Voltage Sag Ride-through Mitigation in Sequence by Increasing Cost

A voltage sag is defined as a decrease in voltage magnitude below 90% of nominal, but not a complete interruption. The typical duration is from 3 to 10 cycles; 50 to 167 milliseconds.   Typical end-use equipment sensitive to voltage sags are: computers, programmable logic controllers, controller power supplies, motor starter contactors, control relays and adjustable speed drives.

A very important distinction must be made when applying any mitigation technique to this problem. Some of the above loads are stand alone devices or control single stand alone motors that can start and stop without causing any damage to the motor, the driven equipment, a process, or personnel. In the case of motor starter contactors, it is necessary to understand the load or process involved before retrofitting any change in the protection scheme that could result in damage to the motor, the process, or an operator. In the case of most motors on pumps and fans in HVAC systems, automatic restart is a desirable feature. On the other hand, restarting a large chiller must be a carefully controlled process.

The EPRI Power Electronics Application Center recently published some documents recording tests performed on over 30 semi-conductor fabrication tools. The results of these tests indicate that retrofitting small components within the tools can dramatically increase the sag ride-through capability. The number one villain was the "emergency-off" relay. The second most common sensitive component was a contactor. The third most common sensitive component was the power supply to Programmable Logic Controller (PLC) or any other DC logic.

The test identified two approaches to extend voltage sag ridethrough. The least expensive approach is for the manufacturer to embed the solution into the design of the machine. The more expensive is to provide some form of selective power conditioning.

A very simple solution found was to make sure that the machine/tool and all its components are operating at the rate voltage. If a power supply, relay, or contactor are supplied with less than the required rated voltage, then the unit will be more sensitive to voltage sags. It is very important to pay close attention to the tap positions on all transformers. It may be sufficient to simply tap up a transformer to improve ridethrough. Another very simple solution was to use phase-to-phase voltage for controls instead of phase-to-neutral.

Some manufacturers use or recommend the use of phase monitoring relay to monitor the phase rotation, voltage magnitude and unbalance. Some are preset and some have variable thresholds. These can be counter productive if they result in nuisance tripping. For sure do not have in the Emergency Off Relay (EMO) circuit.

Recommended Solutions:

1. **Embedded Solutions.** In general, these solutions involve fixing the individual "weak links" components of a machine in order to increase the overall ridethrough of the entire system. Embedded solutions are attractive since they in theory do not require add-on power conditioning equipment, but instead involve using more robust or improved components in the machine design. The very best way to insure that a machine meets your requirements for voltage sag ridethrough is to include the requirement in the purchase contract language and require proof of compliance. The semi-conductor manufacturing industry trade group SEMI has prepared two standards in 1999 to facilitate embedding the solution. SEMI F47 provides for the definition and measurement of equipment reliability and availability during voltage sags. SEMI F42 standard provides for the compliance test protocol. See their website *www.semi.org*. The semi-conductor manufacturers have sought this solution because the cost of lost product is extremely high. The bottom line is economics. The proposed SEMI F47 standard is in this table of values:

Voltage sag duration and percent deviation from equipment nominal voltage

Duration Seconds (s)	Duration Milliseconds (ms)	Duration Cycles at 60 Hz	Voltage Sag Percent (%) of Equipment Nominal Voltage
<0.05 s	<50 ms	<3 cycles	Not specified
0.05 to 0.2 s	50 to 200 ms	3 to 12 cycles	50%
0.2 to 0.5 s	200 to 500 ms	12 to 30 cycles	70%
0.5 to 1.0 s	500 to 1000 ms	30 to 60 cycles	80%
>1.0 s	>1000 ms	>60 cycles	Not specified

2. **Built-in energy storage within the device.** An example is a digital alarm clock with either a storage capacitor or a battery. A few VCRs have high-end models with ride-through capability. The cost of modifying a PC switched-mode power supply could be less than $50. In this competitive market, some manufacturers are reluctant to modifying since that may double the cost of the power supply.

3. **Built-in software programming** within the sensitive device. Several small adjustable speed drive models have user programmable automatic restart. Typically, they wait 30 to 60 seconds for the circuit to stabilize before trying to restart. The number of retries can be programmed, typically it is set at 5 retries. This strategy is commonly used in HVAC fans and pumps in an unattended environment. This applies to both sags and momentary interruptions. There are several ASD manufacturers that have as an option, the ability of the ASD to restart before the load has come to a complete stop and to apply the appropriate torque. Unfortunately, this concept is only applicable to a single stand-alone drive as yet.

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NEMA has a working group to establish a new restart category label for drives. The three categories of restart capabilities after a voltage sag are: 1) stop, 2) delay and try to restart but not in synch, and 3) try to restart immediately in synch with prior speed. On better drives, these will all be available for the user to program as required.

Some computer systems will suspend operations until the voltage anomaly passes and then resume computing. It will issue a "voltage out of tolerance" error message, but the computing operation continues. For desktop computer users, most softwares have an autosave feature to limit loss of data. This is a no-cost option.

For automated process control software it would be very productive if the software knew the status of the equipment when a sag shutdown is executed. This could be an extra cost option but very cost effective because it will reduce the restart time.

4. **Change motor starter contactors from AC to DC to extend ridethrough**. DC contactors and relays are readily available. A DC contactor or relay is stronger because the flux is constant. A rectifier is required to change AC to DC. A small storage capacitor could be added to DC contactor to extend ride-through energy. Disadvantage of DC is increased arcing due to lack of zero crossing to break the arc. According to NEMA standard, an AC motor contactor should ride through a sag to 85% of nominal and a DC contactor should ride through a sag down to 80% of nominal. Some industrial facilities use all DC control relays. Relays are much faster to open than motor contactors because they are smaller, less mass, act quicker. They will open in 5 to 15 milliseconds; this is less than one cycle. There are very important application considerations when considering extending the ridethrough of motor contactors. In making modifications, consider the system approach and consult your OEM. One method to extend the ridethrough is to add a 70va ferroresonant transformer that costs approximately $150. This is cheaper and easier than changing the coils.

