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The Three Source Digital Static Transfer Switch: Taking Redundancy to the Next Level

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Today's power distribution systems cover a broad gamut of capacities and configurations. One thing remains constant in this world of mission critical loads - continuous, fault-free operation of a power system is more important than ever. For example, power interruption can cause a costly lapse in financial transactions or result in life-threatening events. The power distribution industry has devised countless methods to deal with the inevitable failures of equipment by creating layers of redundancy and backup, all at a significant cost. We are continuously seeking ways to create redundancy and reliability in our power systems at a lower cost, using less space while meeting an ever-increasing thirst for power density.

Redundant electrical power distribution systems may rely on several disparate power sources such as utilities, UPSs (Uninterruptible Power Supplies), and generators. Switching seamlessly and rapidly between these sources is no trivial task. For years the industry has been using digital static transfer switches to ensure that the better of two sources is always connected to the critical load. Traditionally, static transfer switches have been the two-source type but there is an increasing application of three-source static transfer switches to add an extra layer of redundancy and reliability.

This paper discusses the additional advantages provided by the three-source digital static transfer switch, which include:

- Economically increased reliability
- Decreased required equipment footprint
- Increased power density
- Decreased overall owning and operating cost
- Maintained redundancy during maintenance and repair

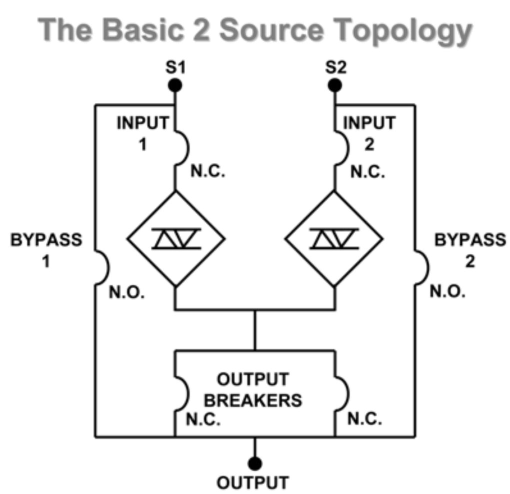
What is a Digital Static Transfer Switch?

We would be remiss if we continued a discussion about three-source static transfer switches without describing the basic characteristics of the classical two-source static transfer switch.

A basic static transfer switch is connected to two power sources and provides a seamless transition between those sources in the event one fails. One source is designated as the "preferred" source and the other as the "alternate" source. The output's critical load is normally connected to the preferred source. Each source's power quality is continuously monitored in terms of its voltage, phase, and wave shape. If a source's power quality falls outside defined limits for a defined period of time, the static switch makes the decision to transfer to the other source. Typically the switching time from the detection of a problem to transfer is ¼ of a cycle, or about four milliseconds. The switching event is an open transition or "break-before-make" using solid state silicon-controlled rectifiers (SCRs). There are no moving parts used in the switching process. The digital static transfer switches we are discussing in this paper are three phase and operate between 200 and 4,000 amps and at low voltage (e.g. 480 VAC). "Digital" refers to the technologies based on Digital Signal Processing (DSP) hardware and the manufacturer's proprietary software that performs real time analysis of the power waveforms and logic control of the static switch.

A digital static transfer switch is functionally a three pole, double throw switch using SCR assemblies as solid state switching elements. To make the device maintainable without causing downtime, the design of the static switch must include breakers to provide isolation for maintenance, as well as, bypass to maintain a path for power even if the switch is not operational. The traditional two-source static switch incorporates up to six breakers for isolation and bypass. A single breaker at each input and two parallel breakers at the output are provided in order to electronically isolate the SCRs for maintenance. The output breakers are paralleled for redundancy to ensure there is no single point of failure in any power path through the static switch. During the times that SCRs and logic elements are isolated for maintenance, one bypass breaker provides a path for power from one source to the output in order to maintain load continuity. Figure 1 shows the various possible power paths through the static switch during normal and bypass conditions.

