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Considerations for reliable closed transition transfer switches

■ White Paper

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Closed transition transfer switches are becoming more popular for transferring power for life safety and critical processing loads. The benefits are that the emergency power system can be tested without interrupting power to loads and power can be re-transferred to the utility after a failure without interrupting power to loads. There are risks associated with closed transition transfer as two live sources are connected together. This paper reviews best practices for minimizing these risks.

Problems with closed transition transfer originate from a difference in voltage between the two sources at the instant when the two sources are connected. The difference in voltage can be caused by several factors:

- A difference in root mean square (RMS) voltage between the sources.
- A phase angle difference between the two sources
- A transient condition on one of the sources caused by a load switching on or off or instability of one of the sources.

The instantaneous voltage difference between the sources results in a current surge from the source with the higher voltage to the source with the lower voltage at the instant of interconnection of the sources. This current is limited only by the impedance of the sources and the cable or bus connecting the sources. It is this current surge that can result in tripping breakers or, in more extreme cases, damaging equipment.

Our recommendations for minimizing risks of out-of-phase closure include:

- Recognize that all sync check systems allow for sources to be a few degrees out-of-phase at closure resulting in some level of surge current between the sources. Breakers, transfer switches and cable must be sized accordingly.
- Consider active synchronizing with voltage matching to minimize the phase and voltage differences between sources
- Minimize the possibility of transient conditions at the moment of transfer by inhibiting multiple transfer switches from transferring at the same time and preventing other loads from cycling during the transition
- Use a transfer switch “fail to disconnect” or maximum parallel timer relay to shunt-trip an upstream breaker to prevent extended paralleling in the event that a transfer switch fails

Phase Difference at Closure – How Much is Too Much?

Very rarely will two sources be exactly in sync at the instant that a switch or breaker closes the two sources together so it is reasonable to ask how far out-of-phase two sources can be and still have a reliable closed transition. IEEE 1547[1] allows generator sets or systems of paralleled generator sets between 1.5 and 10 MVA to be up to 10 degrees out of phase with the utility when closing to the grid, with higher phase difference limits for smaller systems.

Alternators typically can handle connecting to a source that is 10 degrees out-of-phase with it. For other equipment the answer depends on how much surge current the system can handle without tripping breakers or damaging equipment. To design a reliable system it is necessary to consider the magnitude of current that can flow between the sources at the instant of transfer.

The surge current will be proportional to the voltage difference between the phases divided by the total impedance in the system. Surge current can be modeled as:

Isurge = V diff / Zsystem

where

V diff = the instantaneous voltage difference between the sources; and

Zsystem = the total impedance of the system

Total system impedance is the sum of the subtransient reactance of the alternator, the impedance of the utility transformer and the impedance of the cable or bus connecting the sources. In many applications where a single standby generator set is backing up the utility the impedance at the instant of closure will be dominated by the subtransient reactance of the alternator, however a thorough analysis will include all of the sources of impedance in the calculation.

In our example we will use only the subtransient reactance of a single alternator. Note that in applications with paralleled generators the contribution to the current from all of the generator sets will need to be accounted for. This can be done by calculating an equivalent subtransient reactance for the paralleled generators according to the following equation:

Xd"equivalent = 1/(1/ Xd"gen1 + 1/ Xd"gen2 + ...)

Neglecting the reactance of the utility transformer results in a worst case scenario in terms of calculated surge current. With this assumption, surge current can be modeled as:

Isurge = V diff /Xd"

where

Xd" = the subtransient reactance of the alternator, or the equivalent subtransient reactance of paralleled alternators

