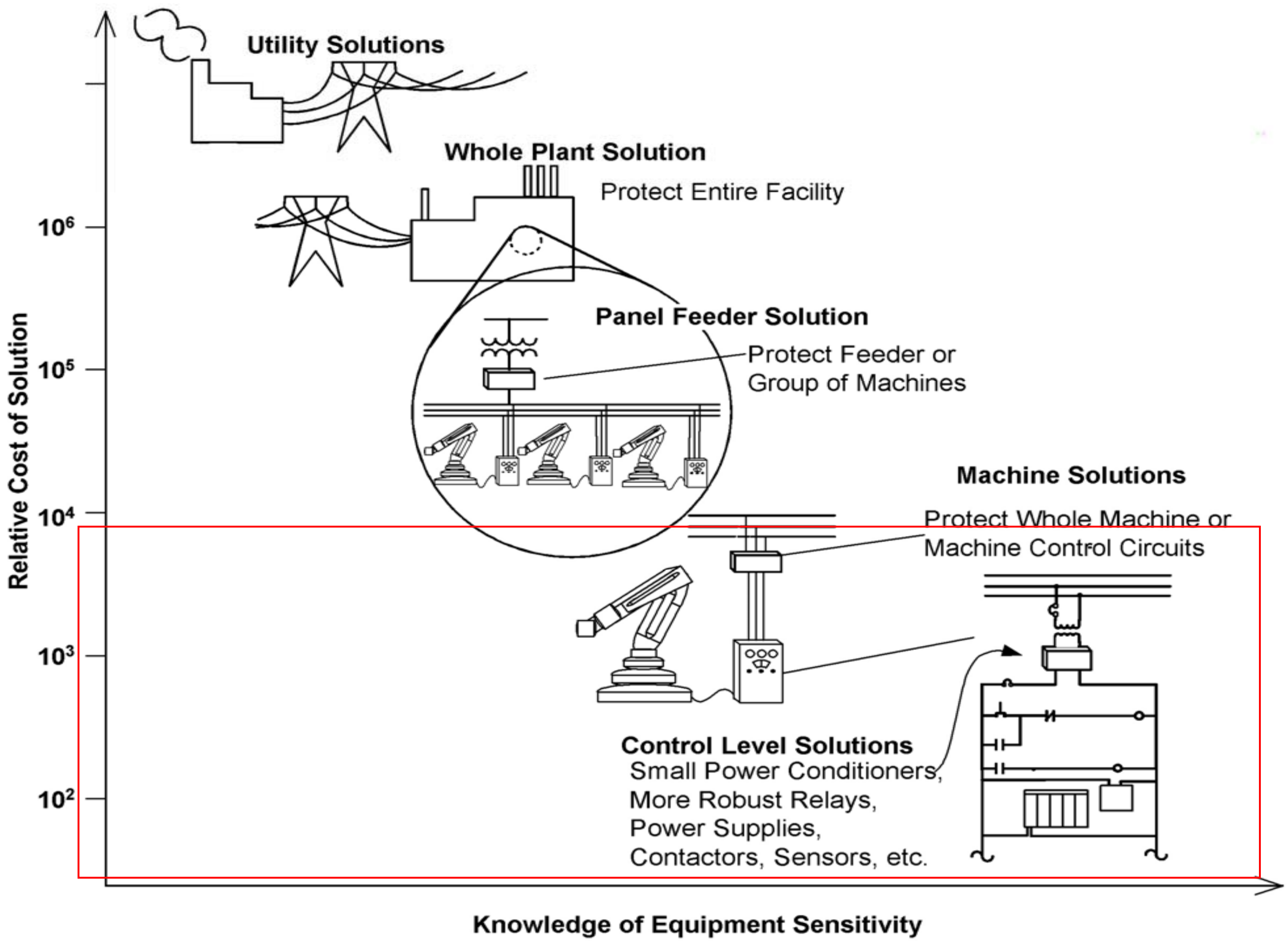
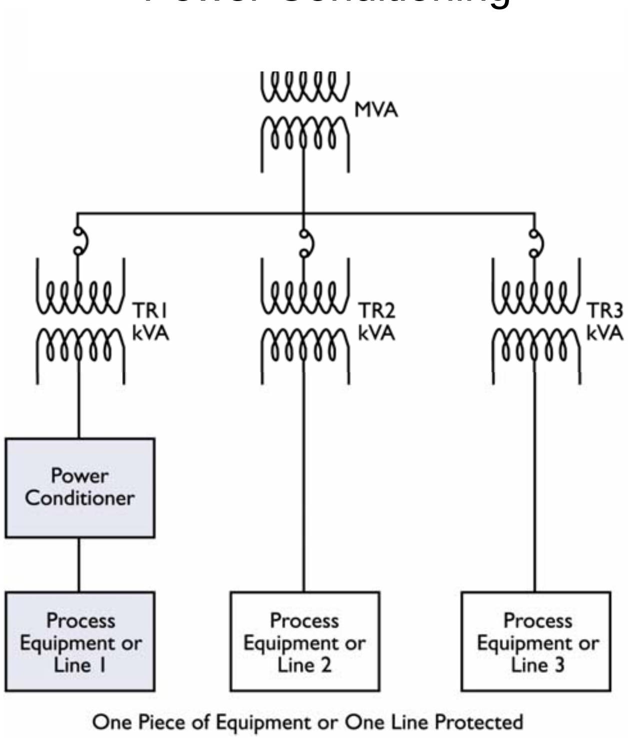
CPS ENERGY

Cost of Solutions Versus Knowledge of Sensitivity



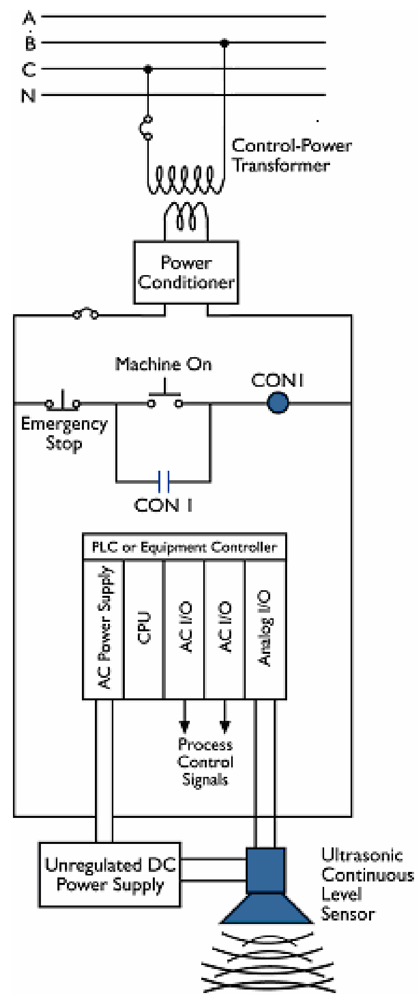
Example PQ Solution Levels

Machine or Subsystem Level Power Conditioning



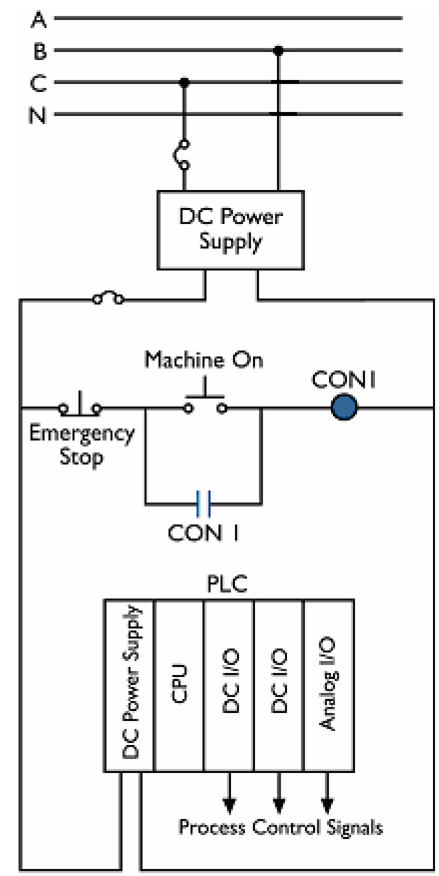
Control Level Power Conditioning

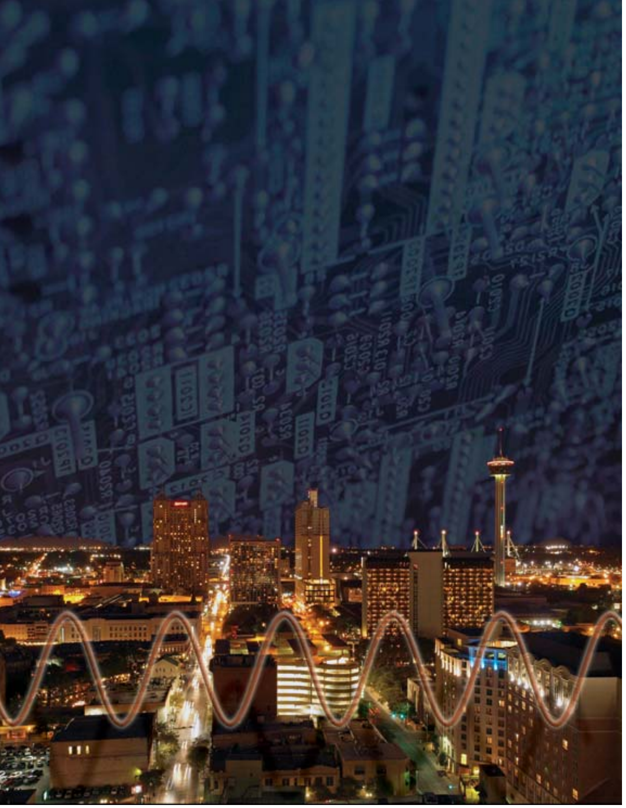
(1/10th to 1/20th of Machine Level Power Conditioner Cost)



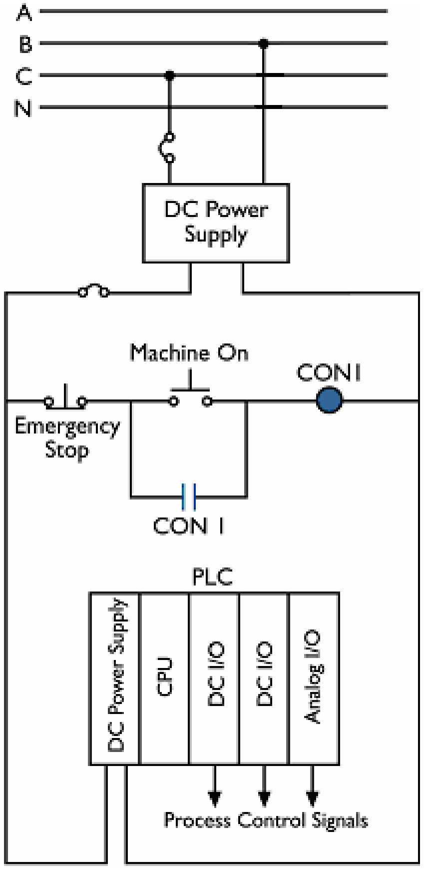
Control Level Embedded DC Solution

(Best done by OEM in design phase)





Designing in Embedded Solutions



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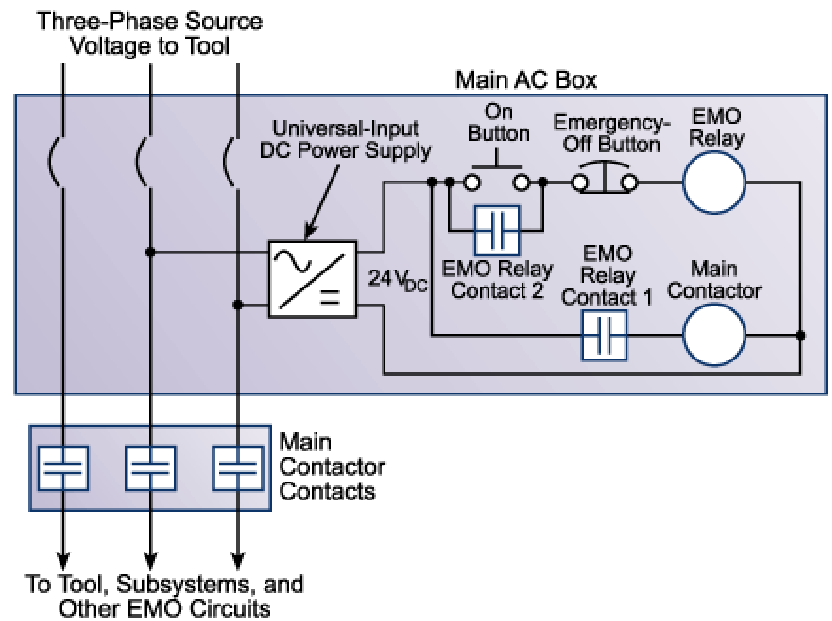
Method 1: Design with DC Power

