

# A Hidden Reliability Threat in UPS Static Bypass Switches

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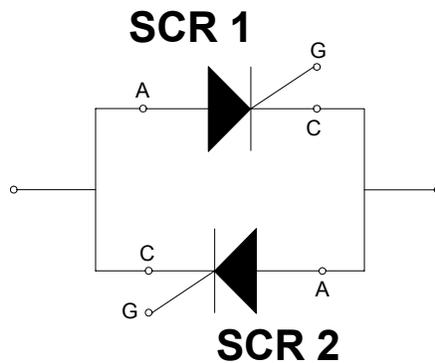
## **Executive Summary**

**IT managers will be surprised to learn that some medium and high power UPS systems on the market today (rated 50 kW and higher) use undersized static bypass switches despite their negative implications. By using a contactor or a circuit breaker in parallel with SCRs, these static bypass switches are able use smaller, less expensive SCRs that are rated to carry less than full load current continuously. This paper shows that the availability of the UPS system is compromised when undersized static bypass switches are employed in the system. The advantages of fully rated static bypass switches are discussed.**

# Introduction

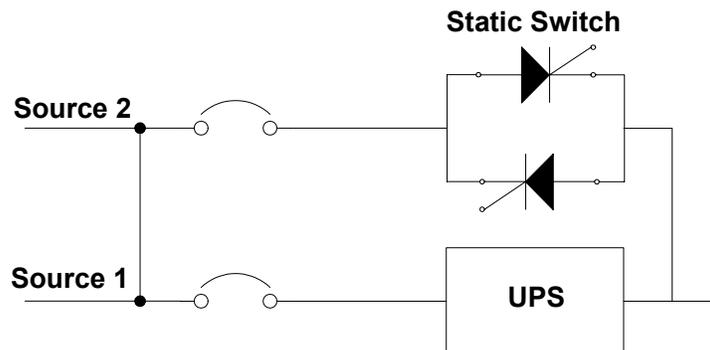
A static switch is an electronic switch that is usually built using silicon controlled rectifiers or SCRs. **Figure 1** shows one phase of a static bypass switch. Each phase of the switch is comprised of a matched pair of inversely mounted SCRs. A 3-phase static bypass switch consists of 3 single-phase switches. One of the SCRs (SCR1) conducts during the positive voltage half cycle and the other (SCR2) conducts during the negative half cycle (SCRs are able to conduct when anode-to-cathode voltage is positive and a gate pulse is applied).

**Figure 1** – Single phase static bypass switch



The diagram in **Figure 2** shows a static bypass switch connected across a UPS. The UPS could be a double conversion or a delta conversion or rotary type. The static bypass switch provides a means to accomplish high-speed transfer to the bypass path in case of UPS failures. Also, the static bypass switch is used to bypass the UPS so that maintenance can be performed on the UPS. Because electromechanical contactors and circuit breakers are not fast enough to accomplish such high-speed transitions, a power disruption could occur. A static bypass switch is employed to provide uninterrupted power to the load during normal-to-bypass and bypass-to-normal transitions.

**Figure 2** – Two-source UPS system with static bypass

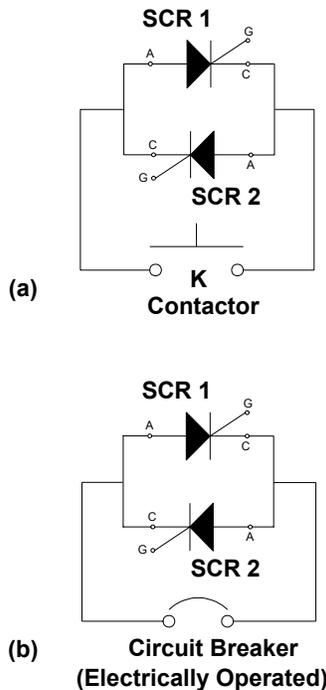


## Fully and Partially Rated Static Bypass Switch

The term “fully rated” or “partially rated” refers to the rating of the SCRs for continuous duty. A fully rated static bypass switch employs SCRs that are mounted on a heat sink and typically cooled by fans. By contrast, a partially rated static bypass switch employs SCRs that are typically mounted on a smaller heat sink without fans. A contactor or an electrically operated breaker is then employed in parallel with the SCRs, as shown in **Figure 3(a)** and **3(b)**, respectively.