TWO SOURCES — 10 DEGREES OUT-OF-PHASE

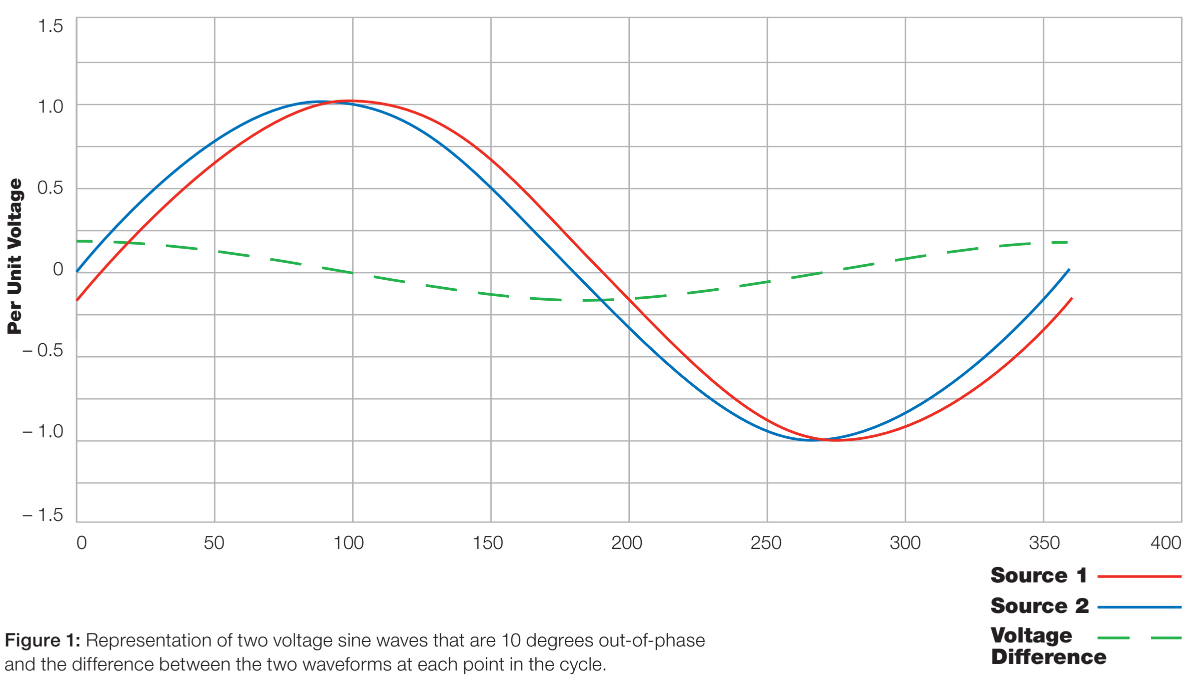

Figure 1: Representation of two voltage sine waves that are 10 degrees out-of-phase and the difference between the two waveforms at each point in the cycle.

[1] IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems 2003, Table 5.

If we assume that the RMS voltages of the two sources are identical and there are no other loads being switched at that moment then the instantaneous voltage difference between the sources will be a function of the phase difference between the sources at the moment in the cycle at which closure occurs. Figure 1 is a representation of two voltage sine waves that are 10 degrees out-of-phase and the difference between the two waveforms at each point in the cycle.

The dashed line represents the instantaneous voltage difference between the two sources. This line is also a sine wave at the same frequency as the two sources. The maximum voltage on this line is the worst case of what the differential voltage could be at the instant the two sources are paralleled. The equation for the worst case differential voltage is:

V diff (per unit) = 2* sin(delta/2)

where

delta = the phase angle difference between the sources in degrees (10 degrees in this case)

The worst case voltage in this case is 0.17 pu.

For example, if this is a 480V system and the two sources are 10 degrees out-of-phase we would have a worst case instantaneous voltage between the sources of 82 V (480*.17 = 82 V). If these two sources were paralleled the voltage difference between them at the instant of closing could be as high as 82 V.

Is that voltage too high? That depends on how much current that causes to flow and whether the equipment in the circuit can handle it.

Consider a 2.5 MW generator set. To calculate how much current would flow we need to know the kVA rating and subtransient reactance of the alternator. This information is available on the alternator data sheet.

In the data sheet shown below (Figure 2) we see that the alternator has a subtransient reactance of 0.144 pu based on an alternator kVA rating of 3660 kVA.

Current resulting from the .17 per unit difference in voltage is given by:

Isurge = V diff /Xd"

With **V diff** = .17 and **Xd"** = .144 the surge current Isurge = 1.2 pu.