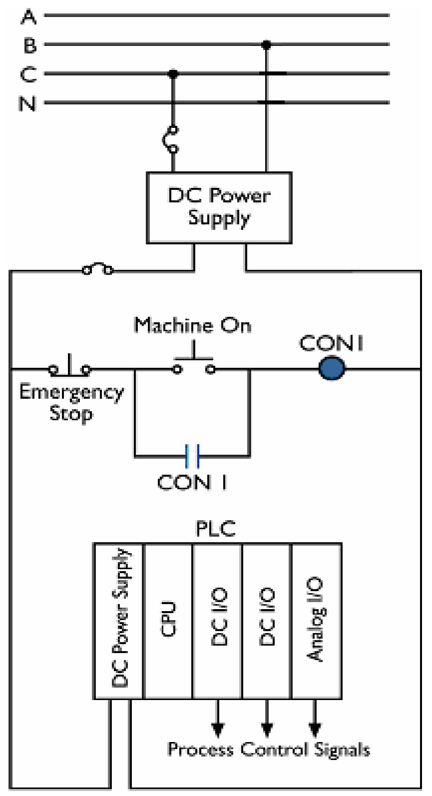
- One of the best methods of increasing the tolerance of control circuits is to use direct current (DC) instead of alternating current (AC) to power control circuits, controllers, input/output devices (I/O), and sensors.
- DC power supplies have a “built-in” tolerance to voltage sags due to their ripple-correction capacitors, whereas control power transformers (CPTs) and AC components do not have inherent energy storage to help them ride through voltage sags
- Many OEMs are moving in this direction to harden their equipment designs



DC Powered Emergency Off Circuit

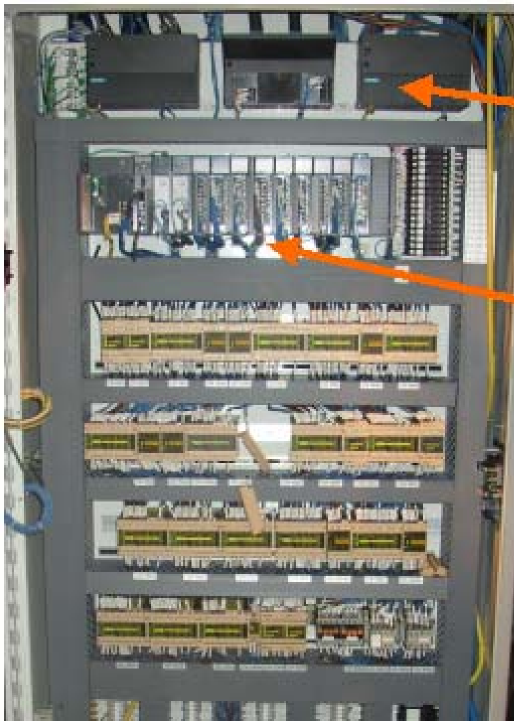
PLC Using DC Power Supply Scheme

- How Much Better is the DC solution?
  - Depth of Sag
  - Duration of Sag
- What other benefits does DC have?
- What are some design considerations with DC?



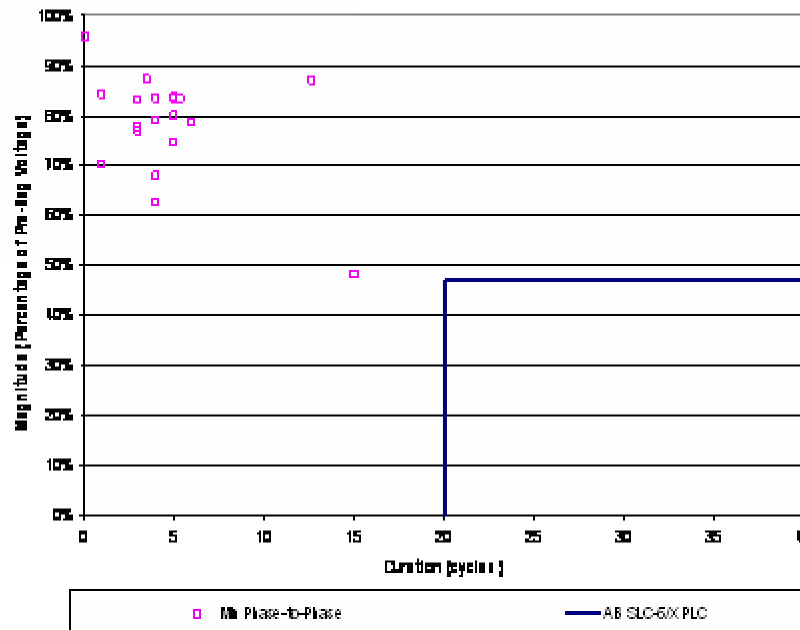
DC Powered PLC Circuit

DC Powered PLC System in Weld Shop

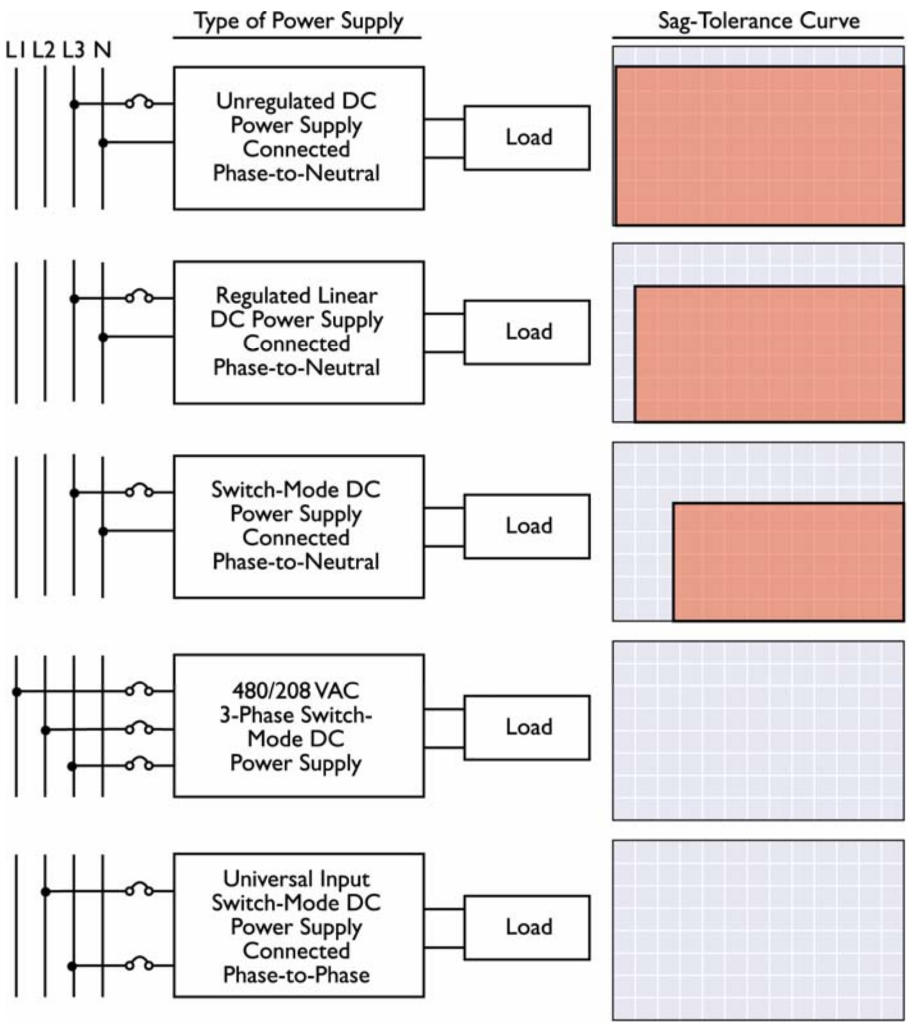


(3) Three phase input Siemens SITOP DC Power Supplies

AB SLC-5/x PLC with DC I/O



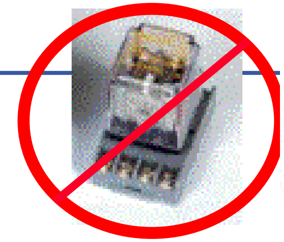
Summary of Robust Power Supply Strategies: Relative Power Supply Response at 100% Loading

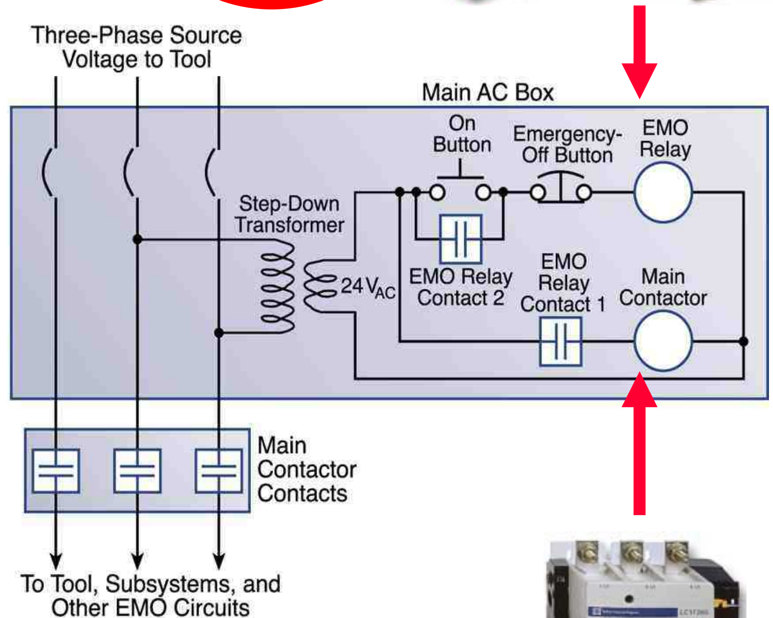


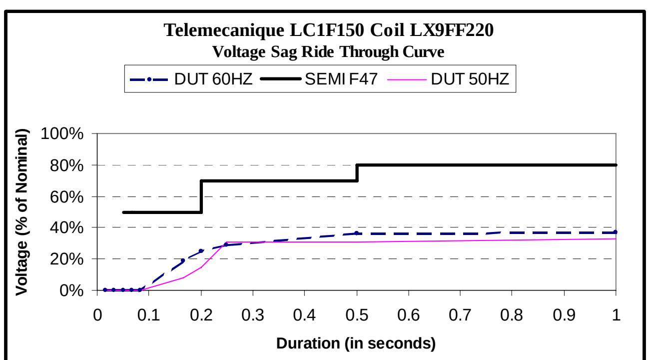
Ride-Through for Single-Phase Voltage Sags

Method No. 2: Utilize Sag Tolerant Components

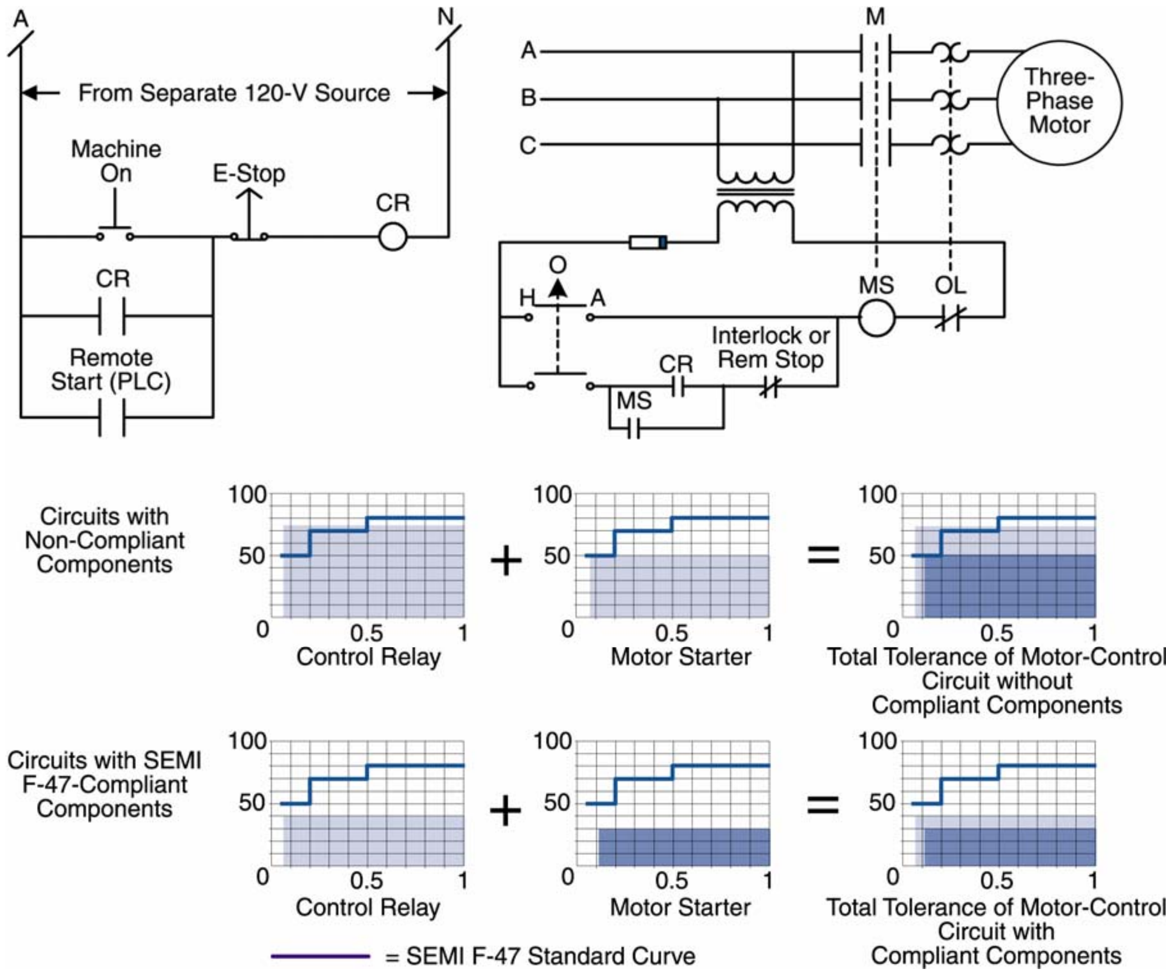
- IF AC Relays and Contactors are used in the semiconductor tool design, then utilize compliant devices.
- Consider response at both 50 and 60 Hz.
- We have certified a many relays and contactors to SEMI F47.





