Electrical System Design

Applying transfer equipment in electrical systems affects many design considerations. The basic function of a transfer switch is to enhance availability of power to critical electrical loads, providing a means to switch the load between two or more available sources of power. The switches can be either manually or automatically operated. In either case, the switches should be connected as near the load utilization equipment as practical, preferably downstream of any devices that may operate to disconnect power to the load (disconnects, breakers, fuses,). Many factors will dictate this including costs, circuit arrangements, physical space, load power requirements, load operating requirements, and many other factors.

Power Reliability

Electrical Interconnection Location

Although economic and physical layout considerations impact where transfer equipment is electrically connected in a facility, recommended practice is to install switches as near to the load as possible. The switch is then available to transfer the load to the alternate source for most abnormal conditions including, failure of the normal source, feeder failure, and circuit breaker and fuse operation. In general, more and smaller, dedicated switches, improve reliability of power to critical loads. In some applications (most notably health care), multiple, dedicated switches are required by code to achieve separation of circuits and increase power reliability. Multiple smaller transfer switches also provide a convenient means to step load the alternate source generator set and make it easier to achieve coordination of overcurrent devices, both on the line and load side of the switch.

Installation of transfer equipment nearer the normal utility source service may require several considerations involving:

- Type of applicable transfer equipment
- Service entrance rating
- Voltage
- Downstream overcurrent device coordination

All of these considerations are interrelated and may force the use of power frame low voltage breakers or medium voltage breakers. In larger facilities, the utility power is taken at distribution voltages above 600 VAC. If the switching takes place at these voltages, medium voltage equipment is required. This equipment is designed for high capacity and the continuous ratings may exceed that required by emergency loads because the equipment must be sized to carry full normal service capacity. It may be more economical to use distribution transformers and switch at lower voltage. Of course, if the loads are medium voltage, there is no choice but to switch at the higher voltage.

Electrical Interconnection Location (cont'd)

Higher available fault current is present at locations closer to the normal utility source. These available fault currents also may dictate the use of power frame breakers in order to achieve the necessary short circuit withstand capability. Low voltage transfer switches have short circuit ratings ranging from 10,000 amps to 100,000 amps depending on continuous rating when protected by low voltage breakers equipped with instantaneous trip units. These switches carry up to 200,000 amp ratings when protected by either current limiting fuses or current limiting breakers. Most of these low voltage transfer switches are required to be protected by fast acting overcurrent devices that contain no intentional time delays typically included with larger molded case and power frame breakers. These delays are necessary to achieve coordination with downstream protection, allowing the smaller downstream branch breakers to trip first, limiting the outage to the individual faulted branch.

Several figures below help to illustrate many of these points.