ALTERNATOR DATA SHEET — **FRAME SIZE LVSI804T**

CHARACTERISTICS

WEIGHTS:				2-bearing weight	
	Stator Assembly:	8521 lb	3865 kg	8521 lb	3865 kg
	Rotor Assembly:	4392 lb	1992 kg	4546 lb	1926 kg
	Complete Assembly:	12912 lb	5857 kg	12766 lb	5791 kg
MAXIMUM SPEED:		2250	RPM		
EXCITATION CURRENT:	Full Load	3.6	Amps		
	No Load	0.86	Amps		
INSULATION SYSTEM:	Class H Throughout				

3 RATINGS (0.8 power factor) (Based on specific temperature rise at 40°C ambient temperature)		60 Hz (winding no)			
		416 (12)	440 (12)	480 (12)	380 (13)
163°C Rise Ratings	kW	2792	2952	3220	2992
	kVA	3490	3690	4025	3740
150°C Rise Ratings	kW	2712	2872	3132	2904
	kVA	3390	3590	3915	3630
125°C Rise Ratings	kW	2536	2684	2928	2720
	kVA	3170	3355	3660	3400
105°C Rise Ratings	kW	2328	2464	2688	2504
	kVA	2910	3080	3360	3130
80°C Rise Ratings	kW	2080	2200	2400	2200
	kVA	2600	2750	3000	2750

REACTANCES (per unit ± 10%) (Based on full load at 125C Rise Rating)	416 (12)	440 (12)	480 (12)	380 (13)
Synchronous	3.113	2.945	2.700	2.900
Transient	0.227	0.215	0.197	0.214
Subtransient	0.166	0.157	0.144	0.158
Negative Sequence	0.240	0.227	0.208	0.226
Zero Sequence	0.031	0.029	0.027	0.029

Figure 2: Alternator Data Sheet

To convert the per unit current to amps we use the following:

Iamps = Ipu * alternator kVA rating/ (√(3) * 480) = 5329 amps (RMS)

(Note that in a thorough analysis the reactance of the transformer would be added to the subtransient reactance of the generator or the equivalent subtransient reactance of paralleled generators. Keep in mind that when adding per unit quantities it is necessary that the per unit values for the alternators and transformer are based on the same base kVA rating.)

Whether this level of surge current can damage equipment or trip a breaker depends on the equipment through which the current is flowing. Circuit breakers typically have their instantaneous trip current set to 7-10 times the long time-trip setting. The surge will only last for one or two cycles so as long as the level of surge current is not in the instantaneous trip range of the breaker, the breaker will not trip. Keep in mind that if the breaker is a current-limiting breaker designed to trip in the first half cycle of a fault this will have to be considered.

Transfer switches listed to UL 1008 are subjected to an overload test in which they repeatedly open and close into 6 times rated current and maintain that current for 10 electrical cycles (167 msec) on each iteration and continue to function at rated load after the test. A transfer switch is capable of operating when exposed to surge current within 6 times its rating.

In our example above, if the load is transferred by a 2000 amp transfer switch protected by 2000 amp breakers, the maximum current surge is less than three times the long time-trip rating of the breaker and less than three times the full load current rating of the transfer switch. This will not cause a problem for the switch or the breakers. However, if this load were being transferred by a 400 amp transfer switch protected by 400 amp breakers located lower in the system there is now a chance that the current surge will trip one of breakers.

Surge current generated by an instantaneous phase difference between sources at transfer must be considered in the design of the system. Equipment must be sized to handle the surge current. Where this is not practical open transition switches should be used. Loads that can not tolerate a momentary interruption in service should be fed by a UPS.

Passive Synchronizing Systems

Closed transition transfer switches have successfully used passive synchronizing systems in many applications. Transfer switches use a sync check function for initiating closure to the oncoming source when the two sources are in-phase. There are two basic algorithms used by sync check systems: a permissive window algorithm and a predictive algorithm.

A permissive window algorithm is commonly used in both active and passive synchronizing systems. The sync check system measures the voltage, frequency and phase difference between the two sources. When the three parameters are within some pre-defined limits the sources are said to be within a “permissive window”. When the sources have been in the permissive window for some pre-set period of time the controller closes to the oncoming source. The required time in the permissive window is typically set to 0.1 to 0.2 seconds for passive synchronizing systems and 0.5 seconds for active synchronizing systems.

A predictive algorithm operates similar to a sync check system except that rather than waiting for the two sources to be in a permissive window for some period of time it measures the rate of change of the phase angle difference between the two sources and calculates an “optimum phase angle” at which to initiate closure so that at the instant the switch closes the two sources are as close to in-phase as possible.