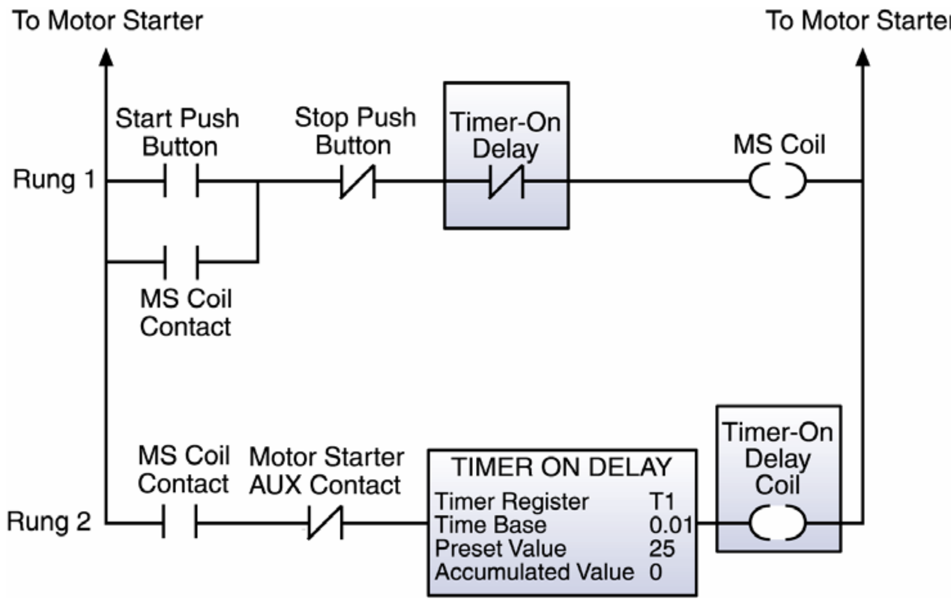


Example Voltage Sag Response of Motor Controls Based on Robustness of Components



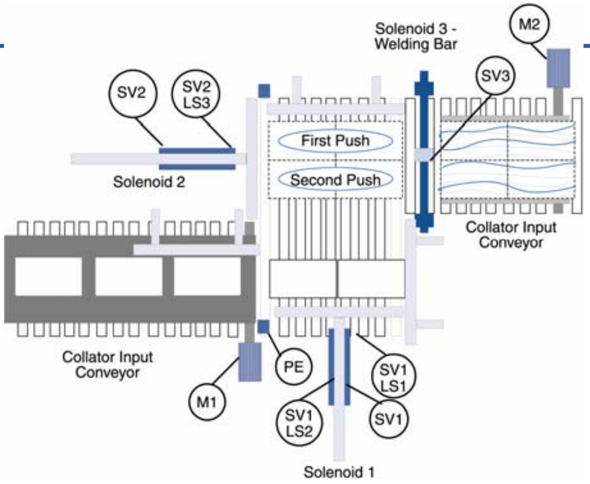
Method 3: Apply Custom Programming Techniques – Delay Filters

- **Delay filters** can be verify the presence of power and work as a "de-bounce" mechanism for when components drop out due to a voltage sag. The PLC motor-control circuit shown demonstrates how this method can be applied.
- The program is designed to detect whether the auxiliary contact is open for more than 250 milliseconds.
- If the contact is open for more than that preset time, then the "Timer On Delay Coil" in Rung 2 will be set and unlatch the previous rung to remove voltage from the motor starter.



Method 3: Apply Custom Programming Techniques –State Machine Programming

- State Machine Programming is based on the idea that manufacturing processes are comprised of a number of steps with the goal of producing and moving a product.
- Therefore, machine-state programming keeps track of every sequential process state and associated variables by writing variables to non-volatile memory in the event power is lost.
- When power returns, the processing step number and variables can be recalled so that the machine can continue from where it stopped.



Machine-state programming uses coding, such as shown below, to store and retrieve data as needed.

1. IF PE_COUNT AND PUSH_COUNT EQUAL 0, THEN TURN M1 ON
2. WHEN PHOTO-EYE COUNT (PE_COUNT) EQUALS 3, STOP CONVEYOR
3. IF PE_COUNT EQUALS THREE AND M1 IS STOPPED, MOVE SOL1 TO LS1 AND INCREMENT PUSH_COUNT
4. IF PUSH_COUNT EQUALS 1 AND SOL1 IS HOME, TURN M1 ON
5. IF PE_COUNT IS EQUAL TO 6 AND M1 IS STOPPED, MOVE SOL1 TO LS2 AND INCREMENT PUSH_COUNT
6. IF PUSH_COUNT EQUALS 2 AND SOL1 IS HOME, MOVE SOL2 TO LS3 AND INCREMENT PUSH_COUNT
7. IF PUSH_COUNT EQUALS 3 AND SOL2 IS HOME, EXTEND SOLENOID 2 FOR 5 SECONDS
8. IF SOL3 TIMER IS DONE, TURN M2 ON FOR 5 SECONDS AND RESET ALL COUNTERS AND TIMERS (PE_COUNT AND PUSH_COUNT)

Method 3: Apply Custom Programming Techniques – Programming Using Phase/Voltage Sensing Relay

- A phase monitor or voltage sensing relay, used in conjunction with programming, can also protect against the effects of voltage says.
- The relay contacts can be used to run a check on the system, retrieve past information stored in memory, or hold control parameters constant until the event is over.

Potential Sensing Devices For Voltage Sags

(Left to Right)

Phase Monitoring Relay

PQ Relay

“Original” PQ Relay (AC Ice Cube)

Method 4 – Examine Configuration Settings

- A low-cost or perhaps no-cost method of increasing the tolerance of AC and DC motor drives to voltage sags is through software configuration settings.
- This method applies to all types of drives, including, but not limited to, AC pulse-width modulation (PWM), direct-current, AC-pulse, stepper, and servo drives.

Method 4 – Examine Configuration Settings

Functional Description:
Automatic Reset and Automatic Restart

- In most cases, drive manufacturers give users access to basic microprocessor program parameters so that the drive can be configured to work in the user's particular application.
- A drive's programming parameters associated with reducing the effect of voltage sags are seldom describes in one section of the user manual.

Parameter	Parameter Description
Automatic Reset	This parameter allows the drive to automatically reset some fault conditions, such as DC link undervoltage or overvoltage, without the need for operator/user intervention. This feature is used in conjunction with Automatic Restart.
Automatic Restart	This parameter defines the method in which the drive automatically restarts after a fault condition is over. Automatic Restart operations may only be used as outlined in NFPA 79. Equipment damage and/or personal injury may result if the Automatic Restart parameter is used in an inappropriate application.
Automatic Restart Attempts	This parameter allows the user to program the number of times that the drive attempts to restart the motor after an undervoltage or other fault condition.
Automatic Restart Interval	This parameter is a user-specified time delay between the automatic restart attempts and the end of the fault condition.
Automatic Restart Time Delay	This parameter is a user-specified time delay between the end of the fault condition and an automatic restart.
Restart at User-Defined Frequency Setting	When the drive senses a DC link undervoltage condition, the drive shuts down the inverter, allowing the motor to coast. The motor is allowed to coast until the undervoltage condition ends. The drive then restarts the motor at a user-defined frequency setting. If the restart frequency is significantly higher or lower than the frequency of the motor, large inrush currents, torque, and speed transients could be induced on the motor (and load). The restart frequency setting, the acceleration rate, deceleration rate, current limit, and torque limit should be considered when using this feature.
Flying Restart	This parameter is similar to the parameter above with one major exception: Rather than restarting at a pre-defined frequency setting, the drive uses a search algorithm to determine the motor speed. Once the speed is recognized, the drive reaccelerates the motor to the desired operating point. The odds of the motor and load experiencing extreme current and torque transients are greatly reduced.

Method 4 – Examine Configuration Settings

Functional Description: Motor Load Control

Parameter	Parameter Description
Kinetic Buffering	When the drive senses a DC link low-voltage condition, the drive uses the combined motor-load inertial energy to maintain a factory-programmed DC link voltage inside the drive by applying a braking force to the motor. This feature does not create a potential for extreme current or torque transients.
Motor Voltage Compensation	When the drive senses a DC link low-voltage condition, the drive's controller changes the inverter firing timing sequences to compensate for a reduced DC link voltage. The objective is to maintain as close as possible the desired output voltage for operating the motor and load.
Controlled Deceleration and Acceleration	When the drive senses a DC link undervoltage condition, the drive begins to decelerate the motor at a user-defined rate. When the undervoltage condition ends, the drive reaccelerates the motor back to the desired operating point. This feature is often used in processes with multiple drives operating in succession, where all drives are expected to operate in unison to maintain process quality. This feature works well for common DC bus drive systems.

Motor-load control uses the motor's inertia or controlled acceleration/deceleration to ride-through voltage sags.

Method 4 – Examine Configuration Settings

Functional Description: Phase Loss and DC Link Undervoltage

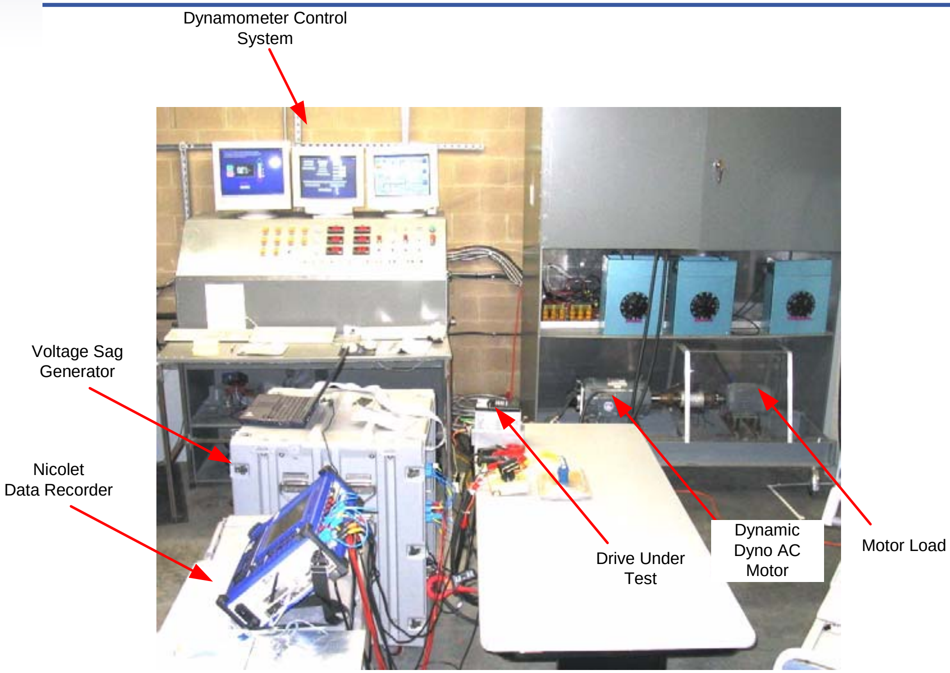
Parameter	Parameter Description
Input Phase Loss	The input phase-loss-detection circuit monitors either the input phases or DC bus current ripple and activates when one of the input phases is lost. In some drives, an input-phase loss alarm will be generated if the duration of the phase loss is greater than the input Phase Loss Delay setting.
Input Phase Loss Delay	This parameter controls the delay time in which an input phase loss must be present before a fault is generated. If the input phase returns to nominal before the delay time, a fault will not be generated.
DC Bus Undervoltage Limit or Undervoltage-Detection Level	Some drive manufacturers allow users to change the DC bus undervoltage trip point. By lowering the trip point, drives and processes may ride through longer and deeper voltage sags without interrupting production. This feature may be standard or may require a drive software upgrade from the manufacturer.
DC Bus Undervoltage Delay	This parameter allows the user to set a time delay for a DC bus undervoltage fault. If the duration of the undervoltage exceeds the delay time, the drive faults. Otherwise, the drive continues normal operation.