In the partially rated static bypass switch, both the SCR switch and the contactor relay (or electrically operated breaker) are simultaneously turned on when the UPS inverter is turned off. After approximately one second, the SCRs are also turned off. Thus, the SCRs are able to bridge the time after the UPS inverter turns off and the contactor or breaker completes the closing cycle. During the transfer from bypass operation to normal operation, the SCRs are turned on simultaneously when the contactor or breaker is turned off. After approximately one second, the SCRs are turned off while the UPS inverter is simultaneously turned on.

**Figure 3** – Partially rated static switch using (a) parallel contactor and (b) parallel circuit breaker



In a partially rated static bypass switch, a parallel power path is established with the contactor or the circuit breaker during both transfer sequences (normal-to-bypass and bypass-to-normal). The contactor may fail shorted or in open position due to failure of the solenoid coil or the actuating mechanism. A contactor failure in shorted position causes a loss of load that will, of course, adversely affect availability. The electrically operated breakers present yet another disadvantage - failure of the motor operated mechanism itself. That will further decrease the reliability and availability provided by the static bypass switch.

## Rating of the Static Bypass Switch

The fully rated static bypass switch is generally designed to carry 125% of the rated load. The partially rated static bypass switch is typically only designed to carry 100% of the rated load, although it can be designed to carry 125% rated load. If there is a continuous overload on the partially rated switch with the system in bypass mode, then either the load will be lost (because the breaker trips due to overload) or the contactor will drop (due to over current). By contrast, a fully rated static bypass switch that is designed to carry 125% rated load can sustain continuous overloads indefinitely, and that will naturally increase the reliability of the system with respect to overloads.

## Cooling Fan Failures

For the fully rated static bypass switch, the cooling fans represent a potential point of failure. However, the failure rate of cooling fans can be reduced and availability increased through the use of redundant cooling fans. The operation of the fans can also be sensed with current sensors to make sure they are continuously providing sufficient cooling. Heat sink temperature feedback provides an additional check on the effectiveness of cooling to ensure the SCRs are not subjected to a higher than safe operating temperature.

## Availability of the Static Bypass Switch

For the fully rated static bypass switch, the failure rate is primarily dependent on whether the switch itself or the controls fail. Typically, the failure of the controls is higher than that of the switch. **Table 1** lists the Mil Spec 217 data used for calculating the availability of the various static bypass switch types which are listed in **Table 2**.

**Table 1 – Mil Spec 217 data**

Description		Mil Spec 217 Failure Rate (events / hr)
A	Controls failure rate	4.65E-06
B	Switch or SCR failure rate	2.65E-06
C	Contactor failure rate	1.00E-06
D	Circuit breaker (ELO) failure rate	3.30E-06
E	Failure rate reduction due to redundant power supplies	1.00E-06
F	Failure rate reduction due to redundant cooling fans	5.00E-07

The actual field failure rate is normally 3 - 5 times better than the Mil Spec 217 calculation, with a failure rate of 1.95E-06 events/hr for the fully rated static bypass switch. The mean time to repair or MTTR is the sum of service response time and repair time. Typically, the service response time is 4 hours and the repair time is 2 hours. The inherent availability of the static bypass switch is determined by  $(MTBF / (MTBF + MTTR))$ .

The availability is higher in those instances where redundant cooling fans are employed along with redundant power supplies.

The failure rate can be minimized by building redundancy into the design. Redundant cooling fans reduce the failure rate of the switch while redundant power supplies reduce the failure rate of the controller. It is interesting to note that a partially rated switch using contactors and redundant power supplies has an availability that is equal to a fully rated switch with no built in redundancy. Only a fully rated switch with built in redundancy has an availability of five nines.

It should be noted that the numbers in **Table 2** assume well-maintained contactors and circuit breakers. There is a higher potential for losing the load due to the failure of electrically operated mechanism of the breaker or the contactor.

