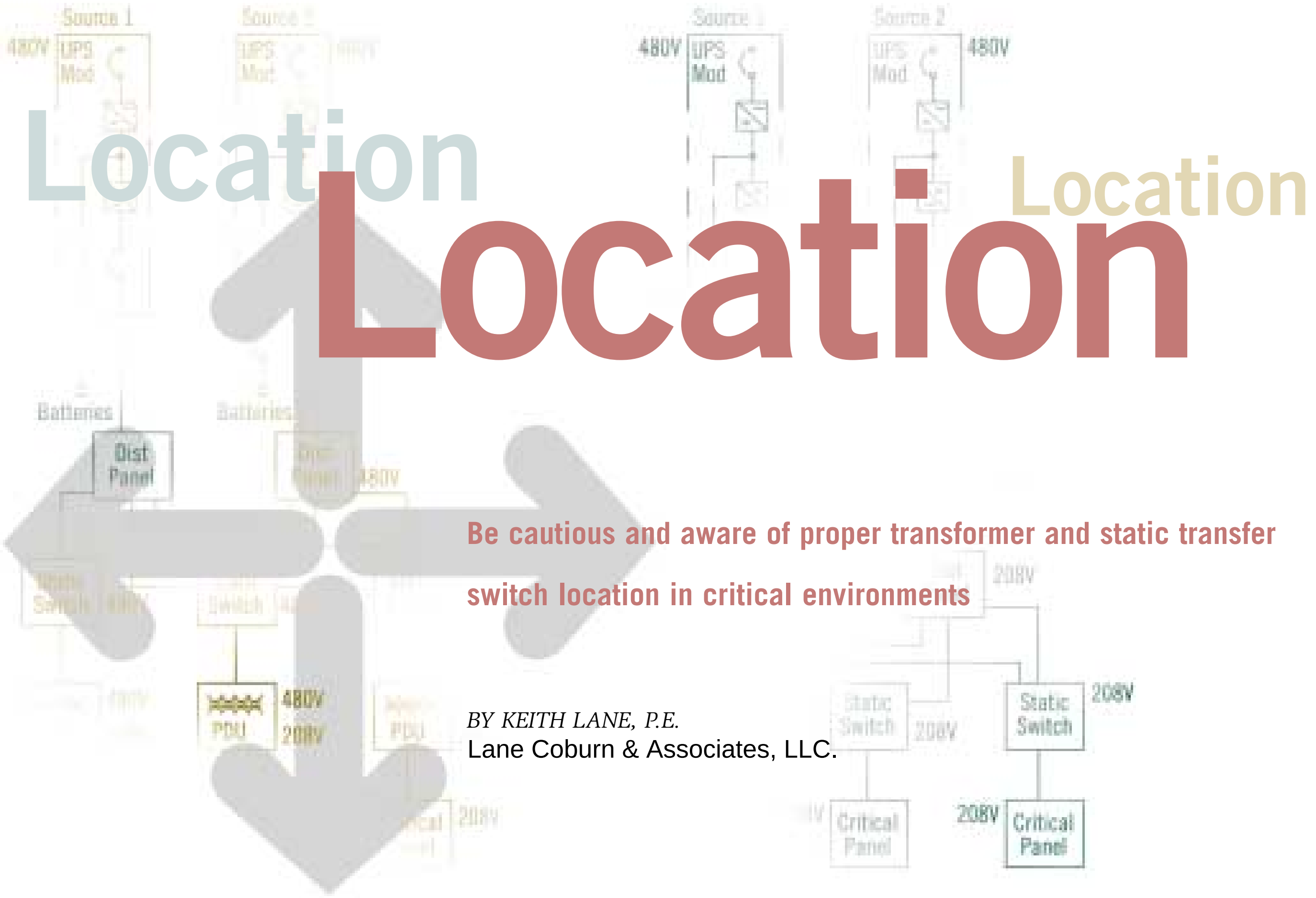

Location Location Location

Be cautious and aware of proper transformer and static transfer switch location in critical environments

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That a majority of outages in critical environments are caused by disruptions between the uninterruptible power supply (UPS) and the critical load has been indicated by a number of studies. Other researchers have noted that 70% to 80% of the outages in critical environments are caused by human error (For more information, visit the Uptime Institute at www.uptimeinstitute.com).