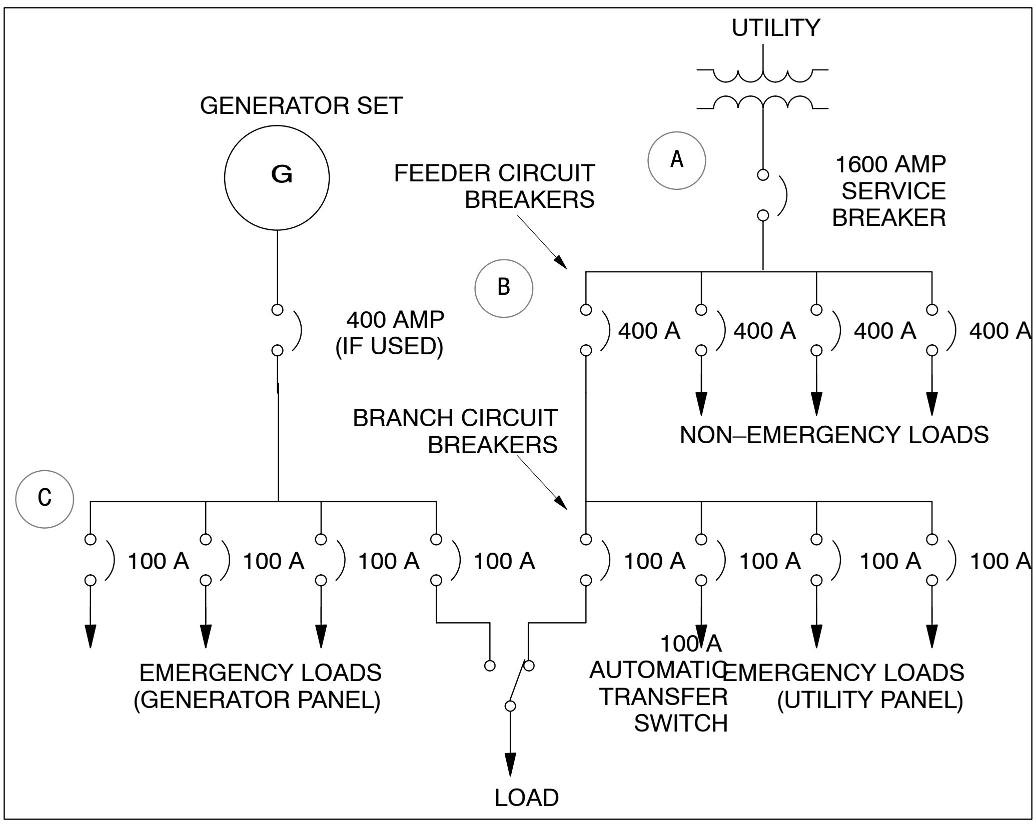


Figure 1. Transfer Switch Connected Near the Load.

Figure 1 illustrates a system where the transfer switch equipment is interconnected nearest the load utilization equipment. The loads can be selected or grouped as required by code or desired for the application. In this case, it is assumed that there are four unique 100 amp loads. These may be individual loads, like a 100 amp lighting panel, or multiple loads which may require additional load side circuit panels and conductor protection. The smallest single load will likely be no smaller than commonly available sized transfer switches, as small as 30 amps from Cummins. All of the emergency loads are served from either a utility

Electrical Interconnection Location (cont'd)

or generator panel through a transfer switch. The incoming utility connects to the utility emergency panel and other facility loads (not required to be served by the generator). The generator connects to the generator emergency panel.

There are three levels of distribution between the utility service entrance and the load (A, B and C), involving application of three levels of circuit protection. The entire facility is served by 1600 amp service equipment using a 1600 amp power frame breaker. Four 400 amp circuits are fed from the utility service, one 400 amp emergency circuit and three 400 amp non–emergency circuits, each of which is protected by 400 amp power frame or molded case breakers. The 400 amp emergency circuit feeds a utility emergency panel containing four 100 amp emergency load molded case breakers that connect to the utility side of four 100 amp transfer switches. The generator is connected to a generator emergency panel at the third level of distribution ©, the panel containing four 100 amp molded case breakers feeding the emergency side of the four 100 amp transfer switches.

The transfer switch must be selected to supply the required load current at the desired load voltage. In addition, the transfer switch must be capable of withstanding the available fault current at the point of interconnection. In this example, the transfer switch shown is a type that does not include integral overcurrent protection. Available fault currents at the different levels range from 65,000 RMS symmetrical amps at the utility service entrance to 25,000 at level B and 10,000 at level C. The transfer switches are required to have line side external overcurrent protection which is provided by the 100 amp molded case breakers. These breakers are required to have instantaneous trips for short circuits in order to provide proper protection for this type of listed transfer switch.

Optimally, in a coordinated system, the system should be designed in such a way that when a fault occurs on the load side of a transfer switch, the fault is cleared by the first upstream breaker, C, and breakers at levels B and A remain closed. For this example, the breakers have trip characteristics shown in **Figure 2**.

Electrical Interconnection Location (cont'd)