Both types of algorithms have been used successfully. Generally speaking the permissive window algorithm is more robust because the predictive algorithm is susceptible to transients on the voltage sources which could skew the calculation of the optimum phase angle.

In many applications a slight frequency difference known as a “slip frequency” is imposed between the sources to make sure that they will come into sync with each other at a controlled rate. A slip frequency of 0.1 Hz has been used effectively.

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GENERATOR VOLTAGE SYNCHRONIZING TO BUS VOLTAGE

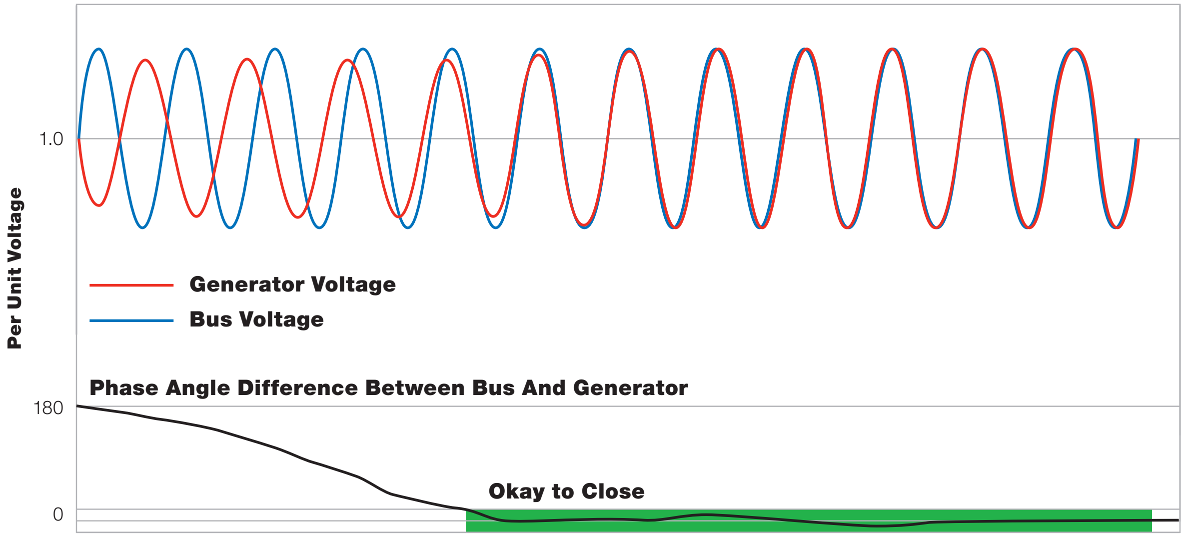

Figure 3: Active synchronizer with voltage matching

Active Synchronizing

Active synchronizing is the process of adjusting the engine governor to bring the waveform into phase with the utility waveform. Many synchronizing systems will also include a voltage matching function, in which the generator sets will adjust the voltage regulator to drive the generator voltage level to match the utility voltage level. The voltage matching function is important in applications where the voltage on the utility transformer varies with load.

Figure 3 represents a generator waveform coming into phase with a utility waveform using an active synchronizer with voltage matching. Note that the utility waveform is constant and the synchronizer drives the generator set waveform in to sync with the utility. The voltage matching function forces the generator voltage to be at the same level us the utility voltage.

The synchronizer will hold the generator in sync with the utility until the synchronizer is turned off unless a sudden load change causes a frequency change. Load changes on a system bus cause a sudden change in phase angle difference as frequency surges or sags in response to the load transient. This can cause the two sources to momentarily be out of sync until the synchronizer forces them back into synchronization. This is why for systems with multiple closed transition transfer switches best practice is to only allow one switch to transfer at a time. With an active phase lock loop synchronizer the time to synchronize is relatively short and reliable so timing between switch operations need not be long.

Transfer and Re-transfer Inhibit

It is common for changes in load on a generator set to cause sudden changes in the voltage and in the phase angle relationship between two sources that have been synchronized. For this reason the possibility of load transients at the moment of transfer should be minimized. For systems with multiple transfer switches best practice is to allow only one switch to transfer at a time. This can best be achieved by either staggering transfer time delays or by using the transfer and re-transfer inhibit functions.