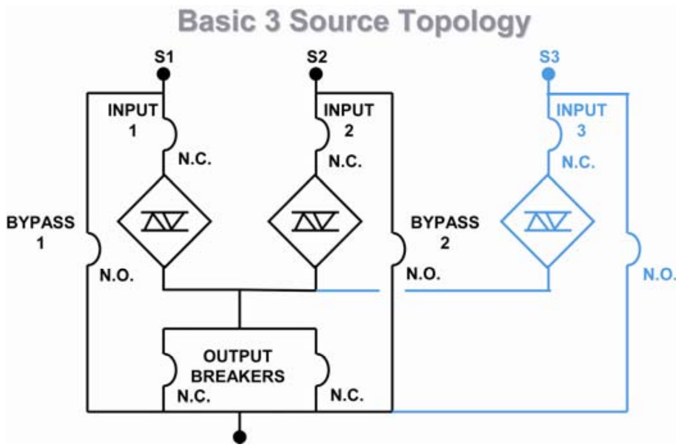
Figure 1



The Three-Source Static Transfer Switch

The three-source static transfer switch topology is built upon the two-source design by simply adding a third SCR switching element to provide a path for the third source. Additionally, the third source to the output can be bypassed by a third bypass breaker. As shown in Figure 2, the three-source static transfer switch usually has a total of eight breakers. The implications of adding a third source have profound effects on control logic, application, and reliability of the static transfer switch and are discussed hereafter.

Figure 2



The traditional two-source static transfer switch is carefully designed to survive a single source failure and faithfully switches to a redundant path without dropping the load. Figure 3 shows that each path through a static transfer switch is prone to failure due to loss of one of the sources external to the static switch (e.g. UPS or utility) or the internal static switch failure of a circuit breaker, SCR, or control logic element. The switch's other path always stands ready to provide continuity of power to the critical load.

But what happens in the even of two simultaneous failures involving both power paths through the switch? One would think this would be a rare occurrence, but experience shows that certain events increase the chances of this happening. In the most common scenario, an equipment failure could require more time than anticipated to repair. While the first failure is being repaired, or while repairs are being scheduled, there is an open window of vulnerability to any second failure event. Statistically that second failure event can and does happen while we are without a safety net of redundancy.

Figure 3

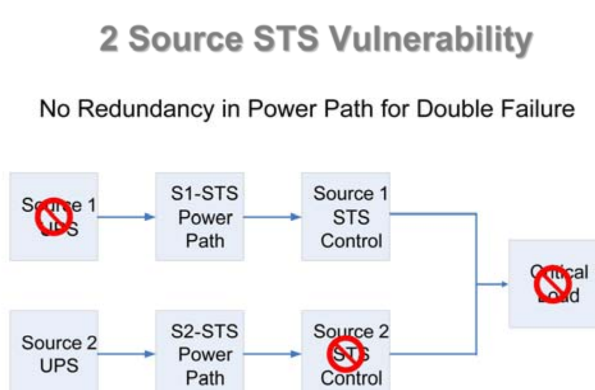


Figure 4 shows the three-source static transfer switch with its additional source and third path providing an added layer of redundancy. This arrangement allows two simultaneous failures in two of the three power paths and ensures that power still flows to the critical load.

Figure 4

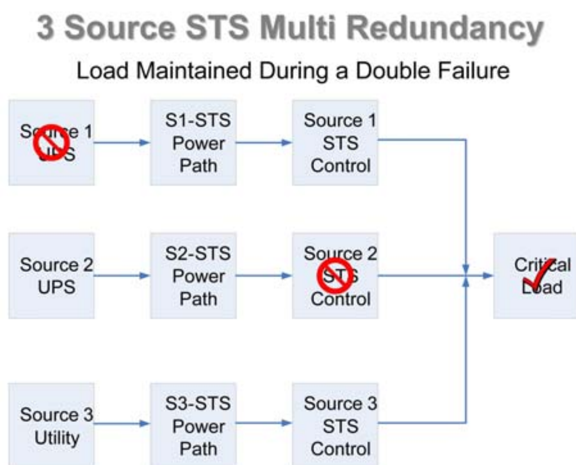


Figure 5 compares a double failure involving both sources and/or both paths. While in all cases the two simultaneous failures in a standard two-source static switch cause a load drop, the same failures in the three-source static switch are successfully rerouted to the third source.