Detecting a loss of phase enables a drive to delay a fault condition and ride through the loss of phase. The DC link undervoltage trip point can be adjusted to enable a drive to ride through sags.

Example Settings Rockwell Power Flex 70 & 700

- Conducted SEMI F47 compliance Testing on Power Flex 70 and 700 Series drives in EPRI Lab.
- Drives have built in parameters that can be used to improve voltage sag performance.
- Drives loaded to 100%

Typical Drive Test Setup

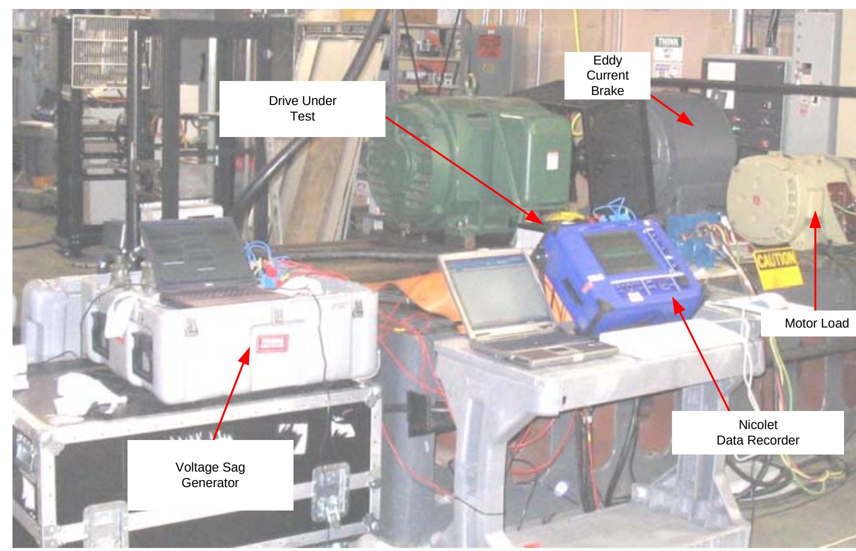


Test Setup for Smaller Drives

(2 to 15 HP)

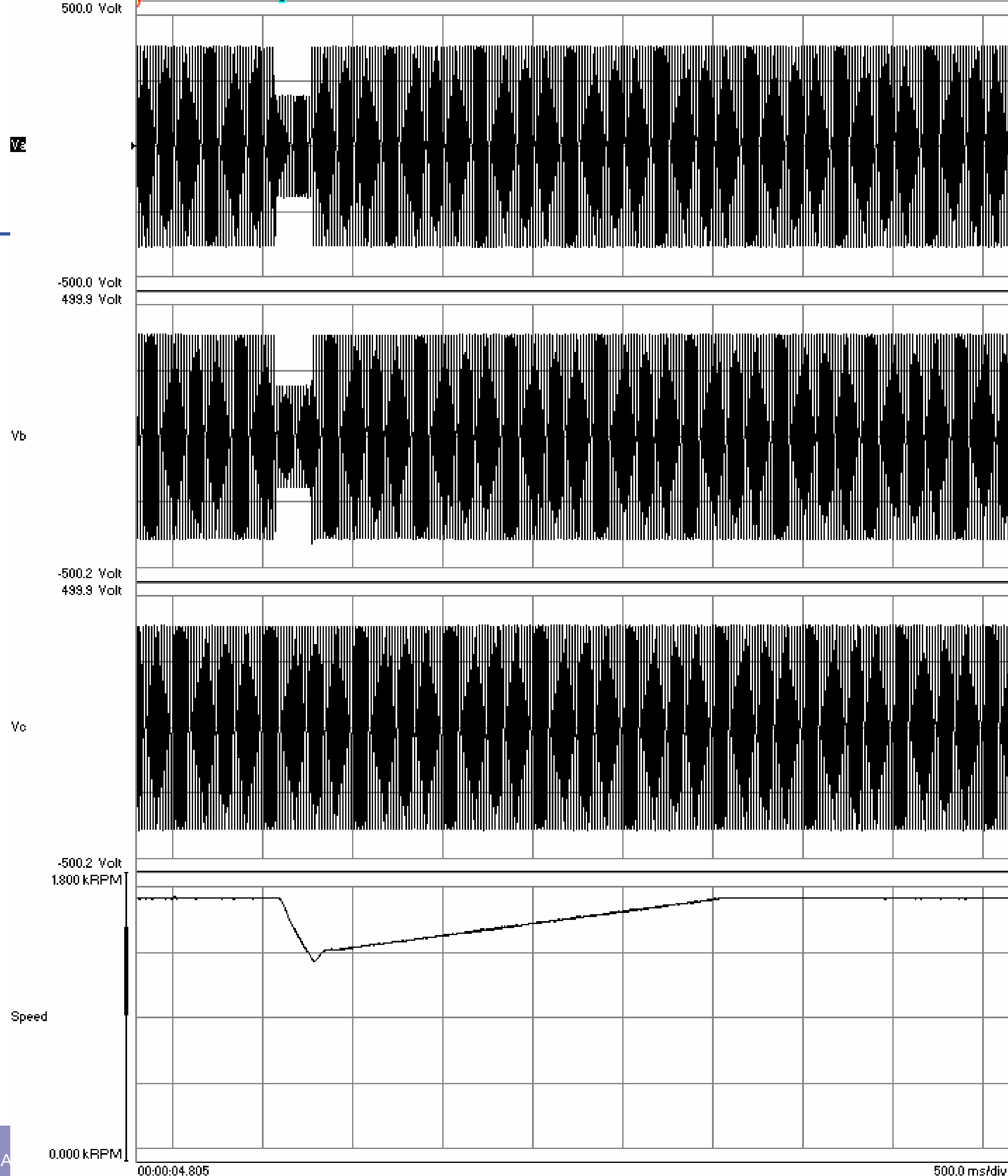
Test Setup for Larger Drives

(20 to 150HP)



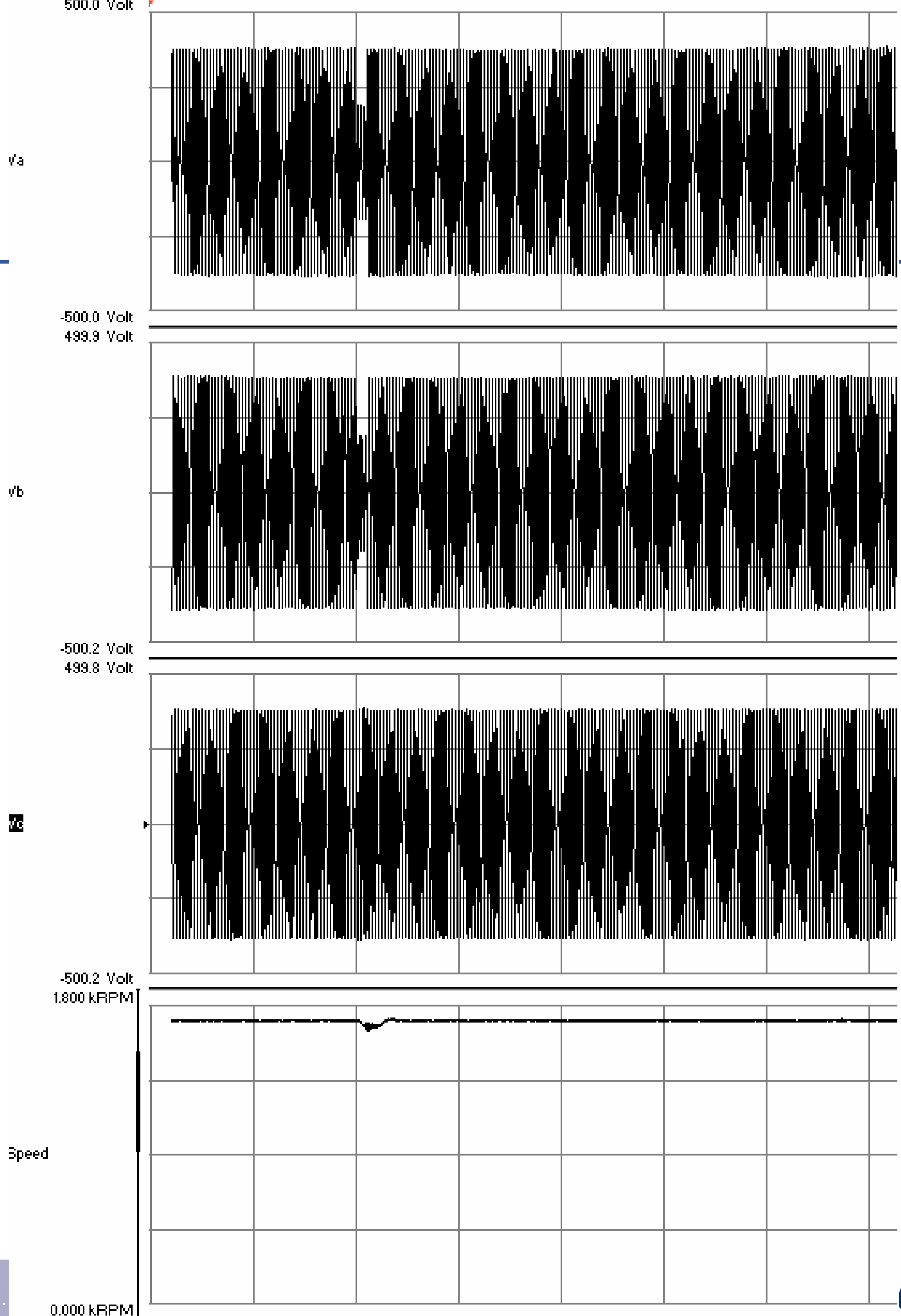
Example Response

- Example Worst Case Speed Deviation: 12 Cycles, 50% Vab without Line Reactor
- **Set for P184= “DECEL” mode**



Example Response

- Example Worst Case Speed Deviation: 12 Cycles, 50% Vab without Line Reactor
- **Set for P184= “Continue” mode**



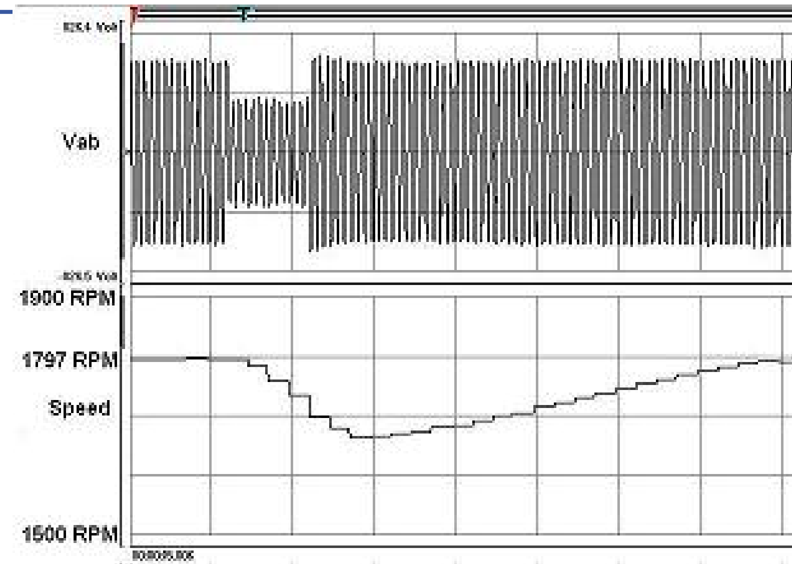
Schneider-Toshiba Altivar 61 & 71 Drives

- This newer drive series was recently tested as a part of the EPRI PQ Star SEMI F47 compliance program.
- Drives were found to pass the standard.
- Certification Relates to multiple drive models manufactured from same control platform
  - STI Altivar 61 and 71
  - ELIN >pDRIVE<
  - MX ECO and MX PRO

Altivar 61 and 71 Series Drives

Schneider-Toshiba Altivar 61 & 71 Drives

- The drives were able to pass the SEMI F47 testing requirements when configured properly.
- Prameters such as "Input Phase Loss", "Catch on the Fly", and Undervoltage Timeout (UV Timeout) had to be set.
- The dynamic torque profile was test to follow the "High Torque A" and the default slip compensation was set to 100%.