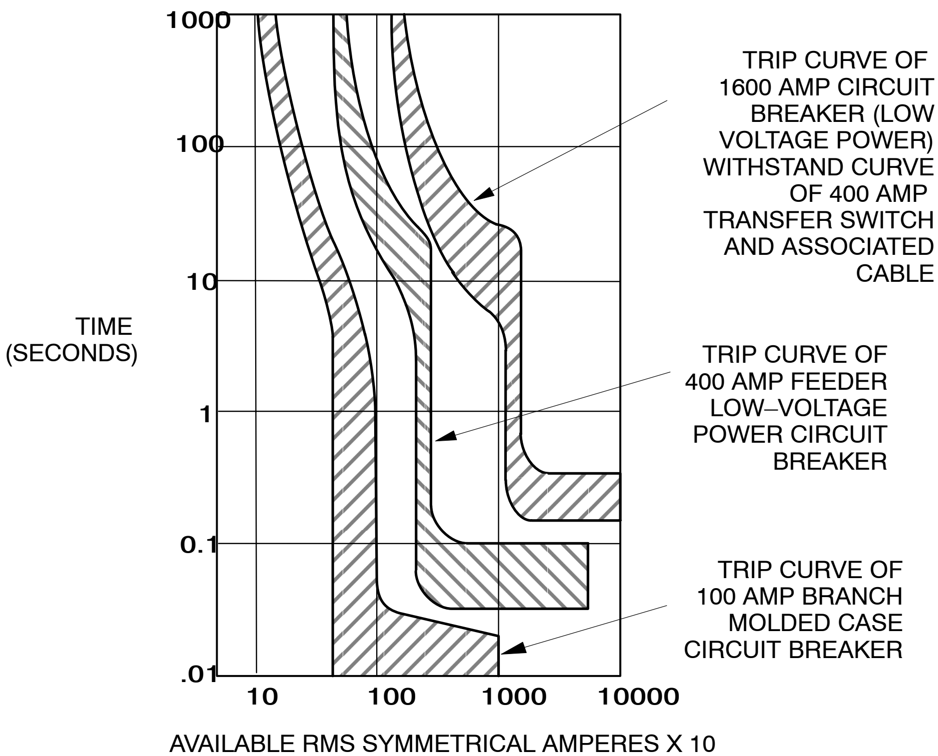


Figure 2. Selectively Coordinated Breakers.

The breakers at level C are molded case with instantaneous trips and have interrupting ratings suitable for the available fault current at that level (10,000 amps or greater). The breakers at levels A and B have no instantaneous trips. Rather, they include intentional time delays (short and long time) to prevent cascade tripping of the breakers at all levels. For any overcurrent condition up the the maximum available short circuit, only the breaker at level C of the faulted branch would trip, leaving all other circuits energized. If one of the emergency breakers is tripped (or, for that matter, merely opened by someone), an automatic transfer switch will detect power loss, signal the generator to start, and transfer the load when proper generator output power is detected. If the fault was temporary or the fault condition was cleared, power to the load will be restored. If the fault is still present (permanent), the generator side breaker will clear it, provided the generator supplies sufficient fault current. This is generally accomplished when the generator has sustained short circuit capability (separately excited PMG, for instance). Note that the generator may be equipped with a main output breaker. Care should be taken to be sure this breaker is coordinated with the branch breakers to avoid loss of power when all emergency loads are on generator and a fault occurs on one of the emergency load circuits. Optionally, generator controls are available that provide overcurrent protection for the generator that include intentional time delays to allow downstream breakers to trip. With these generators, the main output breaker is not required or recommended.

More often than not, the breakers at level B are also molded case with instantaneous trips, sacrificing some degree of coordination. This is shown in **Figure 3.** The degree of coordination achieved in this case is a function of the relative size

Electrical Interconnection Location (cont'd)

of the breakers at levels B and C, the breaker instantaneous trip settings and the fault current that can flow at each location. If the breakers sizes and settings are far enough apart, some degree of discrimination is achieved.

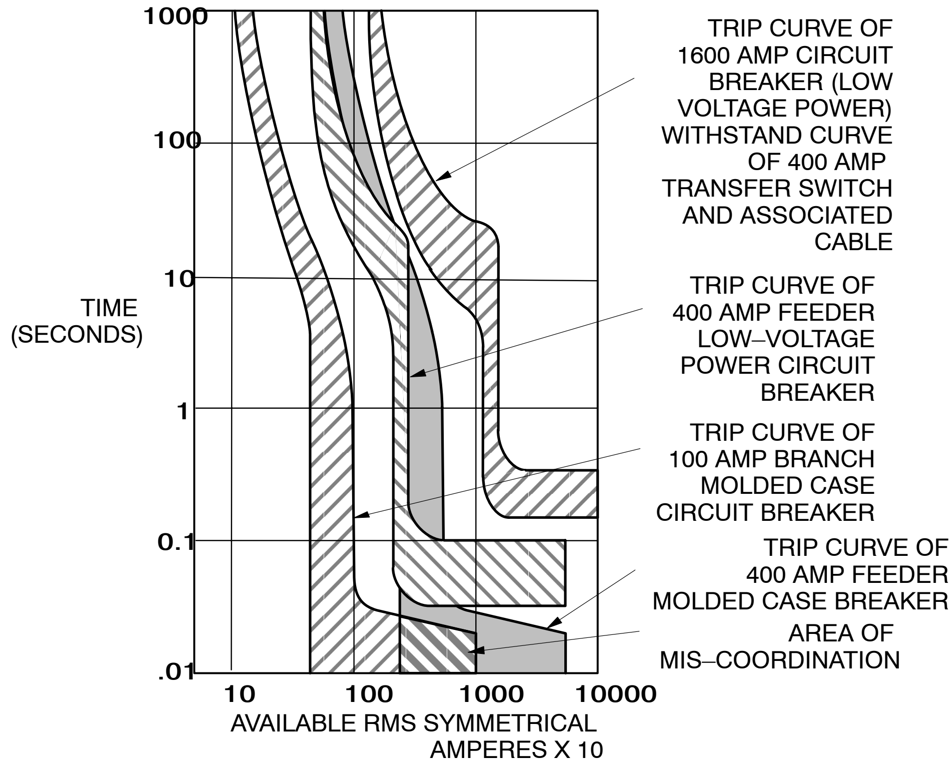


Figure 3. Mis–Coordinated Breakers.