Figure 5

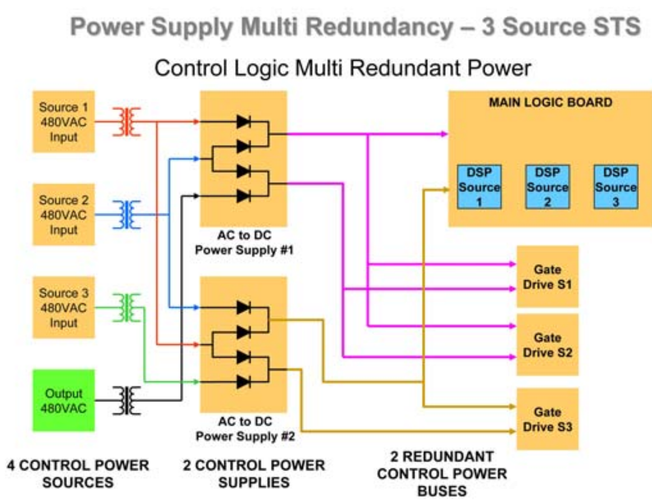
3 Source STS Multi Redundancy

2 SOURCE VS. 3 SOURCE			
Double Failure Scenarios			
	2 sources down	1 source down 1 STS path down	2 STS paths down
SOURCE 1	FAIL	FAIL	OK
SOURCE 2	FAIL	OK	OK
STS S1 path	OK	OK	FAIL
STS S2 path	OK	FAIL	FAIL
Source 3 path	OK	OK	OK
2 Source System	DROP	DROP	DROP
3 Source System	OK	OK	OK

Three-Source Architecture is More Redundant

One of the most critical elements of any complex system (including a digital static switch) is the control power supply. A power supply's component count is high and collectively, all components are under a lot of stress. A redundant arrangement of power supplies is essential in order to avoid creating common points of failure. A classic two-source static switch has a multiply redundant control power system. However, as seen in Figure 6, the three-source static switch takes redundancy even further. Four separate control power sources are fed by each of the static switch's three input sources plus its output source. Each of the four power supplies feed two independent DC output busses, which in turn feed the main logic board and three gate drive boards. The three-source static switch delivers power to the critical load even if up to three of four control power sources fail simultaneously. This is made possible by the redundant control power scheme coupled with the system's innate ability to automatically seek only viable power paths through the switch.

Figure 6

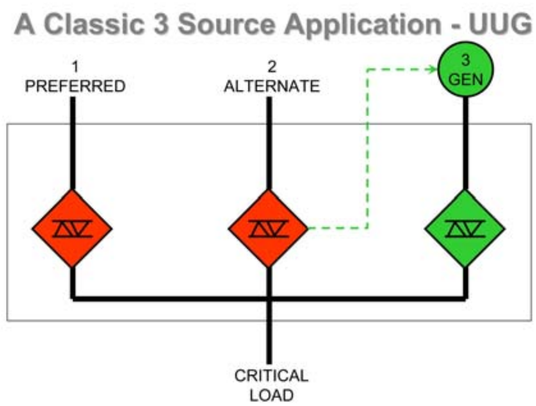


Three-Source Static Switch Applications

The applications of the digital static switch are numerous because of the numerous permutations of sources and their behaviors. Sources can include utilities, UPSs, generators or some combination thereof. One of the most classic applications of a three-source static switch (shown in Figure 7) is frequently found in mission critical facilities with two utility sources and a generator. A hospital is a good example, in which source one is designated as "preferred" and normally provides power to the facility; source two is designated as "alternate". If the preferred source fails the alternate source instantly takes over. At this juncture there is no more redundancy in the system and we must assume it may be unstable. The transfer from the preferred source to alternate source triggers the generator to start. When the generator is synchronized and stable, the static transfer switch transfers the load to the generator. Now, with the generator carrying the load, source two (alternate) is now redundant to the generator.