A means of transferring between sources of power within the confines of the Computer Business Manufacturers Assn. (CBEMA) or ITI curve is essential in critical environments that require high levels of site availability.

A static transfer switch (STS) will permit very fast transfer between power sources and can allow the system to survive a single failure or a single human error. The transfer can be achieved with a floor-mounted STS, with dual-cord computer loads or with a rack-mounted STS. Dual sources of power all the way to the computer equipment, provided with dual-cord computer power supplies or with rack-mounted STS, is the preferred method and provides the highest levels of reliability and site availability. STS may have to be utilized when dual-source computer power supplies or rack-mounted STS are not available, or if the electrical distribution system is serving legacy equipment with a single cords. An STS is a break before a three-phase device that can transfer loads between UPS sources, typically within four milliseconds. Here, we want to concentrate on transformer location with floor-mounted STS.

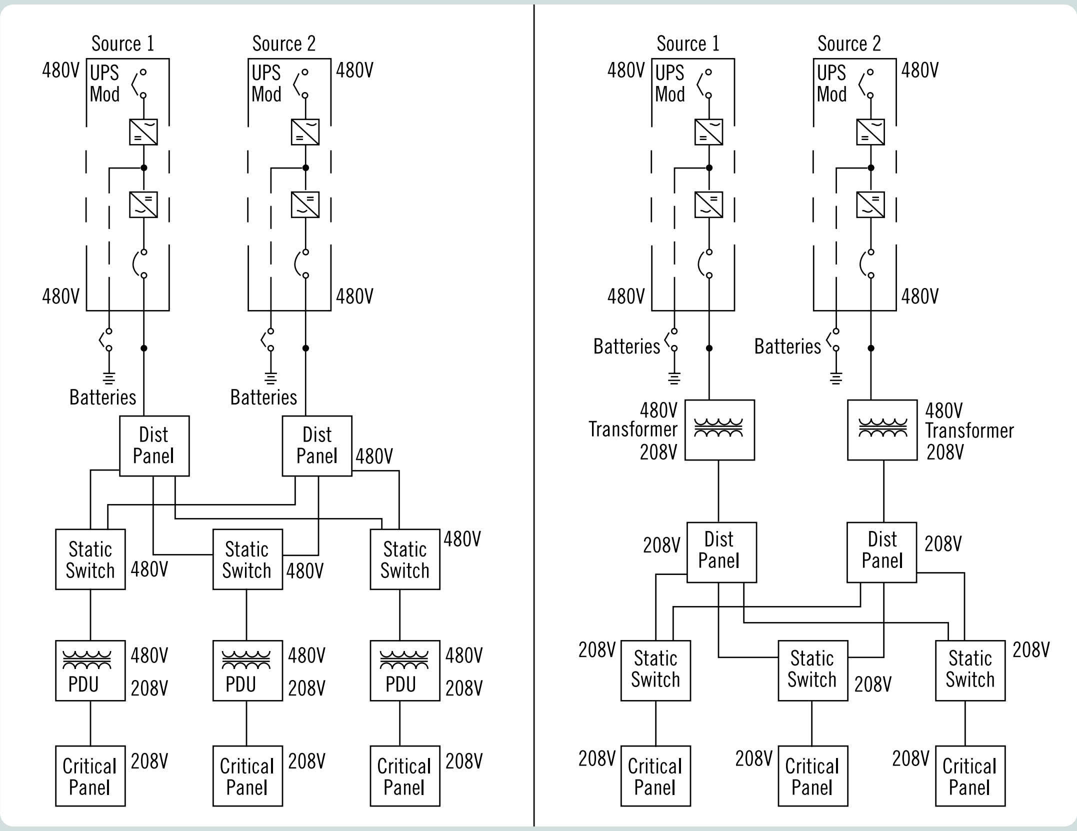
TRANSFORMERS AND STS

Electrical distribution systems that use power distribution unit (PDU) transformers downstream of STS can cause excessive inrush current in the event of a transfer of power sources.