In this example system, the next optional point of interconnection for the transfer switch is between level B and C as shown in **Figure 4**.

Electrical Interconnection Location (cont'd)

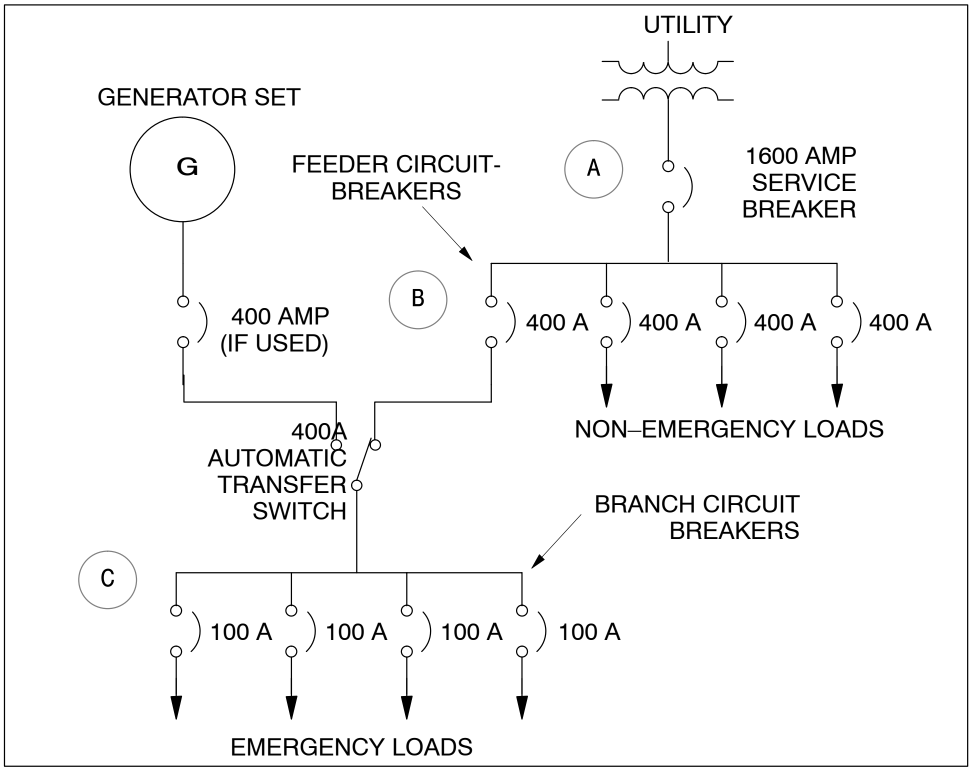


Figure 4. Transfer Switch Connected Ahead of Load Branch Breakers.

In this arrangement, a single larger 400 amp transfer switch is used to provide source sensing and load switching for all four 100 amp emergency load circuits. The transfer switch continuous current rating must be selected to satisfy the total connected load. This sacrifices some degree of power reliability to the emergency loads. For instance, if any one or more of the 100 amp branch breakers is turned off or trips due to overload, power is lost to those circuits, whether or not the disconnect is inadvertent. Another concern may be with lack of selective coordination between the circuit breakers at B and C. If faults on the load side of breakers at C cause a cascade operation of the breaker at B, and B breaker trips, there will be at least a momentary outage to all emergency circuits. Power will be lost until the power loss is detected, the generator is started and the switch transfers the remaining loads to the generator. It also goes without saying that if the switch malfunctions, power may be lost to all emergency load circuits.

The transfer switch must also have a fault withstand and closing rating suitable for use with the upstream overcurrent protection characteristics of devices at locations A and B especially when intentional delays are introduced to achieve coordination.

Finally, consider the arrangement shown in **Figure 5** where a single large transfer switch is installed at the service entrance level between A and B.

Electrical Interconnection Location (cont'd)