Parameter	Setting
Input Phase Loss	Ignore
Catch on Fly	Yes
UV Timeout	3 sec
UV Prevention	DC maintain
Slip Compensation	100% (default)
Dynamic Torque	High Torque A

Method 5 – Select Appropriate Trip Curves for Circuit Breakers

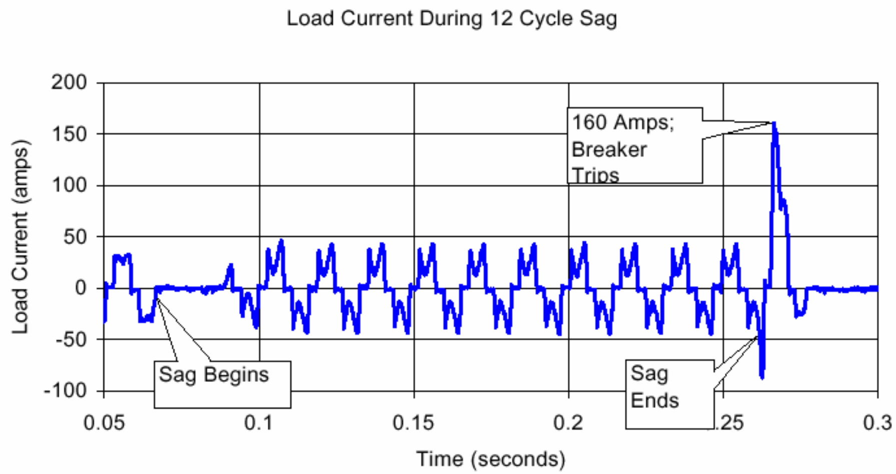


Figure 2. Load Current During Sag

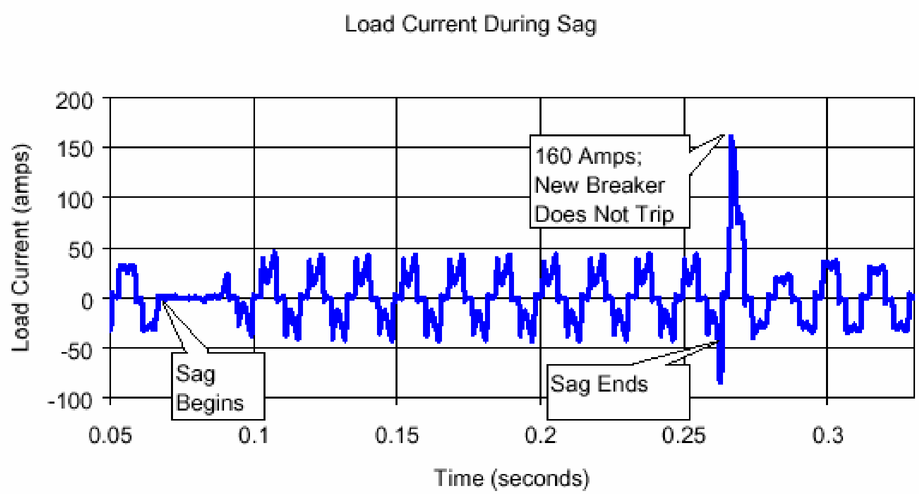
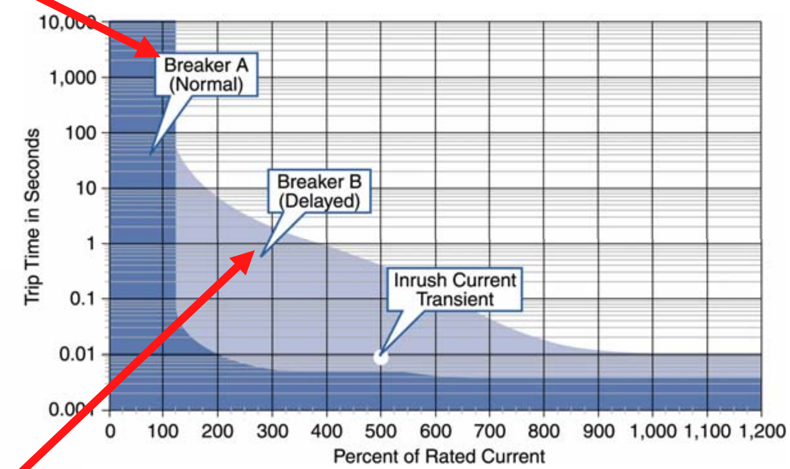
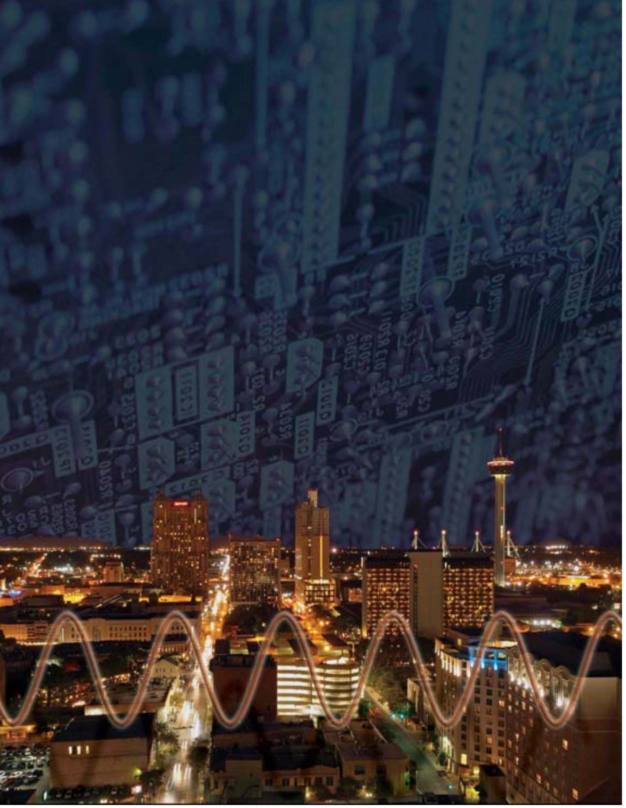


Figure 4. Response of New Circuit Breaker

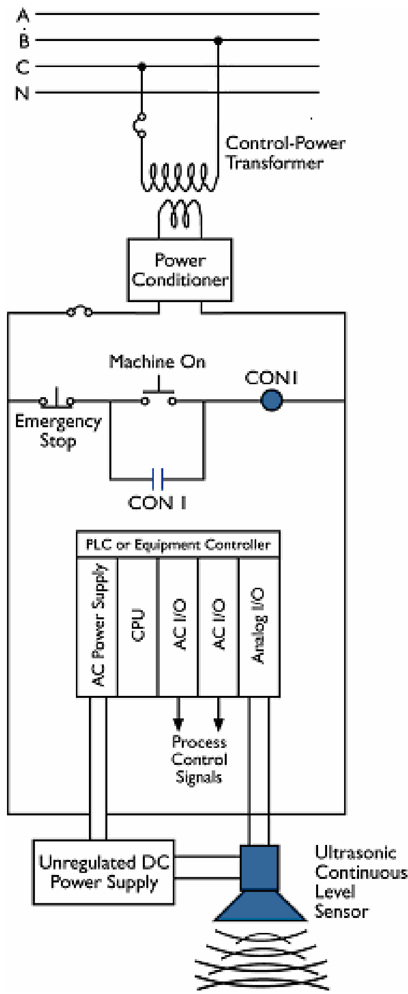


Other Considerations

- Make sure the device rated voltage matches the nominal voltage. Mismatches can lead to higher voltage sag sensitivities (for example 208Vac fed to 230Vac rated component).
- Consider Subsystem performance. Vendor subsystems must be robust for the entire system to be robust. Otherwise, power conditioning may be required for the subsystem.
- Consolidate Control Power Sources. This will make the implementation of any required power conditioner scheme much simpler and cost effective.
- Use a targeted voltage conditioning approach as the last resort. Apply Batteryless power conditioner devices where possible (next).



Use of Selective Power Conditioners



“Selective” Conditioning

The Premise:
All equipment power users are not ultra-sensitive.

The Plan:
To prop up the single-phase “weak links” only.

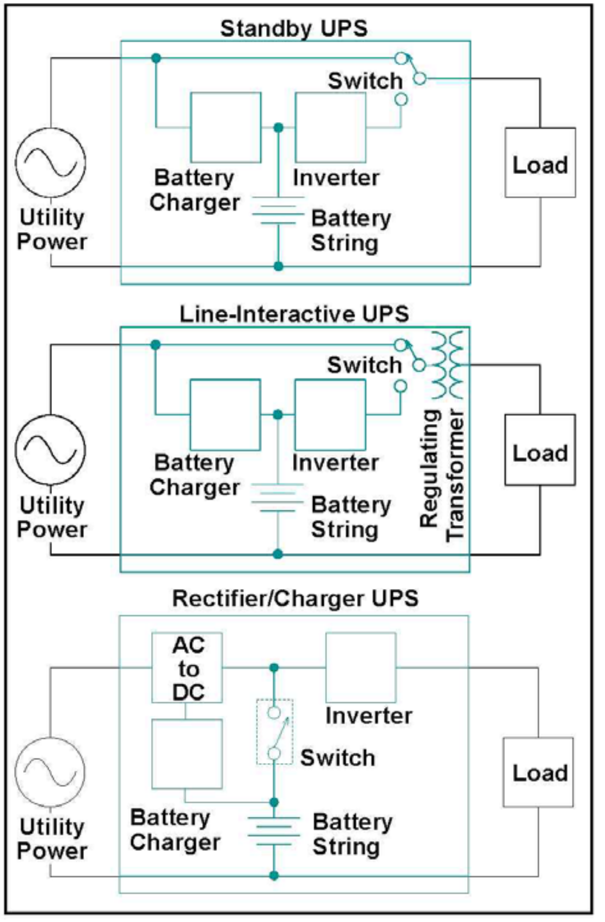
The Weak Links:
Small, single-phase 100Vac-230Vac, typically power supplies, sensors and controls.

The Benefit: Lower Cost than Macro Solutions.

Uninterruptible Power Supply (UPS)

For Control Loads Small 500Va to 3kVA UPS Systems are sometimes Used

Battery Based UPS Are Often "Overkill"