The inhibit functions are used to prevent transfer to either the emergency source (transfer inhibit) or the normal source (re-transfer inhibit). When transferring loads with closed transition transfer switches, at any given time only one transfer switch should be allowed to transfer.

The inhibit function can be controlled by a master control used in conjunction with a paralleling system. All switches initially are inhibited from transferring and the master releases the inhibit on one switch at a time.

TWO CLOSED TRANSITION TRANSFER SWITCHES

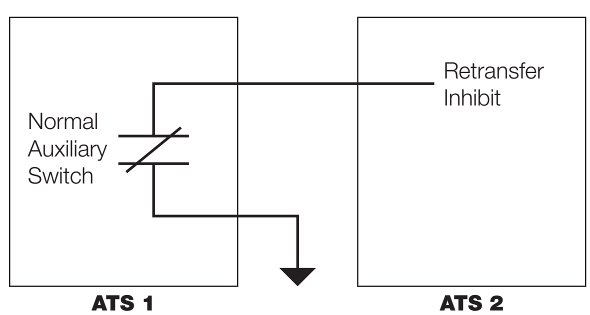

Figure 4: Using aux contacts of ATS 1 to inhibit ATS 2.

About the author

Rich Scroggins is a Technical Specialist in the Application Engineering group at Cummins Power Generation. Rich has been with Cummins for 18 years in a variety of engineering and product management roles. Rich has led product development and application work with transfer switches, switchgear controls and networking and remote monitoring products and has developed and conducted seminars and sales and service training internationally on several products. Rich received his bachelors degree in electrical engineering from the University of Minnesota and an MBA from the University of St. Thomas.

In simple applications one switch can inhibit another. For example consider the system in Figure 4 consisting of two closed transition transfer switches. The normally closed aux contact from the normal side of the ATS 1 is wired into the re-transfer inhibit input ATS 2. This will inhibit ATS 2 from beginning its re-transfer sequence (including all time delays) until after ATS 1 has transferred back to the normal source.

This configuration does create a potential failure mode. If the first switch fails to transfer or if the aux contact fails the second switch will not transfer without manual intervention. For this reason it is preferable in some cases to use staggered time delays to prevent the switches from transferring at the same time. As these time delays are typically set on site it is important to clearly specify the time delays in commissioning documentation.

It should also be noted that the inhibit function is only required when transferring between two live sources. It is not a requirement in the event of a utility failure so there need be no concern about not getting the emergency source on line quickly enough.

Breaker Shunt-Trip

Many utilities require that closed transition transfer switches provide means to shunt-trip the breaker on the normal (utility) side of the transfer switch if there is a failure of the transfer switch that causes the two sources to remain paralleled in excess of 100 milliseconds. Many transfer switches have a “Fail to disconnect” output which can be used for this. It is up to the installer to connect these devices to the shunt-trip of the breaker. Some utilities require maximum parallel timer and lockout relays that are separate from the transfer switch control to implement this function. Regardless of whether or not this is required by the local utility it is considered a best practice to use this function to make sure that two sources are not unintentionally paralleled for an extended period of time. Tripping either the normal side or emergency side breaker will provide the same level of equipment protection although many utilities require tripping the normal side breaker.

Conclusions and Recommendations

Closed transition transfer switches allow for transferring loads without interruption during a test or when returning to the utility after an outage. This is a significant benefit in some applications, however there are risks associated with closed transition transfer as two live sources are connected together. For loads that are not protected by a UPS it is worth considering if the value of not having an interruption during a test or a re-transfer to the utility justifies the risk of a closed transition transfer.

There are several methods for mitigating the risk of closed transition transfer:

- Make sure that breakers, transfer switches and cable are sized to handle the surge current that may result from sources being a few degrees out-of-phase at closure as allowed by the sync check system.
- Consider using active synchronizing with voltage matching to minimize the phase and voltage differences between sources.
- Minimize the possibility of transient conditions at the moment of transfer by inhibiting multiple transfer switches from transferring at the same time and preventing other loads from cycling during the transition.
- Use a transfer switch “fail to disconnect” or maximum parallel timer relay to shunt-trip a feeder breaker to prevent extended paralleling in the event that a transfer switch fails.

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GLPT-5823-EN (09/13)