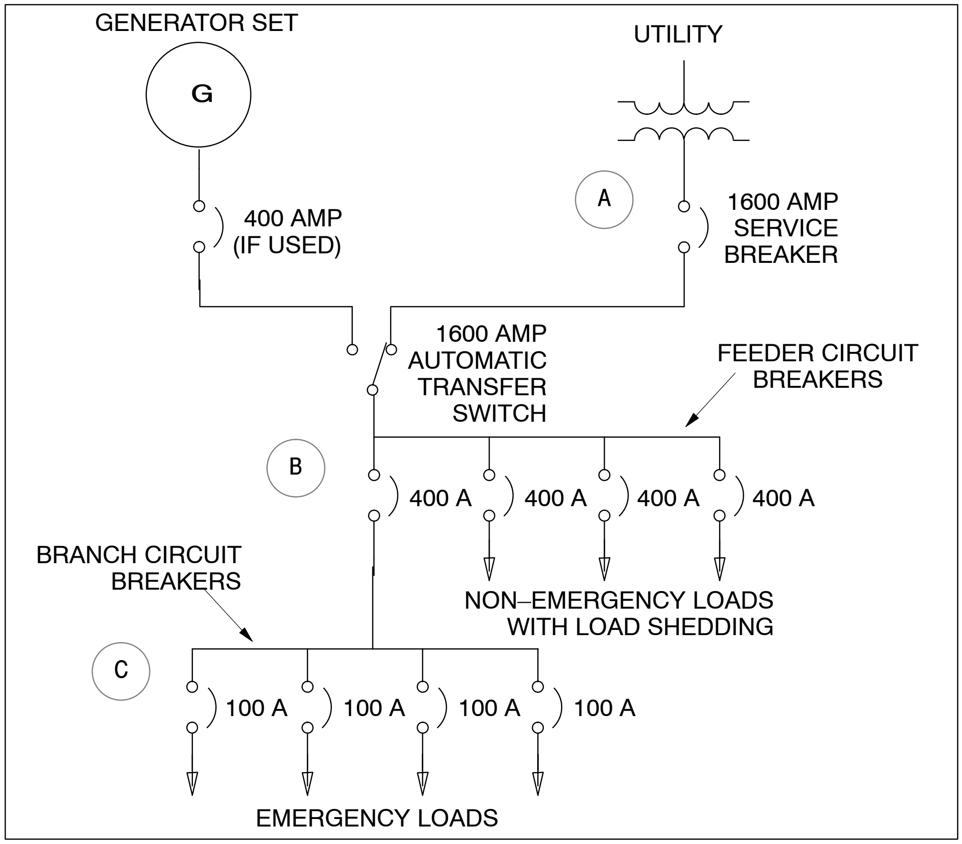


Figure 5. Transfer Switch Connected at Service Entrance.

In this arrangement, a single larger 1600 amp transfer switch is required. The switch must be sized not only for the connected emergency load of 400 amps, but for the normal utility load. Power reliability to the emergency loads suffers even more when the switch is located here. Operation of any of the transfer switch load side breakers results in loss of power to the connected loads and selective coordination becomes an even bigger concern. Unless the generator is also sized to handle all of the facility load, the non–emergency load circuits will need to include provisions for automatic load shedding if the operating load exceeds generator capacity. Some inspection authorities will not even allow this arrangement for some critical applications where life safety is paramount. If the generator is sized to handle all facility loads and only isolated loads remain in use following a utility outage, the generator may be left running too lightly loaded, damaging the engine.

In many applications, where the transfer switch is applied at the service entrance, service entrance rated switches are applied, commonly consisting of interlocked circuit breakers containing integral phase and ground fault overcurrent protection. Depending on the configuration of this type of equipment and the controls, it is possible that power is not restored to unfaulted circuits following a fault in only one.

Separation of Circuits – Certain critical applications, such as health care facilities or where electrically driven fire pumps serve the premises, require the emer-

Electrical Interconnection Location (cont'd)

gency loads to be separated from the non–emergency (non–essential) loads and served by dedicated transfer switches. In these applications, if the generator is going to be used to supply a mix of emergency and non–emergency loads, multiple switches will be required. Step loading is recommended for these applications, connecting the emergency loads first within any code mandated time limitations, typically within 10 seconds. Subsequent load steps should be limited to a capacity allowed by the generator capability to not disturb the connected emergency loads.

Step Loading – Generator sets are limited power sources, generally much lower capacity than the normal utility source serving critical loads. Abrupt transient load changes on the generator will likely result in larger voltage and frequency disturbances on the generator than on the utility source. When transferring load to the generator, either after a normal source failure or during system testing, the load steps must be controlled to limit the disturbance to levels that connected loads can tolerate. Although other building system controls may be used, this is easily accomplished by using multiple transfer switches using sequenced transfer time delays. A few seconds should be allowed between load steps to allow the generator voltage and frequency to stabilize. Some transfer switch controls have optional load sequencing provisions, typically a timed relay output module that can be used to connect designated loads to the load side of the transfer switch in an adjustable timed sequence following a transfer to either or both power sources.

Service Entrance – In some applications, such as a small pumping station, it is desirable or necessary to provide standby power to the entire facility. Although it is advisable to apply individual smaller transfer switches for multiple loads, particularly motor loads with high starting power requirements, it may be desirable to start all of the loads simultaneously. This requires careful consideration for both generator and switch sizing. If a single switch is available suitably sized for the entire connected load, it may be advisable to connect the switch at the service entrance, using a service entrance rated switch. This is particularly true for facilities that do not have an on–site, permanently installed generator which rely on a portable generator delivered to the facility during an outage.