"Abandoned in Place" UPS Systems

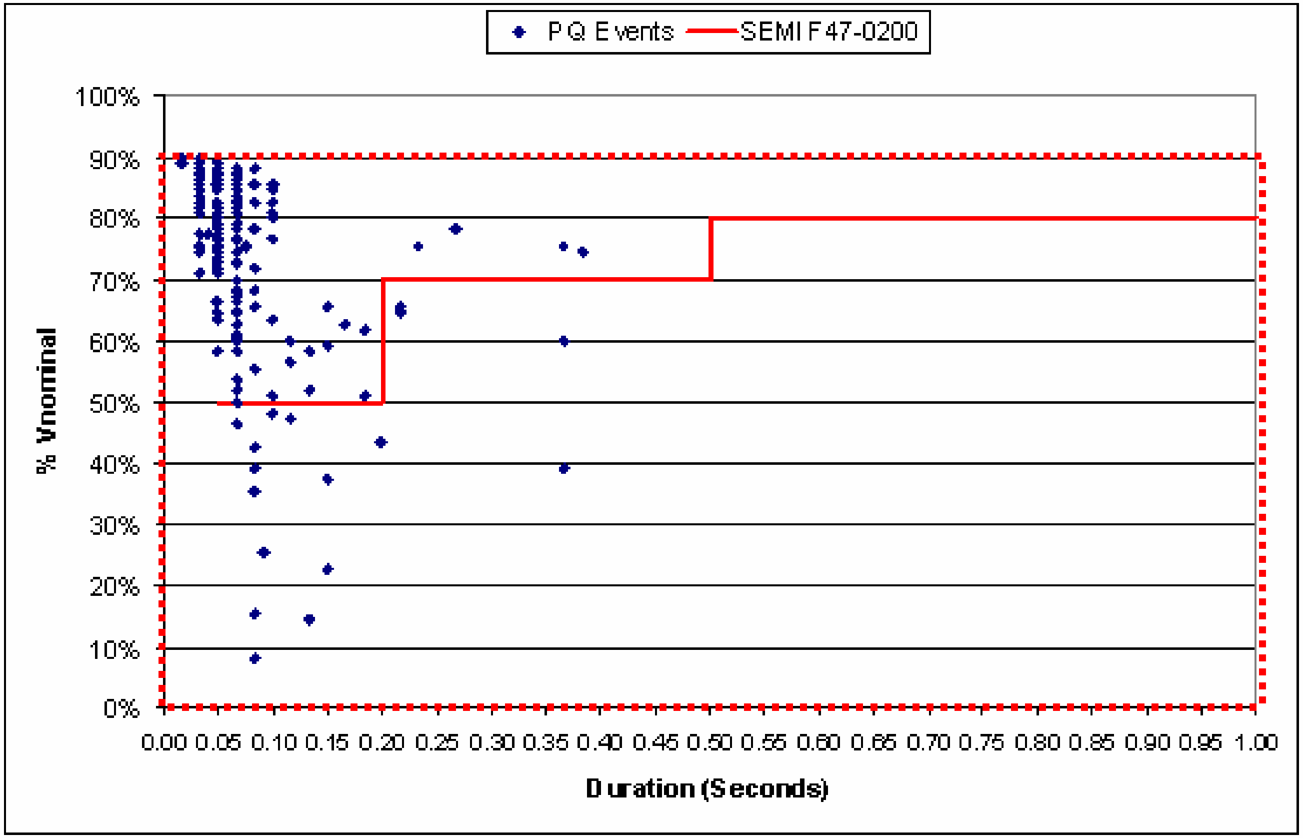
Square Wave Compatibility with PLCs


DPI


Square Wave Output UPS

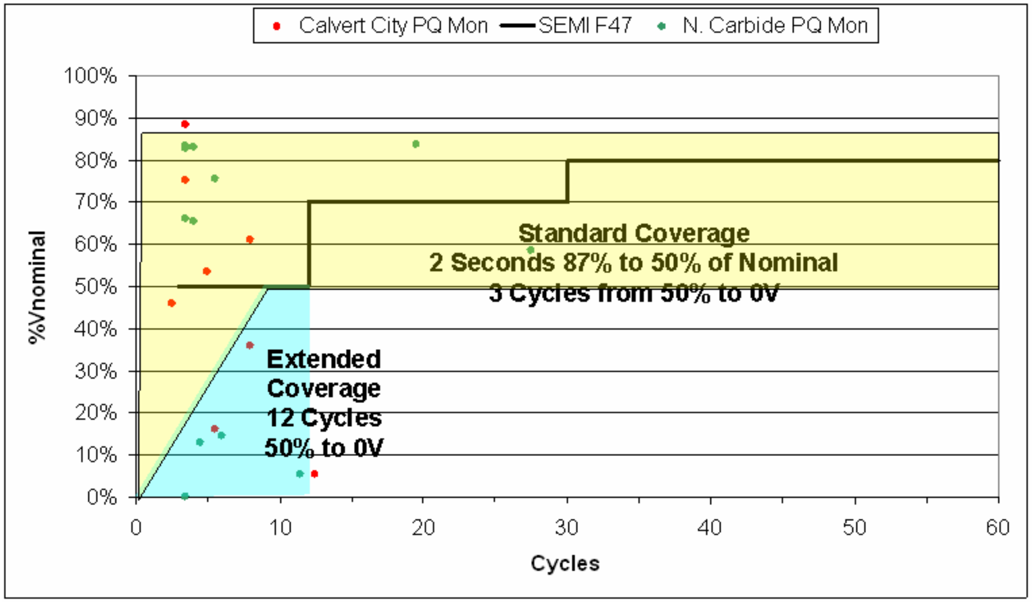
PLC Model	Compatible with 120Vac Input Cards?	Outcome with APC Smart UPS 420	Outcome with APC Back UPS Pro 650
Omron (PLC A)	No	Toggling input could not be resolved	Toggling input could not be resolved
TI 545 (PLC B)	No	All inputs dropped leading to the logical decision to drop the control relay	All inputs dropped leading to the logical decision to drop the control relay
Quantum (PLC C)	No	Same as TI 545	Same as TI 545
AB PLC-5 (PLC D)	**Yes**	**No Effect, System OK**	**No Effect, System OK**
AB SLC 5/03 (PLC E)	**Yes**	**No Effect, System OK**	**No Effect, System OK**

UPS Coverage vs. Sample Historical Data



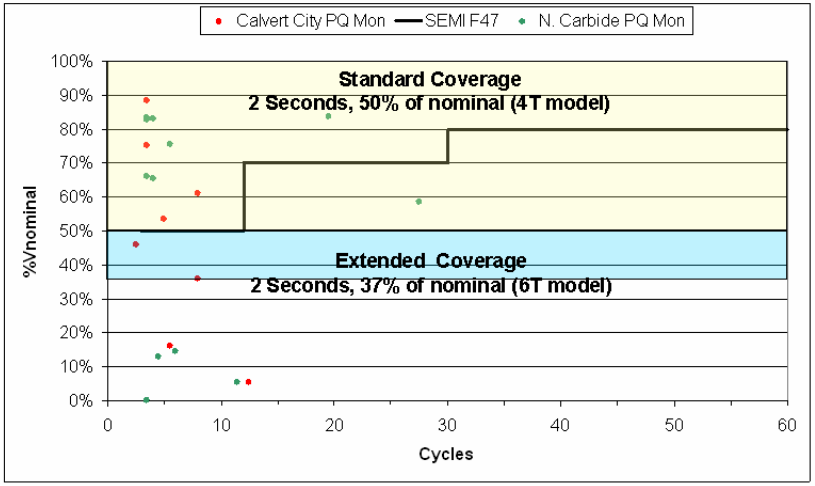
MiniDYSC

- The Dynamic Sag Corrector from Softswitching Technologies
- Deep Sag Coverage especially when lightly Loaded
- Has Capacitors that allow for some ride-through for interruptions
- Would handle all sags seen by equipment during monitoring period.
  - http://www.softswitch.com



Voltage Dip Compensator (VDC)

- No batteries; no maintenance.
- Fast compensation.
- Able to withstand high inrush currents.
- Small footprint, easy to retrofit.
- Support exceeds SEMI F47 standard requirements.
- 120Vac and 208Vac Models
    - www.measurelogic.com
    - www.dipproof.com



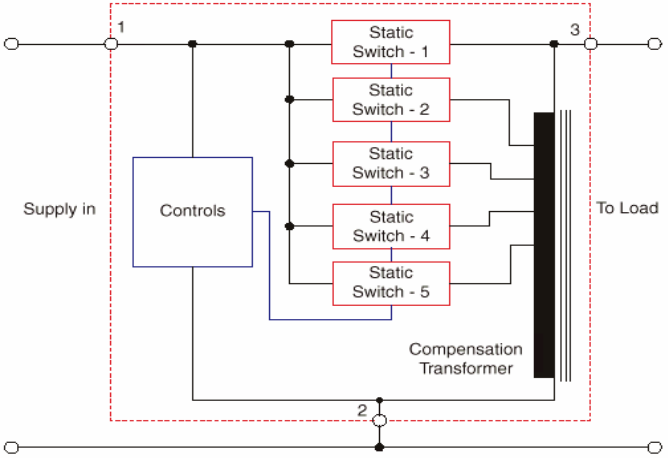
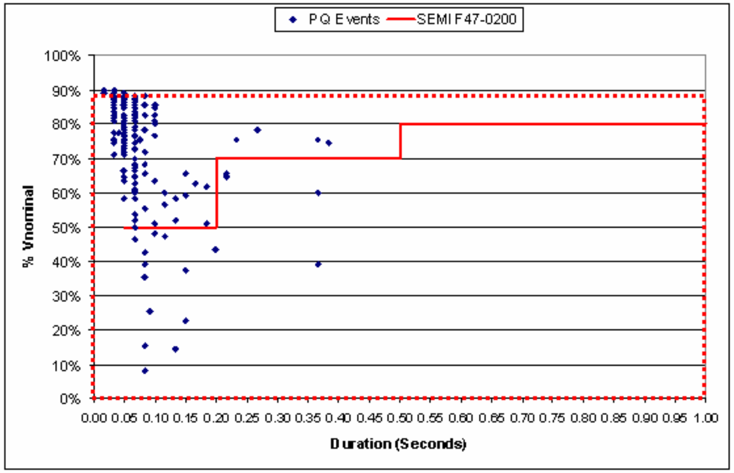


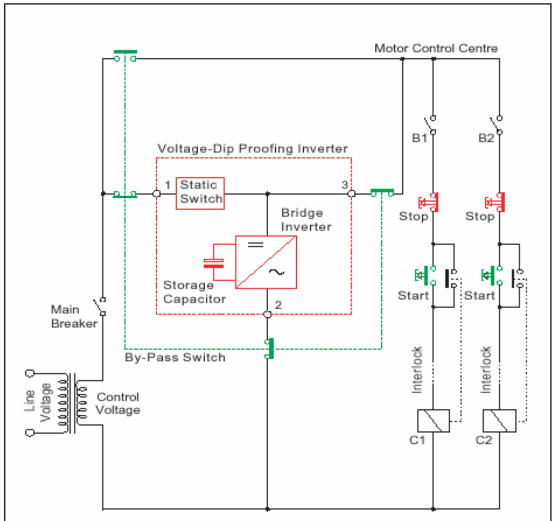
Fig 1
Compensator Block Diagram

Dip Proof Inverters (DPI)

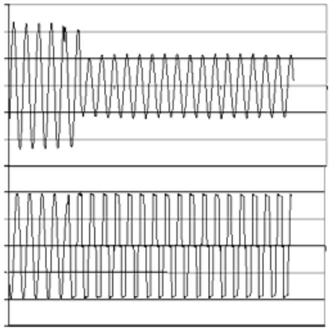
- No batteries; therefore, no replacement and maintenance costs or hazardous waste.
- Fast (<700µS) transfer, off-line system develops little heat & fails to safety.
- Able to withstand high inrush currents; no need to oversize as with UPS's & CVT's.
- Lightweight, small & easy to retrofit; no step-up transformers or batteries.
- Accurate application control; adjustable ride through time & variable transfer level.
- Primarily designed for inductive and low power factor loads.
- 120Vac and 208Vac Models
- Square Wave Output

  - www.measurelogic.com
  - www.dipproof.com

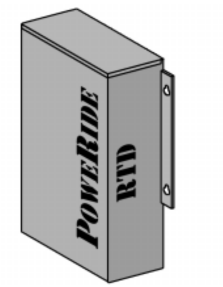




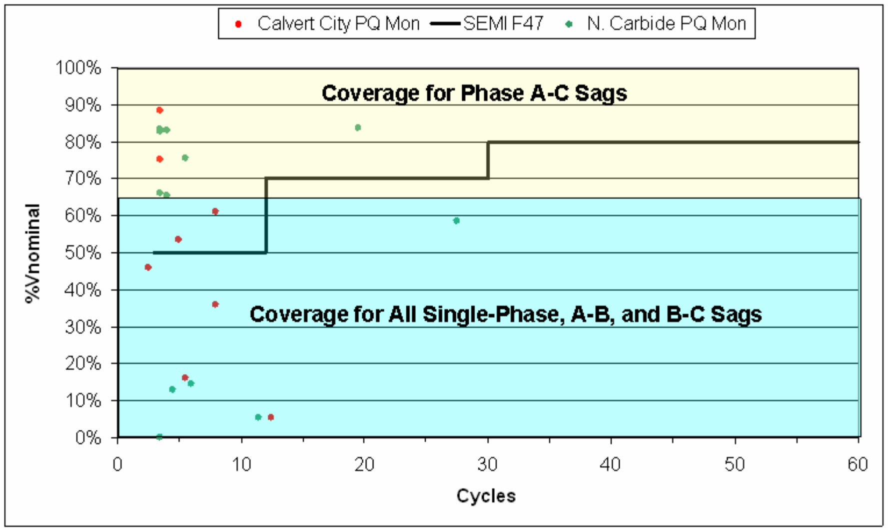
A typical DPI connection diagram

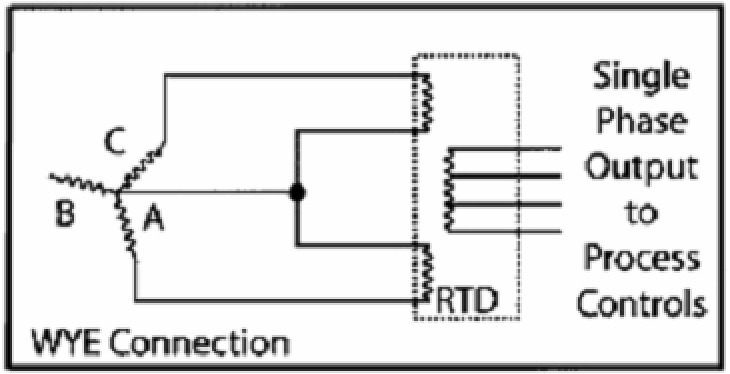


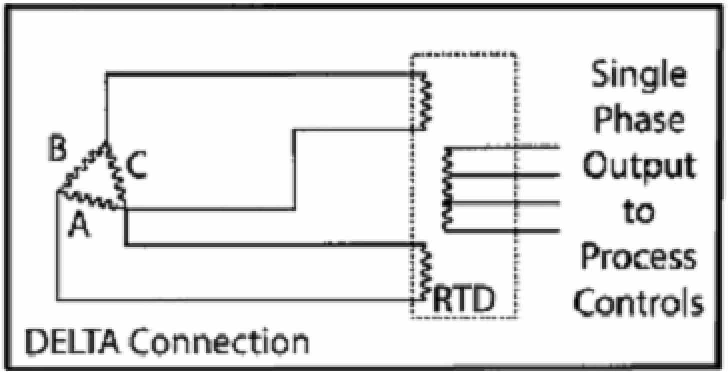
PowerRide RTD



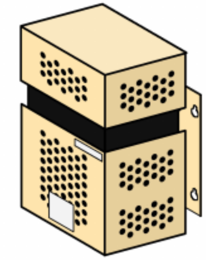
- Uses two phases of a three-phase supply as input and a single-phase output.
- If one phase in interrupted, constant power out of the RTD....Even if the remaining phase drops by a third.
- Typically No Need to oversize for Inrush
  - http://www.uppi-ups.com