This depends on the transfer time, the phase orientation of the sources and the location of the alternating current waveform at the time when the voltage is reapplied after the original voltage is taken away—zero crossing is the worst case scenario. The transformer can saturate and cause excessive current inrush (as shown in Figure 3 on p. 32). Other factors that determine the total inrush current include the total combined size of transformer core, impedance of the source and the sine and value of the transformer residual flux.

Although many critical environments are designed with the 208/120-volt three-phase transformers on the downstream side of the STS, many designers of these environments are

Figure 1 - Electrical Distribution System



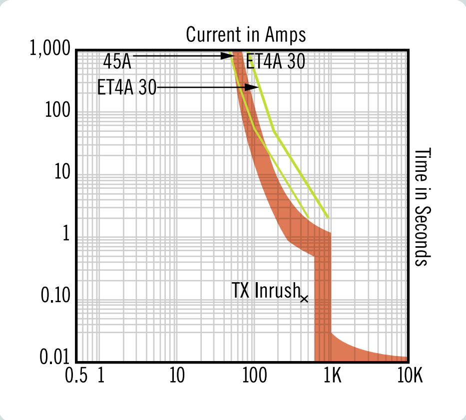
beginning to recognize a problem with this topology and are rethinking this previously accepted design practice.

In situations with multiple 480-volt STS and associated 208/120-volt three-phase transformers downstream of two (N + 1) UPS modules (Figure 1), a large total amount of transformer kVA capacity compared to UPS kVA availability can be achieved. However, a larger transformer kVA capacity compared to UPS kVA availability can exaggerate the inrush current problem. According to transformer manufacturers' data, saturation inrush can be as high as 25 times the full-load current for 0.01 seconds (0.6 cycles) and 12 times the full-load current for 0.1 seconds (six cycles), as illustrated in Figure 2. And saturation current levels can be even higher in a worst case out-of-phase transfer.

The left side of Figure 1 represents the 480-volt STS upstream of the 208/120-volt three-phase transformer PDUs. On the right, the 208/120-volt three-phase transformers on the UPS output are upstream of the 208-volt STS. The system on the right would eliminate the transformer inrush issues associates with a transfer of the STS, but could represent higher construction cost associated with larger ampacity of STS and electrical distribution based on transforming to 208 volt further upstream.

Figure 2 illustrates a 30-kVA transformer protected by a 45-amp circuit breaker. The "Tx Inrush" refers to the transformer inrush at 0.1 seconds (six cycles). The inrush current is based on 12 times the full-load amps (30 kVA divided by 0.831 kV = 36 amps; 36 multiplied by 12 = 433 amps). The 45-amp breaker curve is represented by

Figure 2 - Transformer Inrush



the red hash marks. This instantaneous portion of the breaker curve is to the right of the “Tx” ensuring that the transformer inrush will not trip the breaker during system startup. Keep in mind that an out-of-phase transfer can cause excessive saturation and inrush current that can trip the breaker on the primary side of the transformer.

When a transformer is connected to an alternating-current power source, inrush current can occur. In a steady-state situation, the voltage waveform and the flux waveform are phase-shifted by 90 degrees. The flux is proportional to the winding current. Therefore, the current waveform is also 90 degrees out of phase with the voltage waveform. If a transformer is started at the time the voltage waveform is at its positive peak, there will be no more current than in normal operation.