Overcurrent Device Coordination –Connecting the transfer switch near the load equipment minimizes the number of overcurrent devices between the transfer switch and the load, perhaps even between the generator and the load. All transfer switch equipment that does not include integral overcurrent protection requires external upstream overcurrent protection of the switch. Most transfer switches are designed to be protected from short circuit by either molded case circuit breakers or current limiting fuses. They are not designed to withstand the high level, long duration short circuit currents allowed by circuit breakers incorporating intentional time delays that allow them to be coordinated with other downstream breakers. To some degree, this forces the transfer switch point of interconnection closer to the load in more complex installations.

Care should be taken to provide individual feeder branch circuit protection on the load side of transfer equipment feeding multiple loads. This is necessary to achieve coordination between the source and load breakers for load side faults. The system should be designed so that a fault in one load circuit will not cause interruption of the transfer switch line side breaker, removing power to all con-

Electrical Interconnection Location (cont'd)

nected load. Even if this should occur, the transfer switch design should allow the switch to detect loss of power and transfer the remaining unfaulted load circuits to the generator. This may be difficult to achieve with transfer switches that incorporate integral overcurrent protection.

Load Power Interruption

There are several possibilities for load power interruption. The interruption can be complete power loss or simply disturbances causing the power quality to be disruptive to the load. Most of the discussion will be around complete power loss or forced interruptions resulting from the operation of transfer equipment when transferring the load between power sources.

Utility Normal Source Power Disruptions – Utility power disruptions occur for a variety of reasons and last for varying durations. The usual concern is for complete interruptions of power but many different types of disturbances can be as disruptive or even damaging to load equipment. Transfer equipment is available to respond to many different power quality concerns including undervoltage, overvoltage, underfrequency, overfrequency, phase sequence, even overcurrent. Controls are even available to just disconnect certain loads from either power source until a suitable source is available. The transfer equipment can be very fast acting, particularly solid state devices, and may have practical application in utility to utility transfer schemes. However, note that transfers to a standby generator will require several seconds and may not be suitable for protecting the loads against some power quality conditions without the presence of some type of power conditioning device, even for very short duration disturbances.

Interruption of power to the load is always a concern, more so in critical life safety and many other applications where even short interruptions can be very costly. Even the short power interruption that can occur during the actual load transfer switching time (forced interruptions while switching between available power sources such as retransfer from generator to utility after an outage) can be disruptive and must be considered in power system design. For computer and other life safety and life support systems where it is impractical for load equipment manufacturers to incorporate ride through capability for short power interruptions, some type of power conditioning equipment may be required. This equipment is used to bridge the gap between load equipment susceptibilities and power–line disturbances. For overvoltages or electrical noise problems, isolation transformers or transient suppressors may be an effective deterrent when installed in the building power source. Required stored energy to ride–through low voltage and momentary interruptions may be obtained from a power buffering motor–generator set or, when the need for power continuity warrants, a UPS (battery system).

Transfer equipment is not designed to protect the load during these short disturbances of the normal supply. In fact, transfer switch equipment includes intentional delays to avoid starting the generator unless the disturbance exceeds several seconds, the kind of time interval required to start a generator and have it ready to load.

Forced Interruptions – All open transition type transfer equipment causes a forced interruption of power to the load when transferring the load between two available power sources. This condition would occur when transferring the loads on retransfer to the utility after a power failure or when transferring the load from utility to generator while testing the system. This interruption is typically 3 to 10

Load Power Interruption (cont'd)

cycles for mechanical switches (varies depending on size) and less than ¼ cycle for solid state switches. This can be disruptive to some loads, particularly on mechanical switches, where, the lights will certainly blink, if not extinguish and motor contactors can drop out in 10 cycles. This is an even greater issue when the transfer switch is equipped with controls that incorporate an intentional delay (from fractions of a second to several seconds) in the center off position to protect the load from damage or misoperation. This type of control is used to prevent large motors from being closed out of phase to the oncoming source or computer loads from losing data when not allowing an ordinary shut down. To minimize problems, these types of loads should be placed on separate transfer switches to allow fast transfer of other loads or place on an UPS if the load cannot tolerate the interruption.

A word of caution regarding the application of solid state switches. Although most loads will tolerate the short interruption, the load transfer may not be transparent. In fact, when transferring from a utility to a generator source, as the load being transferred approaches the capacity of the generator, significant voltage and frequency disturbances can result causing secondary load misoperation.