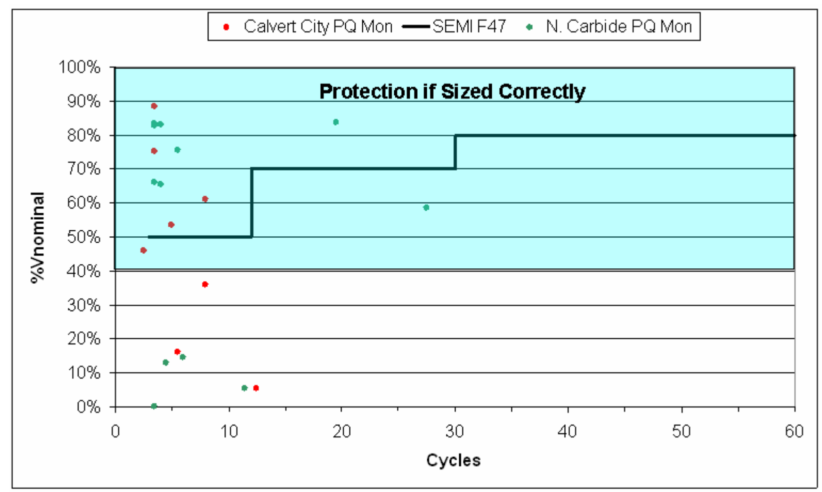


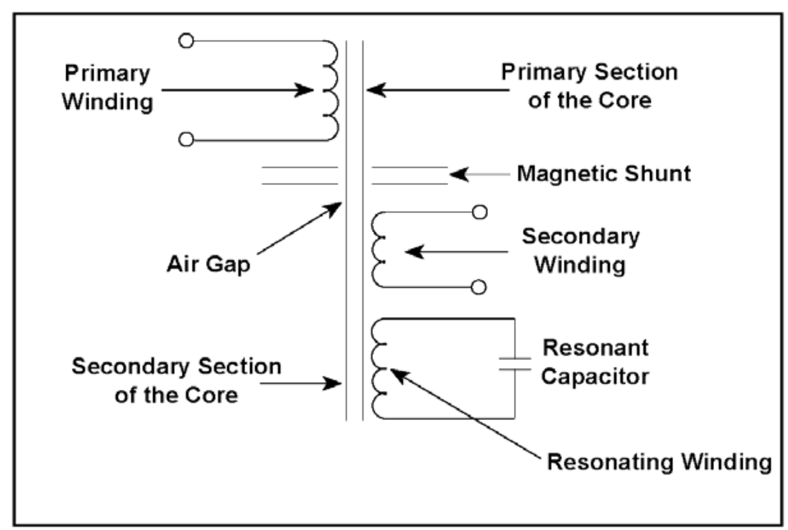


Constant Voltage Transformer (CVT)



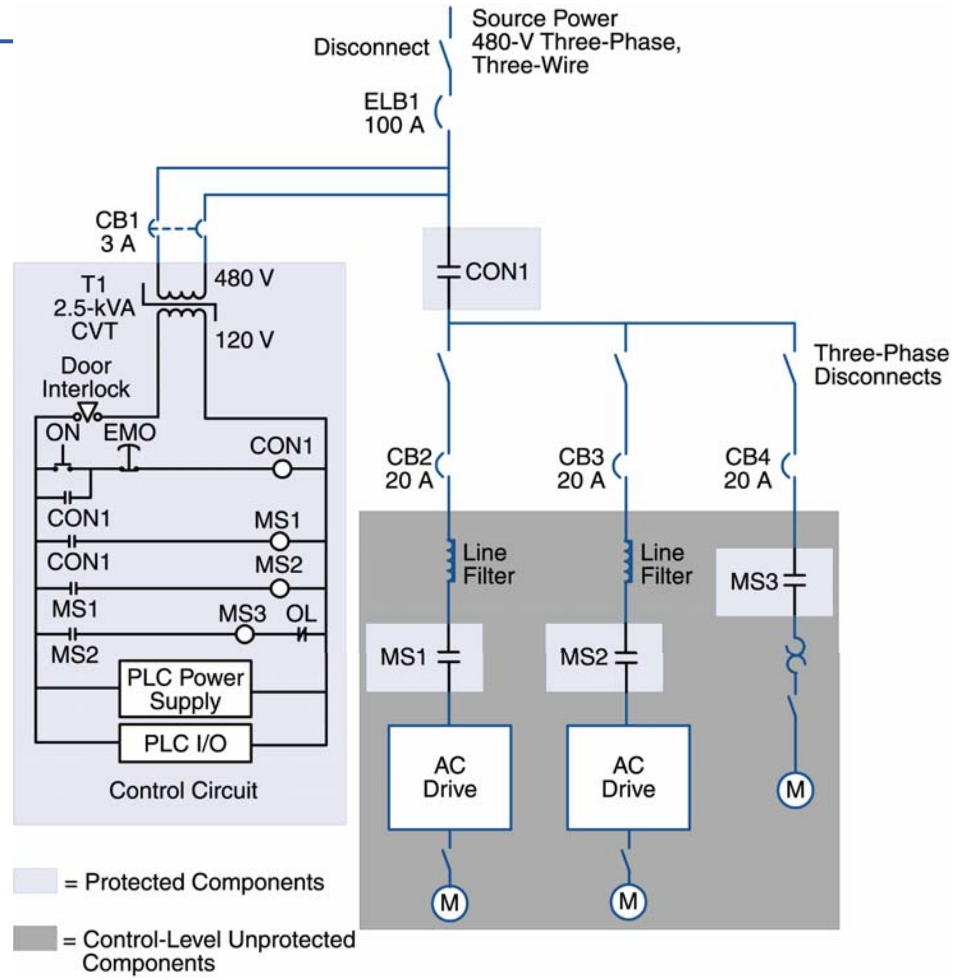
- On-line Device. In-Rush Current of load(s) MUST be considered in sizing.
- Output of CVT can collapse when in-rush current gets close too high (around 4 x rated size).
- Sub-Cycle Response.
- Should be oversized to at least 2 times nominal of load to increase ride-through.
- Acts as an isolation transformer and protects against voltage sags.



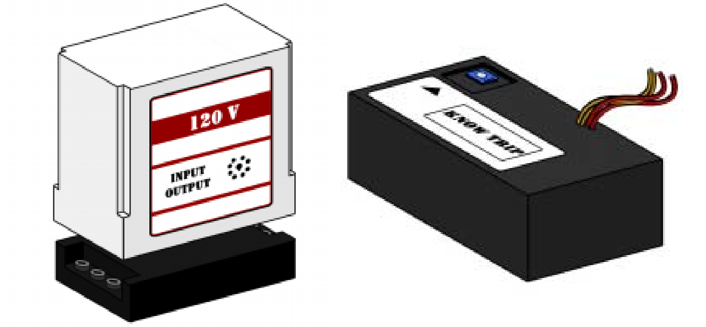


Example CVT Application

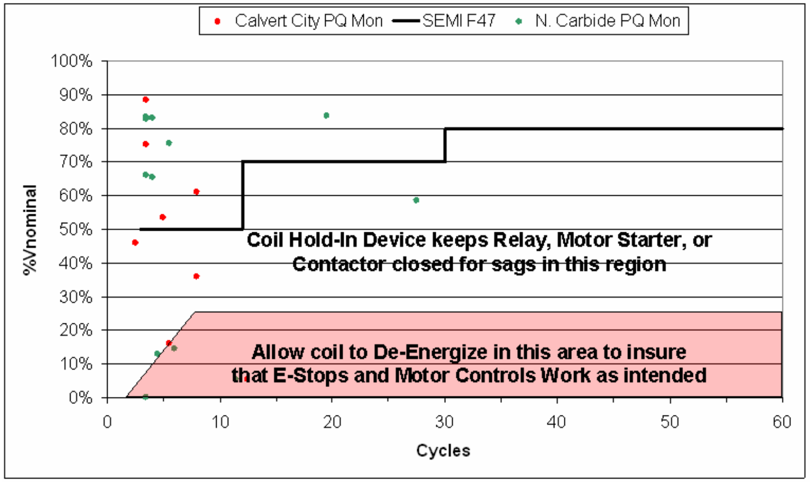
- The CVT is protecting only the AC control components means that the selected power conditioner will be more affordable than one that could protect the entire machine.
- The ride-though of the AC drives in this example can be enhanced by modifying their programming, thus eliminating the need for a large power conditioner.



Coil Hold In Devices



- Will prop up relay or contactor coil down to 25% of nominal voltage sag.
- Customer will need to final Size the coil hold-in device based on Voltage and Coil Resistance (measure with an ohm meter)
- **Cost: less than $150-250 USD per unit**
- **Suppliers**
  - **www.pqsi.com (UL Certified)**
  - **www.scrcontrols.com**



Example Device

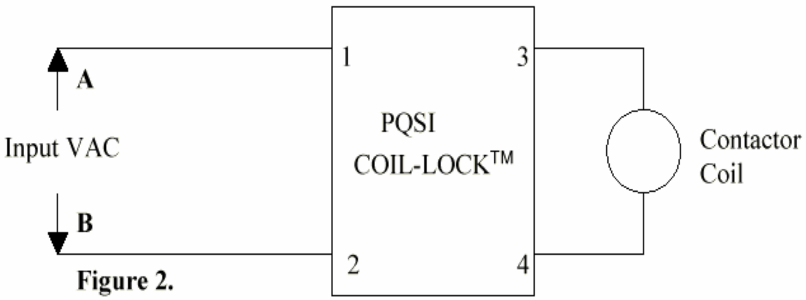
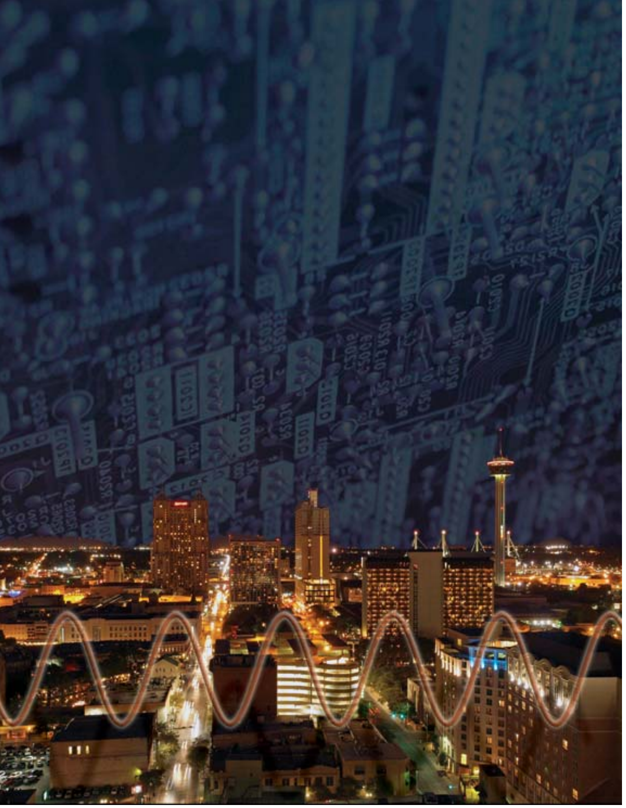
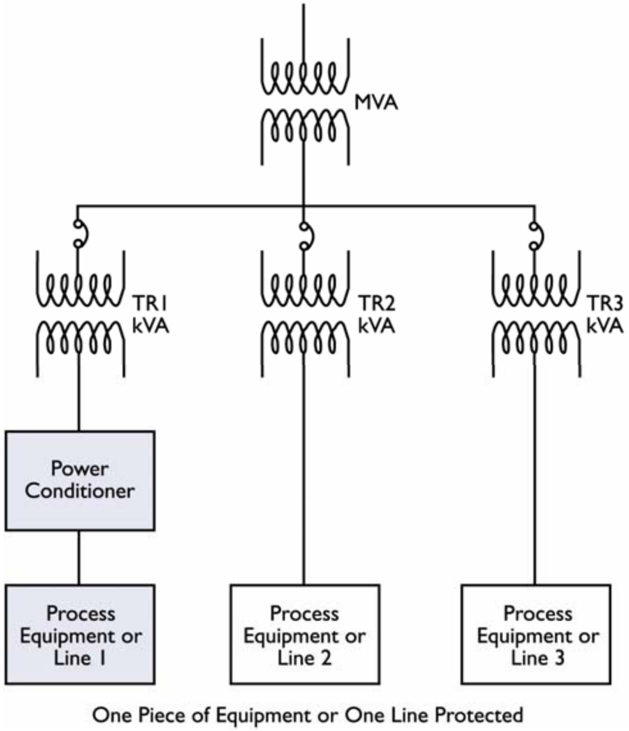


Figure 2.