But on the other hand, if a transformer is turned on at the instant the voltage waveform crosses the zero threshold, the flux will be about twice that of the flux at steady state. In an ideal transformer, the required current to produce this flux would also be twice as much as in a steady-state condition. In a “real” transformer, not designed for this much flux at steady state, the transformer core will saturate and the required inrush current can greatly exceed twice the nominal value, as shown in Figure 3. In certain static transfers and out-of-phase conditions, the transfer can occur that will leave residual flux in the core of the transformer. If this flux is in the same direction as the other applied voltage source, saturation and current inrush can be even greater.

The Figure 3 chart represents the potential for transformer saturation and high inrush current. If the transformer is switched on when the voltage waveform is at the zero crossing, the required flux would be about double the steady-state amount. The winding current required to create this amount of flux in a non-ideal transformer can be significantly higher than twice the steady-state current.

Figure 3 - Flux and Inrush Current at Zero Voltage Crossing

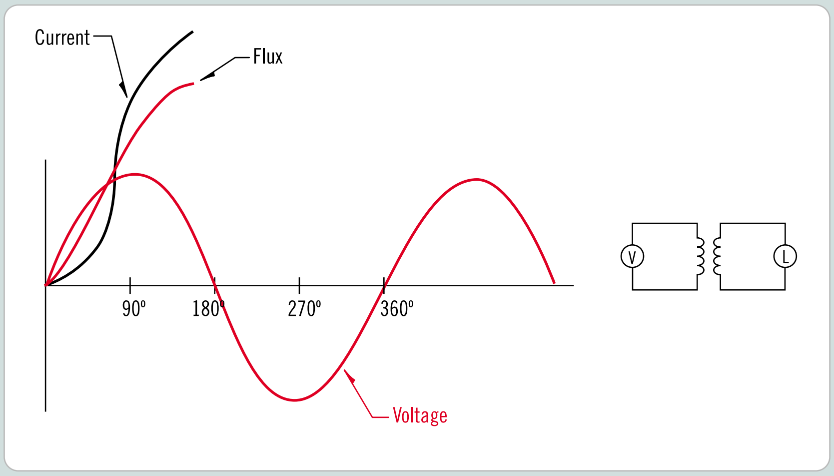
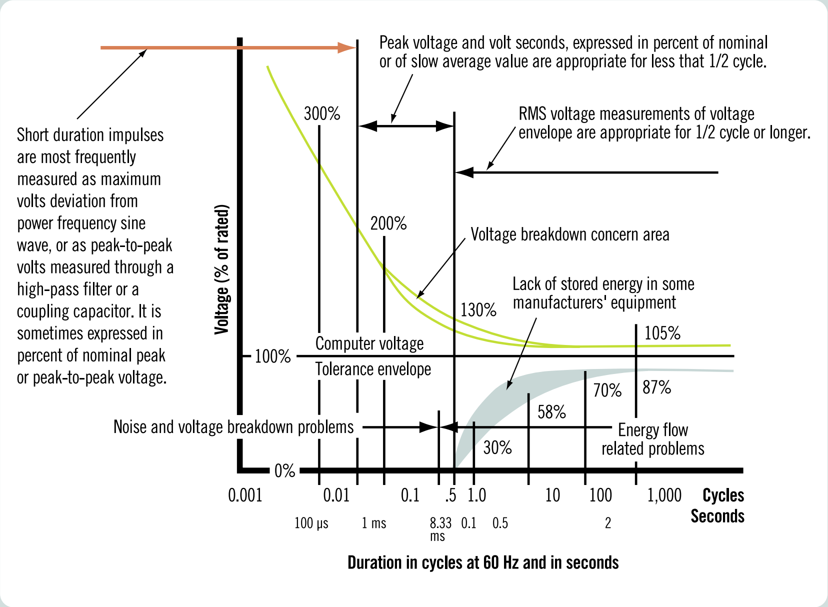


Figure 4 - The CBEMA or ITI Curve



This large current can trip upstream overcurrent protective devices and take a UPS offline. A UPS is more susceptible to overload conditions under battery operation, when a UPS module does not have as much overload capacity as it would under normal utility operation. Therefore, it is critical to maintain load bus synch when the UPS system is operating under battery power.