Some applications will require closed transition switching to minimize problems with forced interruption. However, these switches should be equipped with load ramping controls that limit the rate of load change when transferring from the utility to the generator to limit voltage and frequency disturbance. This requires longer duration utility parallel operation and all of the required protection.

Loss of Back–up Power Source – Whether the back–up power source is a utility or generator, loss of the back–up source will cause a power interruption if the load is not being supplied by a UPS or some other form of alternate power. Automatic transfer switch controls should detect this condition and transfer the load to the primary source as soon as it is available.

Load Sensitivity

Different loads have varying degrees of sensitivity to power source voltage and frequency disturbances, too numerous to cover in detail here. Although the utility is certainly prone to both voltage and frequency disturbances of the utility system, transferring load from a generator to the utility is not normally a major concern except in larger generator paralleling systems where installed capacity approaches rated utility capacity at the point of interconnection. These systems generally have complex load controls to limit these issues. The more common problems occur when transferring load to a generator. A generator will always produce a voltage and frequency disturbance on sudden application of load. These disturbances must be controlled by limiting the rate of load application on the generator to limit the disturbance to levels that don't impact the loads. Load equipment manufacturers specifications should be consulted to determine what the load can tolerate. Some typical considerations follow:

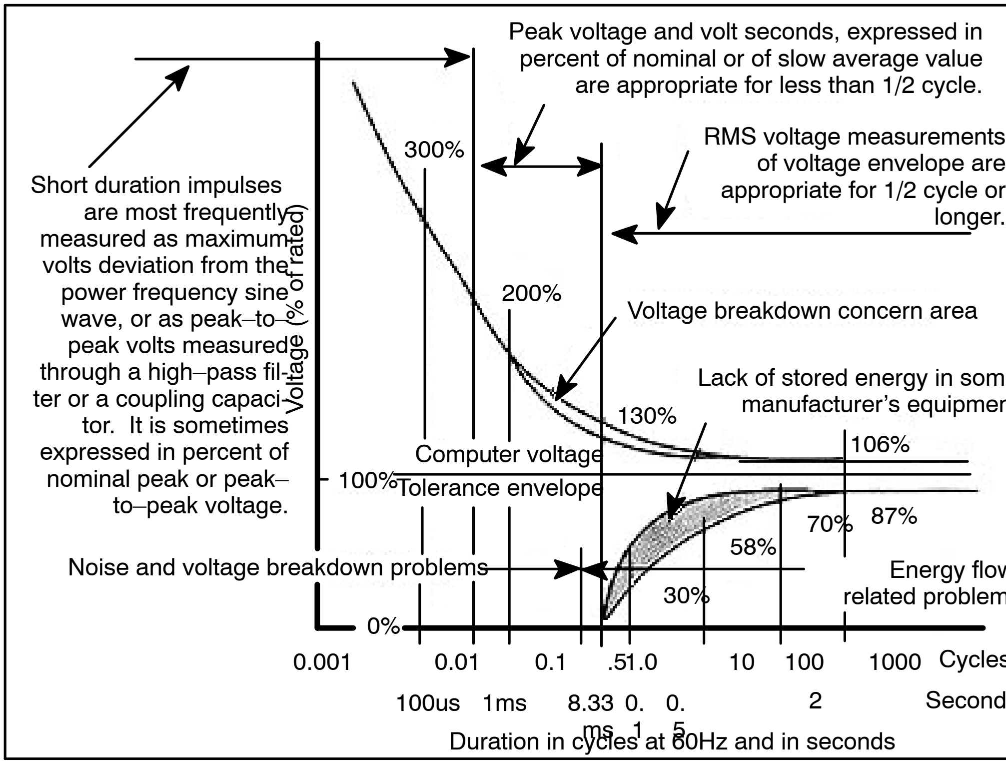
- Lighting: All types of lighting will dim and/or flicker with power below rated voltage and frequency. Of particular concern are the various forms of discharge lighting including florescent and HID. These lights will extinguish completely if the voltage falls below about 80% of rated for even a few cycles. HID lighting will require several seconds to restart after voltage returns to normal.
- Motors: Induction motors will run with voltage and frequency below rated provided adequate torque is available for the load. Speed may be reduced

Load Sensitivity (cont'd)

which could affect the load performance. Running at lower voltage will result in higher current which may cause overheating or overload shutdown. Transient voltage dips below about 65% of rated voltage may cause motor starting contactors to drop out, particularly if the voltage recovery time exceeds more than about 100 msec. Motor controls may also include protection against sustained over/under voltage and over/under frequency.