Machine and Panel Level Solutions



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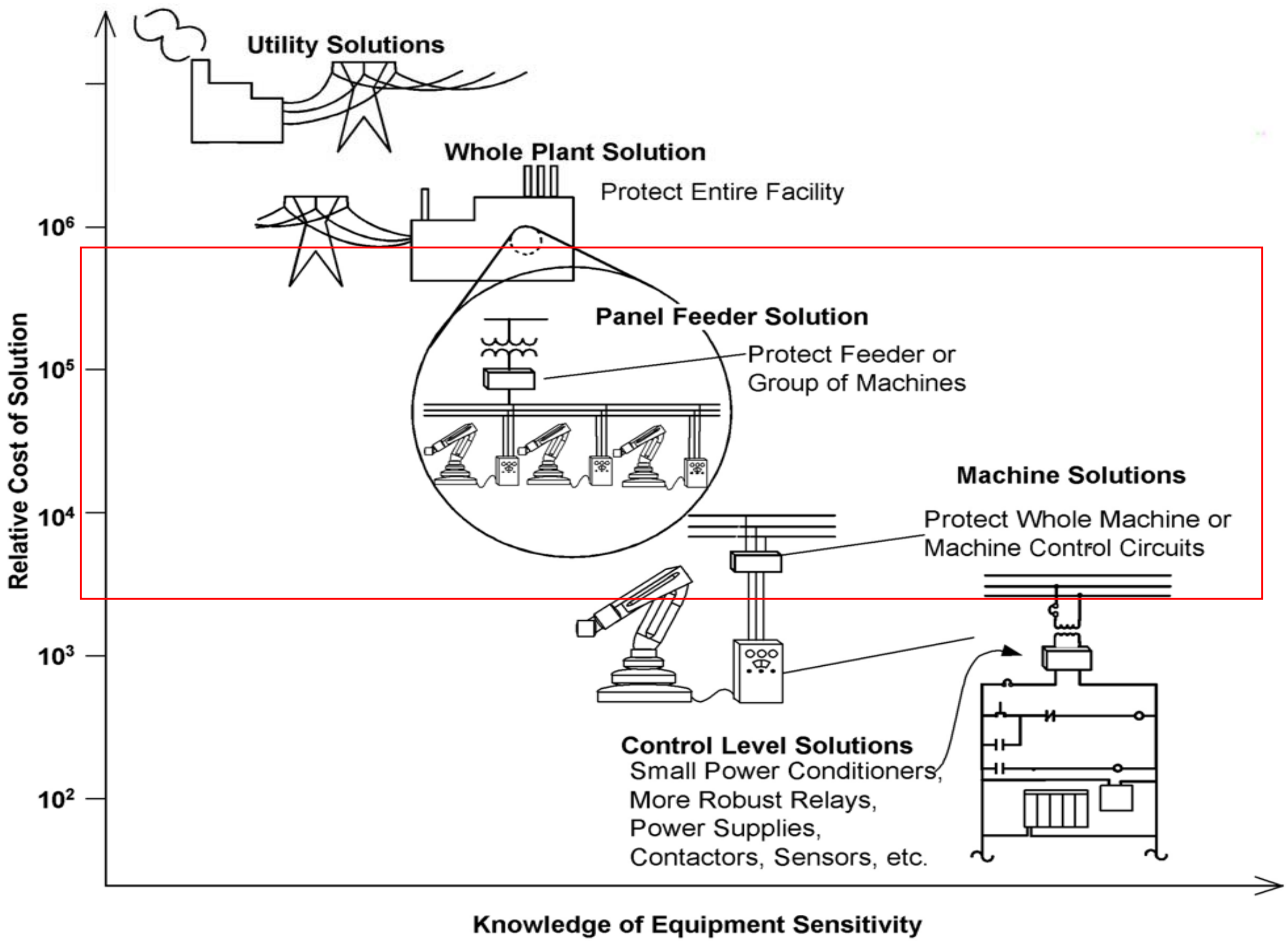
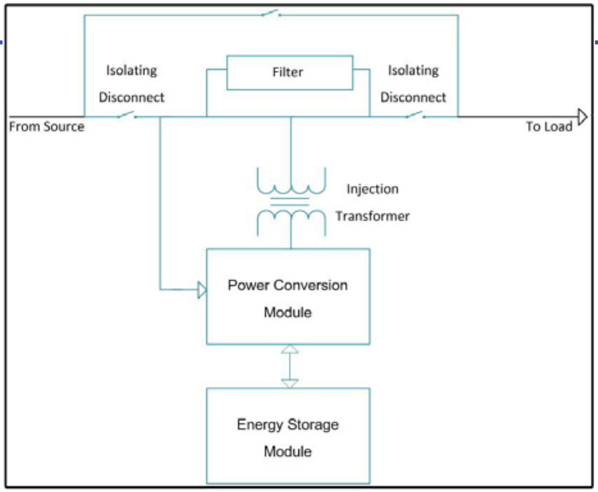
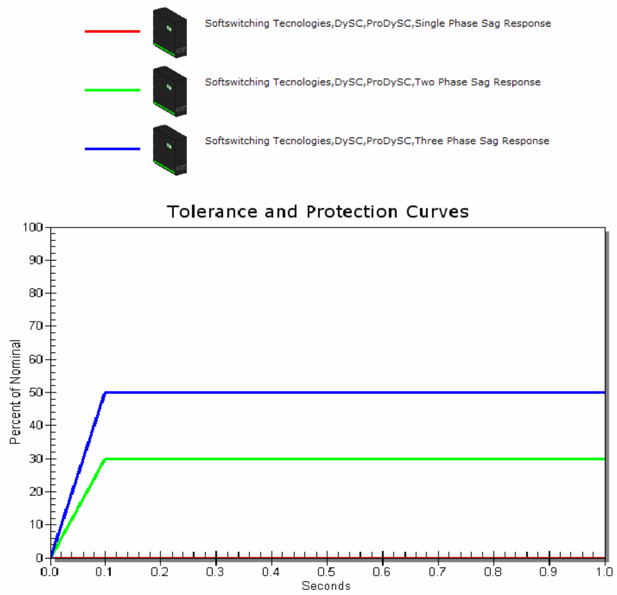
Cost of Solutions Versus Knowledge of Sensitivity



Pro-DySC

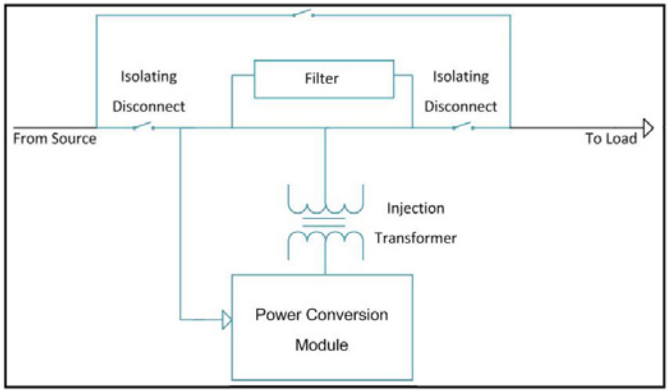


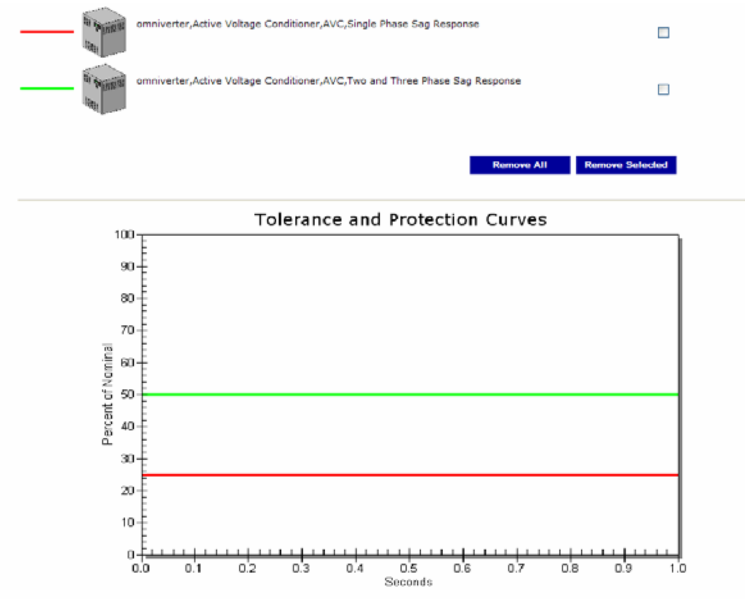
- The ProDySC provides equipment and process level protection without the use of batteries or fly wheels.
- The unit can boost incoming line voltage and provide momentary ride through protection for sags down to zero volts.
- It is designed to handle short-term sags up to two seconds with a 30 second recharge time.
- This unit is three phase, 200-480 volts, 25-200 amps, and supports between 333 and 2000kVA.



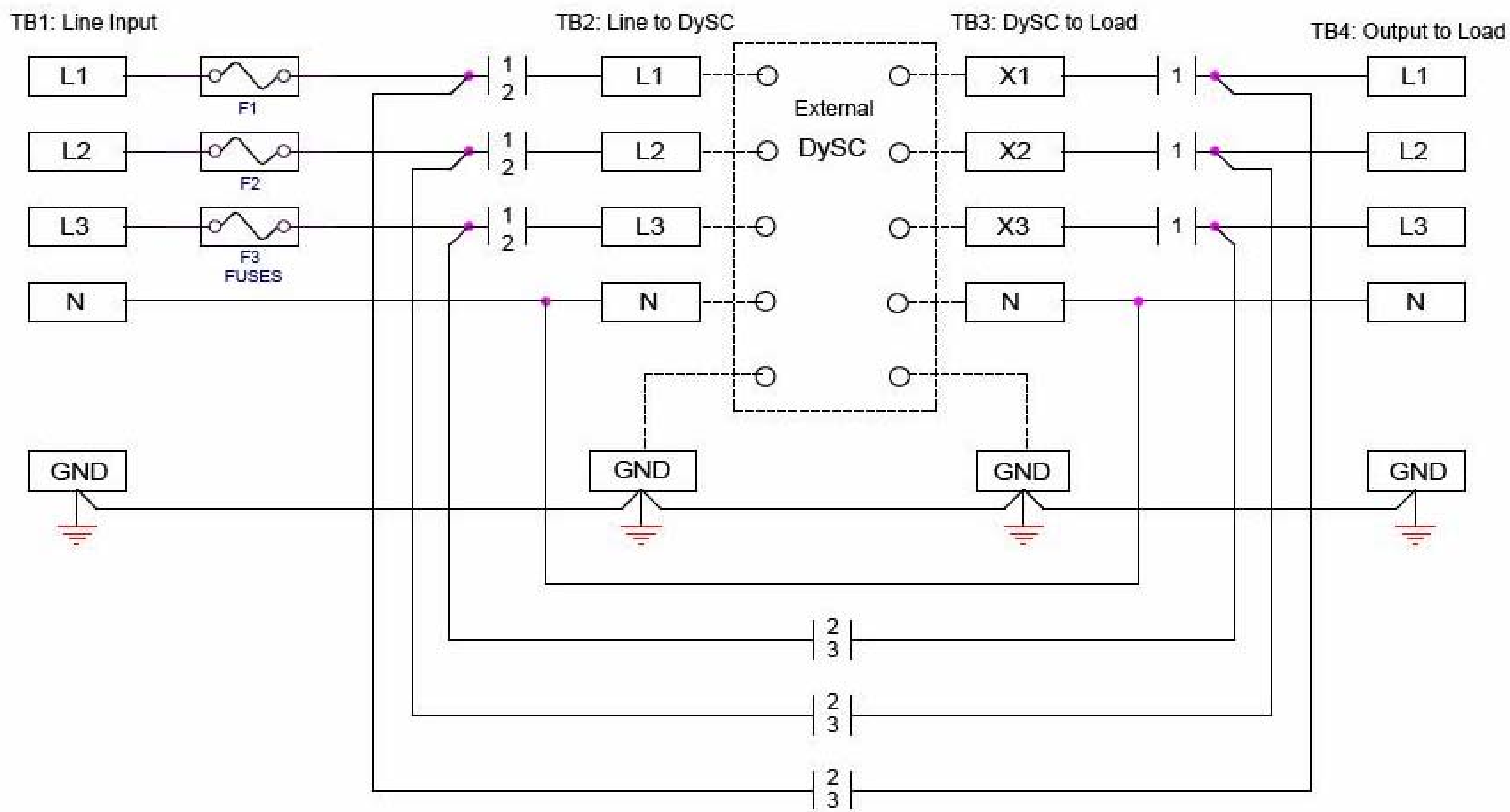
Omniverter AVC

- The Active Voltage Conditioner (AVC) consists of an inverter which feed an injection transformer in series with the utility.
- The inverter allows the unit to correct utility disturbances.
- Since there are no storage devices no maintenance is required. It comes in a three-phase 208, 480, and 600 volts but has 400 and 690 volt options.
- It has a very fast response time of in less than a millisecond because it is continuously running.
- It can also protect against rapid-consecutive sags





Purchase Bypass with unit



Example Control Level Solutions at the Distribution Panel and Recommendations

- Sometimes the most effective solution is to provide conditioned power for the entire IPP Panel. Advantages of this approach include:
  - Simplified Cut Over/Fewer Touch Points
  - Single Power Conditioner for many loads
  - When sized to support kVA of transformer, this approach will support future expansion in panels