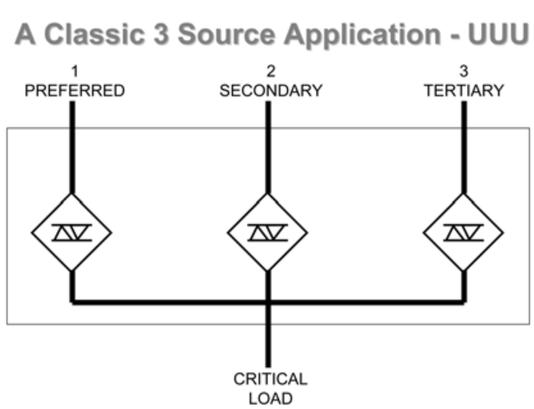
By now, source one (preferred) may have recovered, adding another layer of redundancy. The user usually has the option of selecting whether the static switch is manually returned to the preferred source when it recovers or returned automatically after a pre-determined time period.

Figure 7



The previous example shows a generator as the third source that is inactive during normal times. Other applications for the three-source static switch employ three sources that are operational full time, as in Figure 8. Their sources may be all utilities or UPSs or some combination of both. Most three-source digital static switches have custom software to meet site-specific needs but the following scenario is typical for many, whose three-sources are in continuous operation. Any of the sources can be designated as "preferred" and any source can be designated as "secondary" (or alternate). In a normal transfer scenario, where the preferred source is failing, the static switch automatically transfers to the secondary source. The "tertiary" (or third) source is probably just as viable as the secondary source but stands by in case the preferred and/or secondary sources or associated power paths are lost. The source priorities in terms of being preferred, secondary, or tertiary are user-defined and can be assigned to the three-sources in any order or sequence. For example: 1-2-3, 2-3-1, 3-2-1, etc.

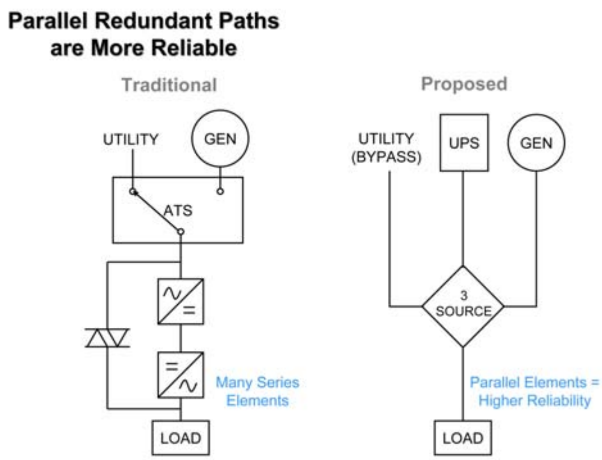
Figure 8



Enhanced Three-Source Reliability and Maintainability

The three-source digital static switch presents many possibilities for enhancing reliability of systems by incorporating parallel redundant elements instead of several series elements. For example, Figure 9 shows two functionally similar topologies each consisting of a utility source, a UPS, and a generator. The system on the left relies on the serially connected utility, automatic transfer switch (ATS), and on-line UPS to feed power to the critical load. In such a system, a failure at the utility will allow the load to be supported by the battery until the generator is started. The reliability of this entire system depends on the ATS and the UPS both working simultaneously to support the critical load. On the other hand, the system shown on the right could conceivably support separate utility feeds – one for source one and one to feed the UPS. The highly redundant three-source STS in conjunction with the three parallel independent sources provides exceptional reliability plus additional bypass options for maintenance and repair.

Figure 9

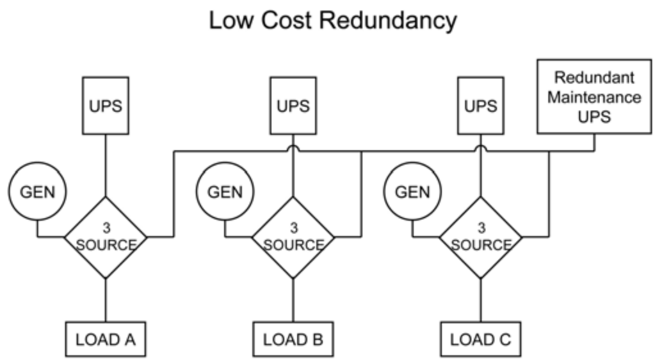


System maintainability is a key concern in any facility. But during any maintenance procedure an entire system may be extremely vulnerable. Redundancy may be compromised or eliminated altogether when the system is in a maintenance configuration; add to that the chance of human error, and the entire facility can teeter on the brink of disaster. Designing a system that provides maintainability, flexibility, and reliability adds tremendous cost.