Load-bus synchronization can be active or passive. A passive synch will operate if the UPS systems lose synch with each other for a predetermined amount of time: The slave UPS will synch with the master. In an active load-bus synch, the slave

UPS module is always synched with the master.

In addition, high inrush currents can occur during a restart of a system after a failure. A shunt trip breaker can be provided on the primary side of the 208/120-volt three-phase transformers (PDUs) to trip them out upon de-energization of the UPS modules. This will allow the transformers to be manually and sequentially turned on upon restart of the UPS. This would reduce inrush current and the potential of re-tripping the system breakers or overload a UPS.

The saturation current can be reduced in a multi-switch scenario by sequentially programming transfer times of the switches upon failure of one of the UPS sources. Transformer saturation levels can take several cycles to dampen out. Based on a research study on the time it takes for transformer saturation levels to be reduced, it can take approximately seven cycles for the transformer saturation current level to return to steady-state levels. The first cycle represents the peak current state; the second cycle has reduced to approximately 60% of the peak condition; and the third, fourth, fifth and sixth cycles reduce to approximately 42%, 30% and 26%, respectively, of the peak inrush condition (This was the finding of researchers Stanley E. Zocholl, Amando Guzman and Daqing Hou with Schweitzer Engineering Laboratories Inc.)

A control sequence that systematically controlled the STS on the primary side of the 208/120-volt three-phase PDU transformers, to switch the loads one by one with enough time between transfers to reduce inrush, could take tens of cycles to transfer multiple loads. The CBEMA (ITI) curve in Figure 4 shows that any transition over 1/2 cycle can cause critical loads to drop out.

In addition, low inrush PDU transformers can be utilized to reduce the inrush current. Transformers that require less current to fulfill the saturation flux requirements of both an in-phase and out-of-phase transfer can reduce the effects of a transfer of power sources. Evaluations of static transfers both in and out of phase would have to be performed to ensure system limits are not exceeded.

Another option is to delay the transfer of all STS from one source to another if the sources are out of synch. The revised (1996) CBEMA (ITI) curve indicates that a voltage dropout or a complete interruption of applied voltage followed by an immediate reapplication of the supply voltage may last for up to 20 milliseconds. This represents over twice the time indicated in the original CBEMA curve developed in 1978. A 20-millisecond timeframe represent about 1-1/4 cycle. When a double-negative or double-positive volt-second is anticipated, based on the phase relationship of the two sources, an intentional time delay can be programmed into the static transfer switch logic.

This program delay can reduce potential out-of-phase saturation inrush current, and if coordinated with the critical-load equipments, zero voltage tolerance can prevent restarting of computer loads. ⒺⓃⒹ

Complex Solutions

These solutions can represent a complicated Band-Aid for a potentially significant problem. The best and most viable solution is not to allow 208/120-volt three-phase step-down transformers on the downstream side of floor-mounted STS for new critical system design projects. There are many solutions that would provide increased reliability for existing facilities that currently have the STS upstream of 208/120-volt three-phase step-down transformers. Some of these solutions have been noted above and include the following:

- **Maintain load bus synchronization during battery operation of the UPS.**
- **Provide a shunt trip breaker on the primary side of the 208/120-volt three-phase transformers to trip them out upon de-energization of the UPS.**
- **Reduce saturation current in a multi-switch scenario by sequentially programming transfer times of the switches upon failure of one of the UPS sources.**
- **Use low-inrush PDU transformers to reduce the inrush current.**
- **Delay the transfer of all STS from one source to another if the sources are out of synch.**

Mechanically, the most ideal solution would include relocating the 208/120-volt three-phase PDU transformers to the upstream side of the STS. This solution can represent voltage drop issues for the system and larger ampacity requirements for the STS based on the transformation from 480/277-volt three-phase to 208/120-volt three-phase upstream of the STS, but would eliminate the transformer saturation and inrush problems. Proper critical facility design and maintenance and operation procedures are of paramount importance to ensure high levels of site availability.