**Table 2 – Availability of fully rated and partially rated static bypass switches**

Static Switch Type	Failure Rate (events / hr) Mil Spec 217	Formula	Failure Rate Actual (events / hr)	MTBF (hours)	MTTR (hours)	Inherent Availability
Fully Rated	7.30E-06	A + B	1.95E-06	513,699	6	0.99998832
Fully Rated with built in power supply and cooling fan redundancy	5.80E-06	(A + B) - (E + F)	1.55E-06	646,552	6	0.99999072
Partially Rated with contactor	8.30E-06	A + B + C	2.21E-06	451,807	6	0.99998672
Partially Rated with contactor and built in power supply redundancy	7.30E-06	A + B + C - E	1.95E-06	513,699	6	0.99998832
Partially Rated with Circuit Breaker	1.06E-05	A + B + D	2.83E-06	353,774	6	0.99998304
Partially Rated with Circuit Breaker and built in power supply redundancy	9.60E-06	A + B + D - E	2.56E-06	390,625	6	0.99998464

## Static Bypass Switch Space Requirements

For smaller kVA ratings (10 - 600 kVA), the static bypass switch is built into the UPS to save space. For larger systems in the MVA range (1 - 4 MVA), the switch needs its own cabinet to accommodate the connection to the switchgear and the UPS via bus bars or multiple large cables. There is very little difference between the space requirements for a fully rated switch versus a partially rated static bypass switch. The fully rated switch can be built on a slide-in frame so that it can easily be integrated into the switchgear. The static bypass switch can be bus connected if it is part of the switchgear, thereby saving space and minimizing installation costs. A static bypass switch that is integrated with switchgear using bus connections provides the lowest possible footprint for a multi-MW UPS installation.

The controller for the static bypass switch for smaller kVA ratings is located inside the UPS enclosure. For larger systems in the MVA range, an independent controller and display unit must be incorporated into the

static bypass switch. This feature facilitates the display of key operating parameters when the system is in bypass mode and the UPS is off line.

## Protection of SCRs in Static Bypass Switch

Semiconductor fuses are typically employed to protect the SCRs in both fully rated and partially rated static bypass switches. The  $I^2 t$  limit for the fuse is typically well below the  $I^2 t$  limit for the SCRs to adequately protect the SCR devices in case of a short circuit.

## Failure modes of Partially rated Static Bypass Switch

In the event of a short circuit in the distribution system, the contactor used in a partially rated static bypass switch is not protected. The contacts may fuse and weld after a short circuit, causing a loss of load during a bypass-to-normal transition. The electrically operated breaker is not series rated, and hence is not self-protecting in the event of a short circuit in the distribution system.

A fully rated static bypass switch does not have these failure modes since a contactor or breaker is not used in the design. Therefore, it should be obvious that availability benefit for a fully rated switch is worth the small incremental cost.

## Conclusions

The fully rated static bypass switch has a number of distinct advantages over the partially rated switch. For instance, a fully rated static bypass switch with built in redundancy offers the highest availability among the options discussed in this paper. In addition, the fully rated switch is self-protecting against a short circuit in the distribution system. The failure of a contactor or a motor-operated breaker will result in a loss of load in a partially rated Static Bypass Switch. Therefore, a fully rated static bypass switch enhances the overall availability of a UPS system.

### About the Author:

**Ashok Kulkarni** is Chief Engineer of the Ancillary Equipment Group at APC. He has 20 years experience in the field of power electronics, motor drives and UPS systems. He was with Thyssen Krupp Elevator research and development for 11 years designing advanced elevator controllers and motor drive systems. He has been designing ancillary components for Symmetra MW, InfraStruXure and Silcon product lines at APC for the last 4 years. He obtained his BS from India, MS from McGill University, Montreal, Canada and PhD from Texas A&M University, USA, all in electrical engineering. He has a number of journal publications in IEEE transactions on Power Electronics, Industrial Electronics and Industry Applications. He has also presented a number of technical papers in IEEE conferences around the world.