Cost Effective Backup

The three-source static switch provides several ways to add redundancy without breaking the bank. The system shown in Figure 10 shows how three-source static switches applied in disparate systems can share a common maintenance UPS to provide 2N redundancy plus flexibility for maintenance. The inclusion of one shared maintenance UPS provides an alternate source for all three systems.

Figure 10

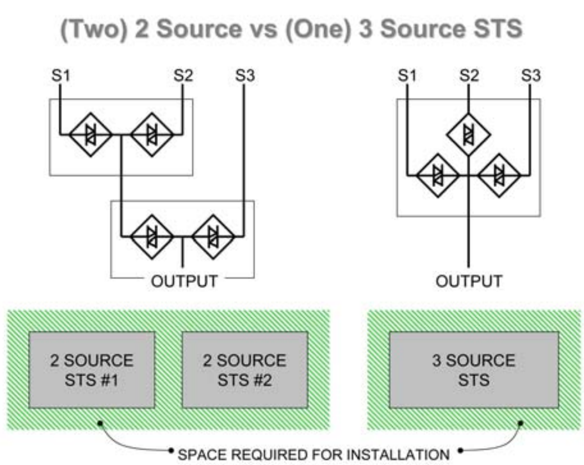


Many of the three-source static switch concepts discussed so far can be (and have been) implemented using two separate two-source static switches in cascade to achieve three-source topology. While this is simple enough conceptually, it is much more economical to combine all elements of the three-source topology in a single cabinet under the control of integrated definite-purpose three-source logic.

Single Three-Source vs. Dual Two-Source

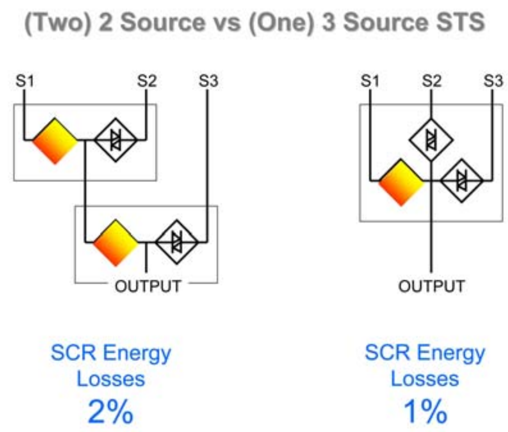
Based on a 2000 amp installation, the physical space required for dual two-source static switches has 54% greater footprint and 20% greater actual space (floor space requirements including access and code-mandated perimeter spacing). See Figure 11.

Figure 11



As shown in Figure 12, there is an additional 1% energy loss associated with cascading two two-sources resulting from the combined losses of two SCR elements in series (versus one SCR element in the equivalent three-source topology). This loss amounts to an additional 18,300 Btu per hour or about $14,000 per year in a 2000 amp STS.

Figure 12



Three-Source Static Switch Decreases Odds of Failure

If a single source has a statistical chance of failure, a system that negotiates the transfer to a backup source increases the reliability of the total system to the square of the single source's statistical failure rate. Add a third source and the chance of failure approaches the cube of the single source failure rate.

For example:

A single source's failure rate is 1 in 10 or 0.1. Two sources' failure rate is 1 in 100 or 0.01. Three sources' failure rate is 1 in 1000 or 0.001.

Conclusion

The three-source digital static transfer switch is an effective way to increase reliability and maintainability while decreasing owning and operating cost in a highly mission critical facility. In review the following points summarize the advantages of using the three-source digital static transfer switch to enhance redundancy and decreasing owning and operating costs:

- Provides an additional layer of redundancy in the event of a double failure due to loss of source and/or logic failure.
- Provides four sources of control power that allow up to three of four power supplies to fail.
- The three-source scenario supports two layers of redundancy including the ability to start up and seek a generator as the backup source.
- Provides parallel redundant paths which are more reliable than series topologies with a single point of failure.
- Allows a single UPS to be shared among three systems as a redundant maintenance system.
- The three-source static switch occupies less floor space and uses less energy than an equivalent configuration of dual two-source static switches.