- UPS: UPS equipment can be susceptible to misoperation if power supply frequency changes at a rate greater than 1–2 Hz/sec. This rate of frequency change is referred to as slew rate. A static UPS typically is equipped with a solid state bypass switch to allow direct connection of the load to the source in the event of severe UPS overload or in internal failure. To accomplish this function, the UPS inverter output must remain synchronized with the UPS input power to allow the instantaneous switch to operate. Typically the UPS load cannot tolerate rapidly changing frequency so, if the source frequency is moving too fast, bypass must be disabled and alarmed until the frequency stabilizes. UPS equipment can also misoperate if the voltage distortion on the input becomes too high. This can occur if the UPS is inducing high levels of harmonic current on a generator source. One of the problems can be the presence of extra zero crossings in the input voltage waveform, zero crossings the UPS is monitoring to determine frequency and slew rate. Most UPS equipment is susceptible to damage if the input power is switched rapidly between unsynchronized sources.
- VFD: VFD equipment is subject to many of the same problems as motor and UPS loads during sustained operation off rated voltage and frequency and is equipped with automatic controls to protect the drive and the drive load. Most VFD equipment is susceptible to damage if the input power is switched rapidly between unsynchronized sources.
- Computers: Computer tolerance to off rated voltage conditions is shown in **Figure 6** (CBEMA Curve). Most computer disc drives are susceptible to damage if the frequency is out of specifications or changing rapidly. This is why most computers are placed on a UPS or have some other form of power conditioning. Most computers not protected by a UPS should not be switched rapidly between power sources. A computers require a definite off time to reset memory and preserve data. Data may be corrupted if a computer is switched open transition with no intentional off delay (such as programmed transition).

Load Sensitivity (cont'd)



The CBEMA Curve from FIPS No.94.

Figure 6. CBEMA Curve.

Electrical Code Requirements

Following is a discussion of many of the known electrical code requirements affecting product design, application of these switches and facility design and installation. Many of these code requirements are specific to North America where they are more prevalent and heavily enforced than in other parts of the world. Although many of these requirements are adopted uniformly by various inspection authorities, the local inspection authority (facility installation jurisdiction) must be satisfied and should be consulted if there are any questions or concerns.

Where Required – Transfer switch equipment is needed wherever loads are required to be switched between one or more available power sources. Where they are required and what sort of equipment meets the intent of the required equipment is usually defined by applicable local building codes or other ordinances. In North America, the NEC is the predominant reference for establishing what types of transfer switch are required or allowed in "Emergency" and "Legally Required Standby Systems".

"Emergency" systems are those legally required and classed as emergency systems by municipal, state, federal or other codes, or by any governmental agency having jurisdiction. Emergency systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply intended to support, distribute, and control power and illumination essential for safety to human life.

Electrical Code Requirements (cont'd)

"Emergency" systems are generally installed in buildings likely to be occupied by large numbers of people where artificial illumination is required for safe exit and for panic control. These are generally buildings like hotels, sports complexes, health care facilities, and similar institutions. These systems commonly also supply ventilation, fire detection and alarm systems, elevators, fire pumps, public safety communication systems, industrial processes where interruption could cause life safety or health hazards.

All equipment in these Emergency systems must be approved for use in Emergency systems in the US. This typically means that transfer switches are listed and certified for use by some independent third party such as Underwriters Laboratories. The switches must be automatic, identified for emergency use and approved by the authority having jurisdiction. They must be electrically operated and mechanically held. The switches must also be dedicated to emergency loads (cannot simultaneously serve emergency and non–emergency loads). Fire pumps must also be served by dedicated transfer switches and approved for fire pump service. Typically, health care facilities are required to have separate switches serving emergency systems (critical and life safety branches) and equipment systems.

"Legally Required Standby Systems" are those legally required and classed as legally required standby systems by municipal, state, federal or other codes, or by any governmental agency having jurisdiction. These systems are intended to supply power to selected loads in the event of failure of the normal supply. The loads are typically heating and refrigeration systems, communications systems, ventilation and smoke removal systems, sewage disposal, lighting systems, and industrial processes that, when stopped, could create hazards or hamper rescue or fire fighting operations.

Transfer switch equipment may also be used for optional loads, those not specifically mandated by code to be on the emergency/standby system. Typically, optional loads must be served by their own transfer switch and are not allowed to be transferred to the generator if an overload would result.

Location – Typically transfer switch equipment can be located most anywhere in a facility, even outside the facility. However, the location should be chosen to minimize potential damage due to acts of nature (lightning, flooding, etc.), vandalism or fire. The normal and emergency electrical circuits should be kept separated to prevent damage in one circuit from damaging the other circuit conductors, with these circuits only coming into close proximity in the switch enclosure. Fire pump transfer switches are required to be located in the same room as the fire pump and must be enclosed in a water resistant enclosure.