   One solution, to improve the ride-through performance for motor/machine starters/controllers, is a small, under $100, electrical device that gets inserted in series with the hold-in coil. During a voltage sag, the device maintains a current flow through the coil that is sufficient to hold in the contacts closed. The circuit is designed to provide current to hold in the coil for sags down to 15-25% voltage. It is not designed to hold in the coil for cases where the voltage goes below 15%. This allows "emergency stop" circuits to act correctly and will prevent any problems with out-of-phase conditions following an interruption.

   FACT: if the voltage drops to 60% of nominal, the available torque is about 1/3. If the motor starts to lose synch with the supply power, then you could have a major torque stress problem, which could result in damage to the drive system.

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5. **Off-line UPS, uninterruptible power supply**, on a PC, PLC or controls to switch to battery on a sag below 105 volts or an interruption. The cost is $150 for a 150-voltamp unit. The down side to this approach is the battery. Batteries have the following disadvantages: a) generates hydrogen gas, must be ventilated, b) battery lead is a hazardous waste, and c) battery life is limited and decreases rapidly when cycled often. An advantage is that the UPS will ride through not only sags, but also momentaries and extended interruptions up to the limit of the battery capacity, maybe 5 to 10 minutes. For a full on-line UPS the cost doubles but you add the benefit of filtering out all disturbances.

6. **Ferroresonant (constant voltage) transformer** on PC, PLC or controls to provide sag ridethrough. They also provide filtering of transients. They will not ride through a momentary or sustained interruption. They have no moving parts, no battery and are very reliable. The cost for a 250-voltamp size is $250 and a 500va size is $400. Oversizing will extend ridethrough. This is probably the most common mitigation measure used at present for this problem. Ferroresonant transformers are also commonly installed to protect large loads up to 15 kVA single phase.

   Note: Isolation transformers do not solve sag problems because they have no energy storage and no regulation capability. Liebert Data Wave has a three-phase unit. They make units from 15kVA to 250 kVA and cost between $14,000 and $50,000.

7. **Power electronics to boost/buck voltage under full load.** This electronic device will ride through a sag down to 50% for 2 seconds and momentary power loss of up to 0.2 seconds. Dynamic sag correctors are available in single and three phase configurations from 1.5kVA to 2000kVA.

8. **Thyristor switched-line voltage regulator** on computers and other three phase sensitive equipment, not on motor controls. It utilizes thyristor control of buck and boost transformers in combination with parametric filters to provide regulated sinusoidal output even with nonlinear loads typical of computer systems. The cost for 15kVA to 125kVA ranges between $20k and $50k. These are custom designs for each installation. Typical tap changing voltage regulators do not react fast enough to ride through sags unless they have power electronic switches.

9. **Dip Proofing Inverter** on PC, PLC, controls or motor starter contactors. This is a technology developed in South Africa for the utility industry initially. It is expensive but adjustable and durable. This device is essentially an off-line UPS but replaces the battery with an energy storage capacitor. This device will switch to backup capacitors in 600 microseconds. With this device, the trip magnitude is adjustable between 50 and 80% of nominal. The maximum time duration is 2.56 seconds and is adjustable to shorter durations in increments of 10 milliseconds. Minimum resynchronization time is 65 milliseconds. The cost for a 250 voltamp unit is approximately $1,000, which makes it a very expensive solution. Its advantages are that they are off line, highly efficient and require no maintenance. It is also more durable than a UPS and has better voltage support time duration limit than the ferroresonant transformer.

10. **Precise Power Corporation's written pole Roesel motor generator** technology. This solution will ride through 99% of all sags, surges and momentary interruptions up to 15 seconds. What makes this product different from typical mgs is that they use power electronic switching to change the number of electrical poles to maintain the 60hz frequency and voltage output even as the input voltage degrades. It does not use a flywheel. The mechanical connection between the motor and generator prevent any electrical disturbance to transfer. A single-phase 15kVA unit costs approximately $22,000 and a three-phase 35kVA unit costs approximately $35,000. Typical motor generator sets have no flywheel to provide ridethrough for sags. With optional flywheels, it is possible to get 100 to 400 milliseconds of ridethrough.

11. **Motor generator with a flywheel.** IBM and Amdahl have used mgs with 400Hz output for years for their mainframes. An mg is an excellent power quality filter because no electrical anomaly can get through it and it has some ridethrough because of the energy stored in the rotating mass. The size of the flywheel can be variable. The downsides of mgs are the bearings. They must be serviced and replaced on schedule. The industry has moved away from mgs in the UPS market but they have strong benefits. Mgs can actually have a lower maintenance cost and higher up time than any solid state equivalent. A German UPS manufacturer has recently introduced a flywheel option to their UPS to provide ridethrough due to voltage sags before the UPS must switch to battery. Sags occur maybe 5 to 10 times more often than outages. A typical UPS will switch to battery every time there is a sag below 90% of nominal. Every switch to battery results in degradation of the battery and a shorter battery life. The computer data center industry typically gets 3 to 4 years' battery life on 20-year warranted batteries. The battery manufacturer avoids a warranty charge because it qualifies the warranty with a clause that says one deep discharge per year. Every time there is a voltage sag, the UPS goes to battery for several minutes. This is classified as a deep discharge. One manufacturer has a motor generator, flywheel with a diesel backup instead of batteries. This product is growing in popularity over traditional battery UPS systems due to the space required and the short life of the batteries.

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